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The Effectiveness of Unconventional Monetary Policy on Risk Premia in the Interbank Market: Evidence from the UK, the US and the EMU

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Abstract

The recent financial crisis beginning In August 2007 depressed the world economies and disrupted the operation of conventional monetary policy instruments. Dramatic increases of three-month LIBOR rate in different currencies were observed and the spread between three-month LIBOR and OIS widened. These phenomena implied a broken transmission mechanism of monetary policy. The central banks of the UK and the US launched unconventional monetary policy tools i.e. liquidity provision and quantitative easing to stimulate domestic economies bypassing the banking systems. The European Central Bank implemented the Enhanced Credit Support scheme to provide liquidity to the banking system as well as fixing the monetary transmission mechanism.

As a consequence, much research has been undertaken to study the impact of the unconventional monetary policies on economies. Most of the literature has studied the effect on long-term variables e.g. GDP, inflation and unemployment. But, our study here focuses on the impact of those policies on the credit and liquidity premia in the money market as represented by interest rate spreads. This aspect is important because the transmission of quantitative easing in the UK and the US to ultimate targets relies intermediately on reducing the cost of borrowing and interbank lending rates are the foundation for many market rates. In the EMU, to fix the monetary transmission mechanism, restoring the communication between EURIBOR and OIS is the primary step.

Our results show that both credit and liquidity premia were the drivers of the widening LIBOR and OIS spreads. The quantitative easing in the UK and the US and Enhanced Credit Support in the EMU reduced credit risks and liquidity premia significantly, relying on the causality between the two premia, respectively.

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Acronyms

AMLF	Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility
APF	Asset Purchase Facility
ARDL	Autoregression Distributed Lag model
BoE	Bank of England
BoJ	Bank of Japan
CAPM	Capital Asset Pricing Model
CBPP	Covered Bond Purchase Programme
CDOs	Collateralized Debt Obligations
CDS	Credit Default Swap
CPF	Commercial Paper Facility
CPFF	Commercial Paper Funding Facility
DMO	Debt Management Office
DWF	Discount Window Facility
ECB	European Central Bank
ECM	Error Correction Model
ECS	Enhanced Credit Support
ECTR	Extended Collateral Term Repo
ELTR	Extended Collateral three-month Long-term Repo Operation
EMU	European Monetary Union
EURIBOR	Euro Interbank Offered Rate
GC	General Collateral
LIBOR	London Interbank Offered Rate
LSAP	Large-scale Asset Purchase
LTROs	Longer-term Refinancing Operations
MMIFF	Money Market Investor Funding Facility
MPC	Monetary Policy Committee

MRO	Main Refinancing Operation
OIS	Overnight Index Swap
OMO	Open Market Operation
OMT	Outright Monetary Transactions
PDCF	Primary Dealer Credit Facility
QE	Quantitative Easing
SLS	Special Liquidity Scheme
SMP	Securities Markets Programmes
SPV	Special Purpose Vehicles
TAF	US Term Auction Facility
TALF	Term Asset-Backed Securities Loan Facility
The Fed	Board of Governors of the Federal Reserve System
TSLF	Term Securities Lending Facility

Chapter 1 Introduction

On August 09, 2007, BNP Paribas froze three of their hedge funds thus signaling to other market participants the complexity and difficulty of valuing collateralized debt obligations (CDOs). This resulted in the close down of some credit markets e.g. mortgage-backed security market, and liquidity quickly dried up. Banks' off-balance sheet vehicles that held securitized financial instruments found it hard to finance their holdings by borrowing (in the commercial paper market) (King, 2007). Banks were reluctant to borrow at longer maturities and hoarded reserves on their balance sheets in order to cope with the possible and unforeseeable funding requirement from their vehicles (*ibid.*). The rate on unsecured interbank lending (LIBOR) therefore increased dramatically resulting in a break between interbank rate and central bank policy rate. This further resulted in broken monetary transmission mechanism

The BoE and the Fed started large-scale asset purchases (LSAP) from the secondary market. The approach is referred as quantitative easing (QE). The benefit of quantitative easing is to bypass the interbank market, transiting monetary policy through different channels to influence asset prices, aggregate demand and boost GDP. The first round of quantitative easing in the US was officially announced on November 25, 2008 with amount of $600 billion purchase of housing agency debt and related securities. In the UK, QE started later than in the US on February 09, 2009. Instead of fixing the total amount of purchase on the announcement day, BoE released their target subsequently. The initial amount was £75 billion announced on March 05, 2009 followed by two £50 billion on May 07 and August 06, respectively, and £25 billion on November 05 bringing the size of the first round QE to £200 billion. Within the £200 billion purchase, 98% were government bonds with a wide range of maturities.

The situation is a bit different in the EMU. The ECB has not so aggressively, as the BoE and the Fed, stepped into asset purchases. They launched Covered Bond

Purchase Programme on June 04, 2009 with only €60 billion to purchase covered bonds. However, they announced fixed rate tender procedure with full allotment on October 10, 2008 and further extended long-term refinancing operation (LTROs) to twelve months on May 07, 2009. The main focus of the ECB's strategy lay with the injection of liquidity to the banking system. Given the institutional set-up of the EMU, the ability of ECB to purchase government bonds on secondary market is limited[1] and the issue of moral hazard may be more important to consider compared with in the UK and the US, because it is a union. Purchasing government debt may reduce sovereigns' incentive to address fiscal deficits, debt levels and structural reform issues.

In the context, Sarkar (2009) points out that an understanding of the prevailing risk environment may facilitate the evaluation of effectiveness of central banks' unconventional policies. The effect of the unconventional monetary policies has been well studied by scholars. Prior to QE, literatures tend to focus on the effect of liquidity provisions to influence money market spread (see Michaud and Upper, 2008, Taylor and Williams, 2008 and 2009, Poskitt, 2011 and Lenza *et al,* 2010). Since the onset of QE, the research focus has shifted to the impact of QE on government bond yield, other asset prices and on the real economy indicators (see Joyce *et al*, 2011, Meier, 2009, Neely, 2011, Baumeister and Benati, 2010 and Kapetanios *et al*, 2012). However, fewer literatures have been done in the area of the effect of QE on money market spreads and how QE would affect the credit and liquidity risk nested in the interbank market.

This possible impact of QE is vital with respect to restoring central banks' control of the market because the BoE, the Fed and the ECB relied on manipulation of overnight interest rate to pursue their monetary target. A break between the overnight interest rate and the short-term interest rate reduces the

[1] Cour-Thimann and Winkler (2012) discuss the institutional set-up of ECB that prevents ECB to purchase

strength of interest rate as a monetary tool. Remarkably, the spread between bank base rate and short-term interest rates widened to a point that was around 100 basis points before the operation of QE. This market data implies that the transmission mechanism of a conventional monetary policy regime failed and required the innovation of unconventional measures. The reason behind the failure can be explained by the structure of the pricing of the short-term interest rate. As suggested by the non-Arbitrage Model[2], the short-term interest rate is not only hooked with the overnight interest rate but also the price of market risk i.e. risk premia. Suddenly the increased uncertainty of asset prices and market liquidity pushed up the risk premia in the money market, so the break of communication between short-term interest rate and overnight rate resulted in the failure of transmission of monetary control. Therefore, understanding the effect of QE on the market risks provides the primary evidence of how QE improves the communication between official overnight interest rate and short-term market rates as well as the recovery of the transmission mechanism.

In the UK and the US, asset-purchases took a major role in the central banks' measures to control the impact of the recent financial crisis on money markets and the economy. The QE has been written in the Red Book of the BoE[3] indicating its important role in stimulating the transmission of monetary policy. In the US, the acquisition of long-term securities is named the 'Large Scale Asset Purchase (LSAP)'. It is recognized as just one balance sheet tool. The expected impact of LSAP on financial markets is to re-active the trading activity in some severely affected asset market e.g. corporate bond market through portfolio rebalance channel. Under the framework of CAPM, investors' activities are driven by the relationship between risk and return. Therefore, learning the impact of QE to change the risk premia i.e. interest rate spread in the money

[2] More details of the model is discussed in Chapter 4.2.

[3] The latest update of the Red Book at the time of writing the thesis is January 2014. The link provides the PDF version of Part 2 of the Red Book and point 55 – 59 describes the QE in the UK. http://www.bankofengland.co.uk/markets/Documents/money/publications/redbookpart2.pdf

market gives the inside view of the movement of financial market under QE policies.

In the Euro zone, the ECB has operated the 'Enhanced Credit Support' (ECS) to combat the liquidity shortage during the financial crisis. LTROs is part of the ECB's ECS and the operations have run on a daily basis providing long-term liquidity to the banking system. The main distinction of LTROs during the crisis is frequency and maturity. In normal market condition, ECB operated their refinancing operations on a weekly basis to fund the structural shortage of liquidity rising by the demand of central bank money i.e. note and coins and the requirement of bank reserves and the term of refinancing was shorter e.g. three-month compared with operations during the crisis e.g. twelve-month. González-Páramo (2010)[4] identified the broken link between the ECB policy rate and money market rate which affected negatively the ECB's ability to precisely steer the short-term money market rate by setting the minimum bid rate in the refinancing operations, so the change of interest rate impulse from the ECB failed to transmit to the real economy. Moreover, one of the purposes of the ECB's ECS is to restore the transmission mechanism of monetary policy so it is important to examine the purpose from the first link in the mechanism – the overnight official rate and the short-term money market.

Our research fills the gap by investigating the effect of quantitative easing in the UK and the US on changing the credit risk and liquidity premia in the money markets in the two countries. As stated previously, the short-term money market rates are priced against risk premia and agents' expectation of future interest rate movements. For the EMU, the research adapts the difference of the ECB's policy approach by looking at the effect of LTROs on the risk premia contained in the short-term Euribor rates. Also, it looks at how the interaction between credit

[4] Speech 'The European Central Bank and the policy of enhanced credit support' available at link http://www.ecb.europa.eu/press/key/date/2010/html/sp100618_2.en.html

risk and liquidity premia changing during the operation of the unconventional policies works.

The research takes the risk-decomposing model that has been developed and employed in the literature. The dataset is at daily frequency. For each market, the sample covers the first round of QE (The EMU data stops before the SMP operation because the facility aids sovereign crisis, which is an issue in the EMU only). One of the novelties of the study is that pre-QE and QE periods are distinguished during the crisis period. This is important because it helps to reveal how the central banks' interventions change the role of credit and liquidity components in determining the interbank spread, which in turn provides the ground for better understanding of the risk environment in the interbank market and would help central banks to conduct effective monetary policy. The transmission mechanism of monetary policy relies on the central bank's ability to manipulate money market rates and the risk premia influence money market rates significantly, as seen in the non-arbitrage model that is applied by Taylor and Williams (2008, 2009) to analyze the risk premium in the money market in the US. But, they looked at the Term Auction Facility (TAF), which is a facility that operated at the earlier stage of the crisis with smaller scale and focus on supply of liquidity. They found there was little effect of TAF to reduce the money market spread because the main driver of the elevated risk premium was credit risk and expectation of future interest movement, which TAF was not designed to affect, and Angelini *et al.* (2011) support these findings. Controversially, later studies found that TAF has successfully reduced the spread on money market, that is, the unconventional liquidity support reduced the risk premia in money market e.g. McAndrew *et al.* (2008), Wu (2008), Christensen *et al.* (2009), Hesse and Frank (2009) and Nobili (2009). But, again, there is little work that looks at the effect of QE on the money market, so the discussion of this aspect remains unfolded.

Another contribution of our research is that the extent of the QE is measured by the ratio of cumulated government bond purchase (or liquidity provided to the banking system, where applicable) to total bank assets. The idea is original and it is one of the major contributions of the study. Compared to the conventional dummy measures that can only capture the occurrence of intervention, these ratios represent the increasing likelihood of meeting the liquidity needed in the interbank market. In the EMU, the non-standard provision LTROs and CBPP are together measured ratio of total of open market operation (OMO) and CBPP to total bank assets, because LTROs have been operated under OMO. Compared to the conventional dummy measures that can only capture the occurrence of intervention, these ratios represent the increasing likelihood of meeting the liquidity needed in the interbank market. This is particularly helpful while interpreting the EMU result because the target of ECB's non-standard measure largely is to work through banking system and repair the transmission mechanism by meeting the liquidity need of banks in the EMU. The coefficient on EMU Ratio provides reference for the ECB to set the amount of liquidity they offer to banks to achieve a prevailing effect on money market spreads.

The empirical improvement of our research compared with others is to fully consider the feature of non-stationary of variables. Given the existence of unit roots in the data, the simple OLS approach may not be able to correctly capture the relationship between risk measures and QE intervention variable. The non-stationarity has been ignored in Taylor and Williams (2009). To deal with the issue, McAndrew *et al* (2008) used the first difference of variable for risk premium and applied autoregression distributed lag model (ARDL). But, this loses the long run effect. Therefore, our research has employed the error correction model (ECM) because cointegration has been found between variables. In addition to ARDL model, the ECM model shows the long run relationship and causality between variables.

Moreover, the study investigates the relationships between credit risk and liquidity premia, respectively, in the three markets, UK, US and EMU. The UK is the representative of small open economy countries. During the crisis the Bank of England heavily and actively implemented a series of liquidity provisions in the banking system and had been running quantitative easing to boost market liquidity and maintain financial stability. The US is the major economy and it is where the crisis originated. The Fed was one of the central banks that first reduced the interest rate during the crisis and its liquidity provisions targeted ~~on~~ different asset markets and different types of financial institutions. For instance, the Term Auction Facility provided term-liquidity to depository banks and Commercial Paper Funding Facility targeted the commercial paper market. As the crisis developed, the Fed started Large-Scale Asset Purchase programme on December 2008 in order to put downward pressure on long-term yields and to stimulate recovery of economy. Differently from the UK and the US, the European interbank market is being operated in monetary union. The institutional set-up of EMU constraints the ability of the ECB to run large-scale asset purchase as it happened in the UK and the US. For instance, the proceeding from purchase of sovereign bonds on secondary market is likely to be going into private investors and it would also cause the problem of moral hazard on the country basis so the sovereigns may have little incentive to improve/reform their fiscal structure. Moral hazard still exists in the UK and the US, but it is a concern within the country. Moreover, firms in the EMU largely rely on bank finance, so that the ECB the unconventional policies primarily targeted on the banking system by providing full allotment longer-term liquidity. Therefore, the relationships of credit risk and liquidity premia in the three markets, respectively, should provide a good overall image of the risk premia changing during the crisis and the effectiveness of liquidity provision and quantitative easing in the interbank market.

Our result shows that the spreads in the UK change roles over the crisis period in determining the LIBOR spread, whereas credit risk, especially long-run credit risk dominates the spread across the whole sample period in the EMU. The UK QE significantly reduces risk premium in the money market by reducing liquidity premia directly. Relying on the causality from liquidity component to credit risk, UK QE reduces credit risk indirectly. The ECB's non-standard measure of monetary policy reduces both liquidity and credit risk directly. The result also suggests that the increased credit risk in the EMU may not be mainly driven by the liquidity condition instead the capital adequacy or other factors that related to banks' financial healthiness may be considered and worth investigating. The feedback from the Ratio variable tells that with the increase of the amount of purchase or liquidity equivalent to one percent of total banks asset has reduced the liquidity spread by 8.4 and 69 basis points in the UK and the EMU, respectively. In the US, there is dual causality between long-term credit risk premium CDS and liquidity premia RMO and the Ratio variable has significantly reduced both credit and liquidity premia by 30 and 4 basis points, respectively. This finding can be used by the central banks to set the size of operation to manipulate money market spreads.

The thesis contains six chapters. The following chapters proceed as follows. Chapter 2 reviews the urgency to employ unconventional monetary tools and summarizes the innovative facilities that have been created during the crisis in the UK, the US and the EMU; Chapter 3 looks at the limited impact of these tools on risk premia; Chapter 4 provides research methodology; Chapter 5 shows the empirical results and Chapter 6 summarizes and concludes the findings in the study.

Chapter 2 Unconventional Monetary Policy During the 2007 Financial Crisis

In the recent financial crisis, central banks in the UK, US and EMU cut their policy rates to the lowest boundary in order to counteract the worsening money market conditions as well as to prevent any further impacts on economies. However, these reductions were not wholly successful and credit condition in money markets worsened and slower growth of GDPs were recorded. To this extent, it revealed that the monetary regimes with interest rate as primary instrument to influence economy have failed under the unprecedented financial crisis. Therefore, Bank of England (BoE), the Federal Reserve (the Fed) and European Central Bank (ECB) have created and implemented a series of so-called unconventional monetary policies to ease market conditions as well as boost the growth of economies.

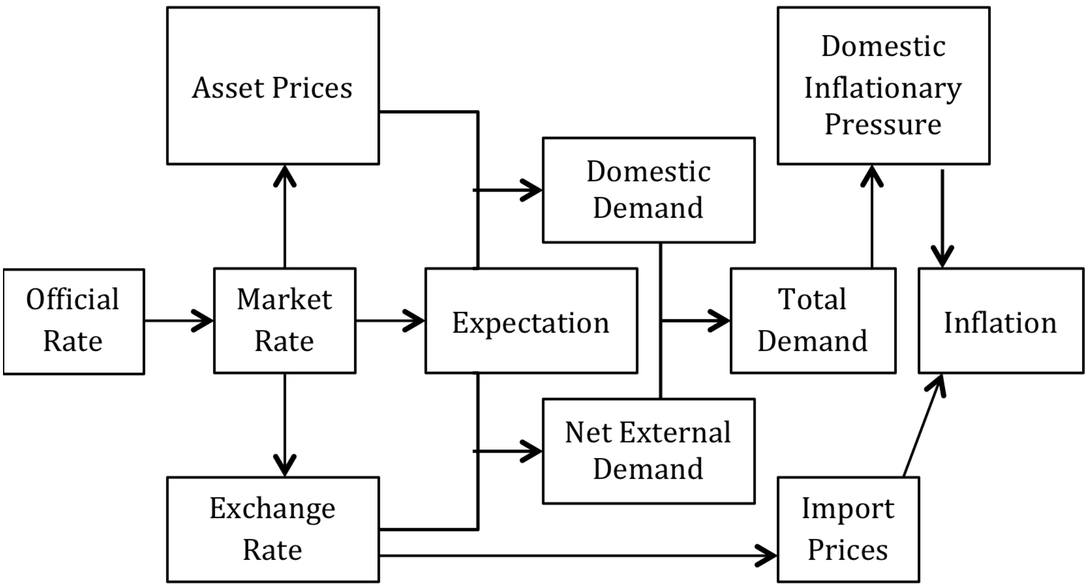
In this chapter, we first briefly reveal the reasons that interest rate as an instrument failed to transfer central banks' intention to markets. Secondly, the definition and origins of unconventional monetary policy is discussed. Finally, the chapter compares the innovative monetary facilities in the three markets.

2.1 Reason for Failure of Interest Rate to Ease Market Conditions

It has been widely recognized that money supply is an endogenous process whereas interest rate is an exogenous variable that is employed by central banks in the UK, the US and EMU to implement their monetary policy (Bain and Howells, 2009). In normal circumstances, a reduction e.g. in the policy rate will lower borrowing cost with consequence of an enlarged demand for loans that banks will seek to satisfy. The increased amount of loans enlarges the broad money supply M endogenously ('loans create deposits') and expand monetary base B, eventually as central banks meet banks' demand for the additional liquidity in order to maintain short-term interest rates. Under the interest rate regime, the transmission mechanism of monetary policy turns out to be ultimately relying on the communication between official and market rates, since it is market rates (containing a variety of mark-ups and premia) that borrowers actually pay. In order to emphasis the role of market rates, Bain and Howells (2009, p123) modified the diagram below (from the Bank of England Quarterly Bulletin, May 1999) by placing the 'market rates' box immediately after the 'official rate' and before everything else. Interestingly, the corresponding diagram from the ECB (2010) does the same.

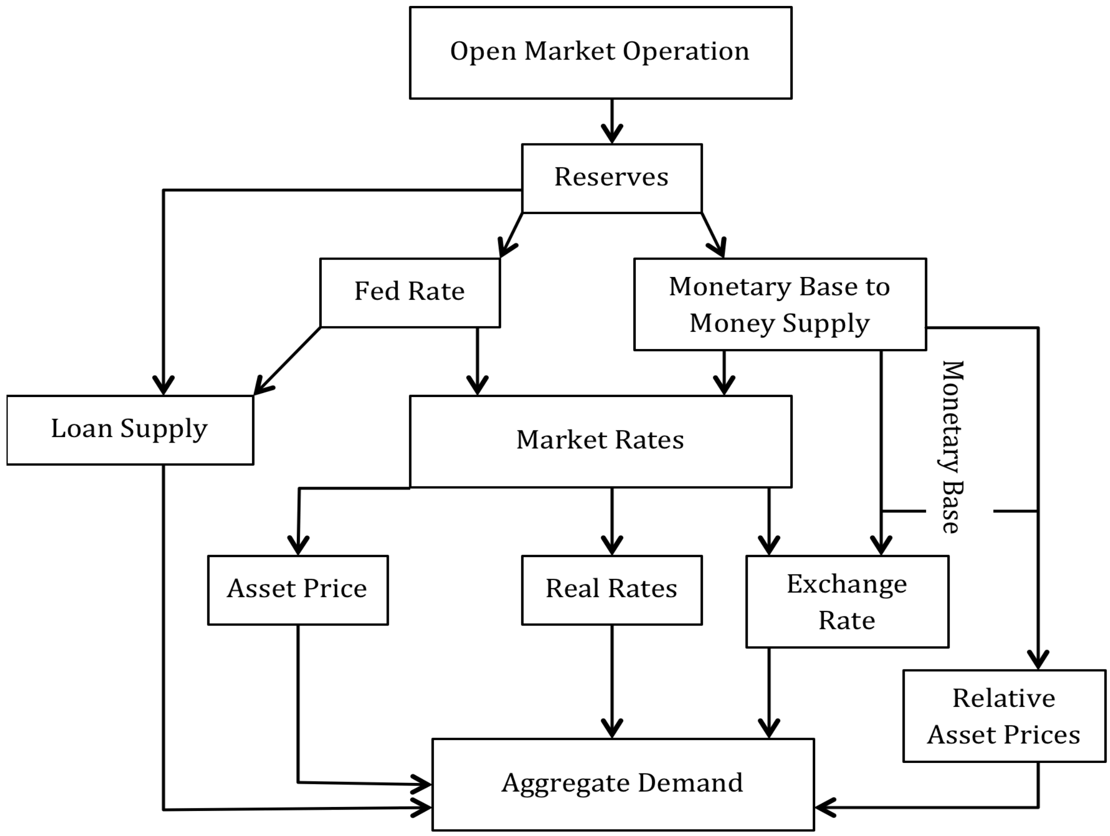
Figure 2.1 Illustration of the Transmission Mechanism from Official Rate to Price[5] in the UK, the US and the EMU

a. UK Transmission Mechanism



[5] Each individual transmission mechanism can be found on the following resources: for the UK http://www.bankofengland.co.uk/publications/Documents/other/monetary/montrans.pdf ; for EMU http://www.ecb.europa.eu/mopo/intro/transmission/html/index.en.html; for the US, Kenneth N. Kuttner and Patricia C. Mosser (2002) Economic Policy Review, May, the Federal Reserve Bank of New York, pp. 15-26

b. US Transmission Mechanism



c. EMU Transmission Mechanism

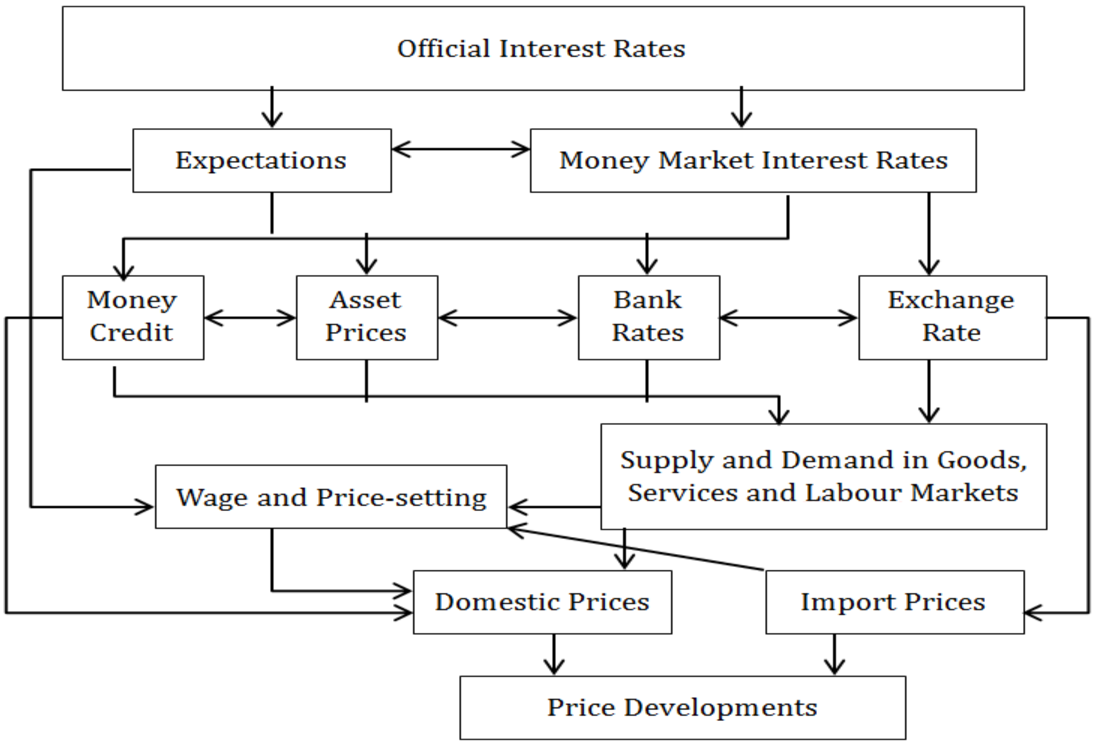


Figure 2.1 shows the way in which the policy rate affects the rest of the macro economy as visualized by, respectively, the Bank of England, the US Fed and the ECB. The first most striking feature is, ignoring the differing levels of detail, the similarity of the links between the policy rate and the level of aggregate demand. In all three cases, the policy rate must first affect market rates and, from there, it is the effect on asset prices, bank lending and the exchange rate that influences the level of demand. The second striking feature concerns the US Fed diagram, which stops short of linking aggregate demand explicitly to the price level. This may well be the result of the US Fed's 'dual mandate' that requires the Fed to steer the economy with respect to both the rate of inflation and the level of unemployment. By contrast, the Bank of England and ECB are both charged with giving overwhelming priority to an inflation target.

Set out in this way, we can see that monetary policy must act with a considerable time lag. It takes time for a change in policy rate to affect spending and then, in world where fixed term contracts are commonplace, it takes time for firms to respond to changes in demand by revising their output and pricing decisions. In Bain and Howells (2009, p124) the authors draw a vertical line in the BoE diagram immediately to the right of the 'total demand' box in order to emphasis the view, commonly expressed by policy-makers, that the first phase of policy (policy change to demand) takes about one year and the second phase (demand to prices) takes about the same.

Phase 1 starts with a pass-through effect from official rate to market rates then to transit the effect through four channels

- The behavior on borrowing/saving
- Asset prices
- Agents' expectations
- Exchange rate

The effect is intermediately transferred through the channels to domestic demand and external demand and eventually reaches total demand that is the medium- to long-term target. Any change in total demand will have an impact on domestic inflation, which is the final target of central banks (shared with full employment for the Fed). Moreover, the exchange rate channel will have a direct effect on import prices apart from any effect on aggregate demand. Therefore, in Phase 2 the change in both aggregate demand and import prices will result in a change in domestic inflation, despite the effect from import price being relatively small (Biefang-Frisancho Mariscal and Howells, 2002). Once domestic inflation is moving towards the target, maintaining the official interest rate at a given level can stable inflation at desire rate if there is no shock. In this chapter, we mainly focus on the beginning of transmission i.e. the link between official rate and market rate because the transmission from official rate to market rates is the first link in transmission mechanism of monetary policy in all monetary regimes (Biefang-Frisancho Mariscal and Howells, 2002).

It is clear that the ability of central banks to affect, total demand and eventually inflation primarily depends on their power to change market rates. Moreover, one of the operational targets of central banks is to control short-term interest rate in conjunction with other monetary instrument of implementation i.e. standing facility, open market operation and reserve requirement (Bindseil, 2004 p77; BIS, 1997; Borio, 1997; Iris Biefang-Frisancho Mariscal and Howells, 2002 and 2011). The three-month interbank lending rates LIBOR in the UK, US and EMU, respectively is a good proxy for short term market rates as it acts as reference rate for a wide range of financial products in the markets (Dale and Haldane, 1993; Heffernan, 1993; Iris Biefang-Frisancho Mariscal and Howells, 2002 and 2011; Bank of England, 2007Q4, p498). Hence the transmission of interest rates in the first link can be separated into two stages, the official rate to money market rates, and money market rates to wider financial service and products rates (de Bondt, 2005; Becker et al, 2012) despite the pass-through is asymmetric due to time lag of banks' responses to change of official rate (Dale and Haldane, 1993 and Heffernan, 1993). ECB (2010) also agreed that the transmission mechanism in EMU depends critically on the behavior of banks and on their willingness to entertain smooth exchanges of liquidity in the interbank market. It is therefore very important for money market rates to track the movement of base rate closely and tightly on the same direction in order for monetary policy to get a successful launch into the first phase of the transmission mechanism.

We have explained that a close relationship between money market rates and the official rate is fundamental for monetary operations to influence the general economy. In the following paragraphs, we will show what happened in the interbank markets during the financial crisis period.

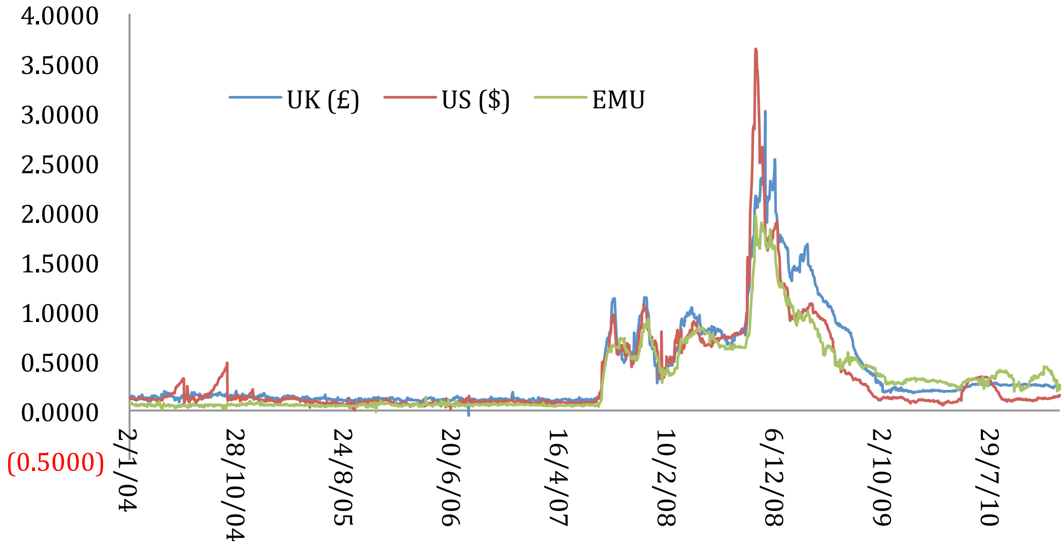
The recent financial crises can be traced back to December 2006 with the bankruptcy of American company, Ownit Mortgage Solutions (Gorton, 2008). Arguments about the trigger of this crisis identified an innovative financial product, subprime mortgage- and mortgage- backed security in the US, whose value was closely tied to housing market and whose risk was not correctly assessed (Mizen, 2008). The main buyers of these securities were special purpose vehicles (SPVs) and hedge funds. In some cases, those SPVs were banks' off balance sheet vehicles so banks may have lent to them and accept ed collateralized debt obligations (CDOs) as guarantee. However, these CDOs were rarely traded so the value and risk of them remained unclear (Bain and Howells, 2009 p138). When the default of subprime borrowers accumulated to the level that repayments in the security pool cannot cover interest on securities, the crisis emerged. Bain and Howells (2009, p139) pointed out two 'novel' problems of the crisis. The first was the implicit ownership of the loans since the subprime loans and other prime loans were mixed in one pool and the new issuance of securities was backed by these loans without clear alignment of underlying assets. The second was down to the recognition and diagnosis of risk containing in those securities. Based on the two problems, we start to reach the core of the failure of interest rate as an instrument to ease market condition – the break between official rate and money market rate.

As we have discussed, the transmission of monetary policy within an interest rate regime relies on the close and prompt response of money market rate to official rate. On August 06, 2007, a dramatic increase of three-month LIBOR rate in different currencies were observed even though there was no announcement of increase of official rates and the rate remained elevated for a considerable long time until central banks intervened. These phenomena implied a broken connection between official rate and market rate. According to BoE (2007), LIBOR rate is benchmark rate for short-term market interest rates in major currencies worldwide. LIBOR rates in general reflect 1) current and expected future overnight risk-free interest rates – the expected path of monetary policy and 2) a wedge between unsecured and secured interest rates, which may reflect liquidity premia or perceived credit risk (Bank of England, *Quarterly Bulletin*, 2007Q3). In turn, these elements connect market rates with official rate. Moreover, the BoE (Bank of England, *Quarterly Bulletin*, 2007Q4) admits that the impact of monetary policy expectations differs across monetary regimes. Therefore, to study the drivers of the increased LIBOR rates across regimes, BoE (2007Q4) compared three-month LIBOR rates with the corresponding overnight index swap (OIS). They used OIS as proxy of expectations of future policy rate because OIS is overnight transaction so it is less affected by interbank liquidity and credit conditions. Moreover, OISs are financial derivatives so the margining agreements reduce counterparty credit risk. For the liquidity aspect, OIS transactions do not involve an exchange of principle at the beginning, so they are not used for funding purposes in practice.

Therefore, the spread between three-month LIBOR and OIS in the corresponding term should reflect the level of credit risk and/or liquidity premia in interbank markets in the three regimes without the influence of difference on impact of monetary policies. Figure 2.2 reveals the spreads from January 02, 2004 to February 04, 2011 including pre-crisis, crisis and post-crisis periods in the three regimes, the UK, EMU and the Fed. Since the recorded date of crisis August 06, 2007, the spreads jumped by over one percent i.e. 100 basis points from their pre-crisis level about 0.05 percent i.e. 5 basis points, especially in the UK and the US. While the crisis intensified after a series of market events e.g. the collapse of Bear Stearns and Lehman Brothers in September 2008, the spread climbed to its peak of 3.6 percent in the US and 2 percent in the EMU on October 10, 2008 and 3 percent in the UK on October 20, 2008. The wider spreads indicated a dramatic increase of risk premia in the interbank markets. The reason may be due to the large amount of losses of financial institutions in the capital market as well as the unclear credit interconnection between banks and non-bank financial entities e.g. Special Purpose Vehicles. For example, Hesse *et al* (2008) pointed out that the difficulties for banks to understand their liquidity position included uncertainty of their own funding liquidity demand that was raised by moving off-balance-sheet positions onto their balance sheets and uncertainty about asset valuation.

These wider spreads had the equivalent effect of tightening monetary policy because for example, with 100-basis-point spread (the spread stayed around ten basis points before the crisis.), it can pass an increase of around one percent to rates of other financial instruments and products even though the official rate is unchanged. Furthermore, given the widened spread, a 100-basis-point reduction in official rate would only offset the increase rather than ease market conditions. In addition, tighten monetary policy will reduce the quantity of money supply in circulation. Joyce *et al* (2012) stated that the loose communication between official and market rate indicated that monetary policy became more than setting a base price of lending and that a quantitative approach should be adopted with consequences for the size of the central banks' balance sheet.

Figure 2.2 Three-month LIBOR – OIS in the UK (£), in the US ($) and in the EMU (€) in Percentage 02/01/2004 — 04/02/2011[6]



Furthermore, the credit position of banks became a serious problem for their counterparties because of the widespread error in assessing the risk of mortgage-backed securities. Banks themselves began to worry about their liquidity because they need to meet the liquidity demand from their off-balance-sheet vehicles rising from loss of mortgage-backed securities. That is, the uncertainty about liquidity position resulted in unwillingness to lend and a desire to hoard cash on balance sheets. Heider *et al* (2009) tried to establish the process of liquidity hoarding leading to breakdown of interbank market. They found liquidity hoarding started when the safer banks with a liquidity shortage drop out of the interbank market. That is, the root of liquidity hoarding is that some banks are insolvent (Heider *et al*, 2009). This can be further explained by asymmetric information and adverse selection. Mishkin (1990) attempted to

[6] In the EMU, LIBOR – OIS is substituted as Euribor – OIS because Euribor may more specifically reflect condition in European interbank market.

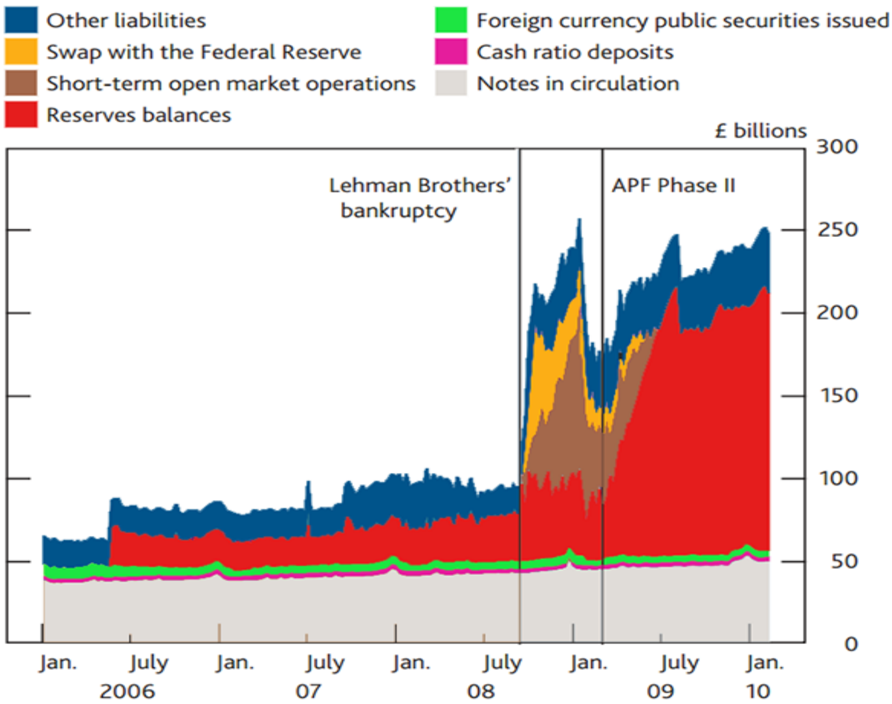
explain financial crisis in respect of Lemon Problem that was advocated by Ackerloff (1970) i.e. asymmetric information together with credit rationing of lenders by Stiglitz and Weiss (1981) i.e. adverse selection. Mishkin (1990) named the analysis as adverse selection-anaylsis.

Due to the uncertainty of a counterparty's creditworthiness, banks could not correctly calculate the risk premium on loans made in the interbank market. They ignored any reduction in official rate preferring to quote an extraordinary high interbank lending rate for protection. In context of asymmetric information and adverse selection, bank A may be willing to lend in interbank market at a high interest rate. A potential counterparty B may be willing to take the price, but then asymmetric information and adverse selection start to step in. On the assumption that bank B has superior information about its credit position than bank A, bank A is very likely to believe that the counterparty is having big trouble with a high risk to default. If this is the case, bank A will not lend to bank B at any rate. On the other hand, in order to protect its reputation, bank B will not accept and borrow at a higher rate. As a result, liquidity in interbank market was quickly dried up. Banks have been observed to an increased amount of deposit on their balance sheets.

As shown on Figure 2.3, prior to the middle of 2006, the level of reserves of banks in BoE (red area) was very low. The level suddenly jumped to about £70 billions and increased gradually since June 2006 until September 2008. Since Lehman Brothers filed bankruptcy, the level of banks' reserves jumped again and remained at a higher level until the operation of QE. Firstly, the increase of banks' reserves started about one year earlier than the widely recognized date of beginning of financial crisis, August 09, 2007, possibly indicating reduced amount of liquidity available to banks. ECB (Press Release, 01/06/2006) warned investors about the possibility of underestimated risk or taking excess level of risk in the Euro area. Moreover, BoE (Annual Report, 2006) also mentioned the phenomenon of low risk premia. The statements from ECB and BoE with observed increased banks' reserves prior to the crisis may imply that banks had felt the possible liquidity constraints. Secondly, the first liquidity provision in the UK was launched on December 18, 2007 and a series of liquidity boosters had followed during 2008 to the beginning of 2009 prior to the direct asset purchase. The intention of those liquidity provisions was to ease banks' refinancing position so they can continue on their role to supply credit to private sector i.e. transfer excess liquidity into credit. However, it is unlikely to be the case given the elevated level of banks' reserves. Due to the great uncertainties in interbank market and other credit markets, banks had to hoard excessive liquidity on their balance sheet in order to fight with unexpected cash demand e.g. rescue for their off-balance-sheet vehicles or cover potential capital loss due to uncertainty of asset valuation. Thirdly, the increase of banks' reserves after QE is not considered at this stage because QE involves expansion of size of central bank's balance sheet so the increase of banks' reserves does not necessarily mean hoard of liquidity.

Other financial institutions screamed for cash to fulfill their credit lines, make payments or hoard liquidity for uncertainty of their exposure to the crisis (Gordon, 2008; Mizen, 2008). There may be more reasons for dysfunction of interbank market e.g. Bain and Howells (2009, p424) also pointed out that capital adequacy can lead to unwillingness/reduced-ability to generate new loans because banks are highly leveraged so the withdrawal of capital, due to reduced profitability and loss of confidence on banking industry from shareholders, may be magnified and expressed as reduction of assets. But all these explanations lead to the fact that interbank market became dysfunctional and it failed to fulfill the transit of monetary policy.

Figure 2.3 Bank of England Balance Sheet – Liabilities



Source: modified from Cross *et al* (Bank of England, *Quarterly Bulletin*, 2010Q1, p35). Used with permission of the publisher

As a consequence of this breakdown, the interest rate as an instrument of monetary policy is largely compromised. In addition, given the wider spreads, the power of official rate to influence market rates was eliminated significantly as we have shown in the example. The BoE, the Fed and ECB all reduced their base rates several times to virtually zero between the beginning of the crisis on 2007 to mid-2008 but the spreads were still large despite dropping slightly from their peaks.

In addition to these difficulties, Joyce *et al* (2012) argued that central banks would need N instruments if they have N policy objectives. As the crisis developed, the focus of central banks shifted to financial stability in addition to inflation targeting. Therefore, central banks needed to seek for other measures to implement their monetary targets and tackle the credit and liquidity issues in the financial crisis. That gives the role of unconventional monetary policy.

2.2 Unconventional Monetary Policy

In the section, we will first discuss the situation when central banks should consider unconventional measures. Secondly, the unconventional measures that have been adapted by the three central banks will be analyzed in a timely order. Finally, a comparison between each central bank's policies is carried out. Due to the different institutional structure of ECB, they have limited power to adapt quantitative easing policies. Therefore, we see there are fewer innovative unconventional policies that have been implemented by ECB. Indeed, the non-standard monetary policy as ECB named themselves mainly consists of extension of collateral and term of refinancing operations in open market, which is conventionally applied approach under severe market condition. In spite of this, we use the term unconventional monetary policy across the section, aware limits in the case of the EMU.

Unconventional monetary policy by its name encompasses non-price based approaches for central banks to manipulate the size and/or composition of their balance sheets in order to restore and stimulate total demand so conventional monetary policy can be reinstated (Bernanke and Reinhart, 2004; Sharpe and Watts, 2013; Joyce *et al*, 2012). Unconventional policy is sometimes divided between quantitative easing and credit easing. For example, the BoE refers the unconventional measures as quantitative easing whereas ECB use the term non-standard measures and the name 'Enhanced Credit Support' for such facilities (Trichet, 2009). Sharpe and Watts (2013 quoted Klyuev *et al*, 2009) argued that credit easing mainly involves interventions into specific segments of credit markets to purchase assets (that are less liquid under market disorder e.g. commercial paper and asset-backed securities) so to extend credit. For example, before embarking on QE, the BoE sought to help banks buying illiquid assets in exchange for treasury bills. There is a change in the composition of the BoE balance sheet i.e. fewer treasury bills but more lower quality illiquid assets, but the size of the BoE balance sheet did not expand (John *et al*, 2012).

In addition to providing liquidity, quantitative easing may contain implicit and explicit commitment of central banks to reduce long-term interest rates through large scale of purchase of long-term government bonds (example from BoE Asset Purchase Facility) and/or supply of massive amount of long-term credit at extremely low price (to banking system)(Meier, 2009).

However, those funds may not be transformed to 'credit' in circulation for benefit of households and corporates if banks hoard them on their balance sheets because of credit and liquidity problems and capital adequacy concerns (see Bain and Howells (2009, p423-p424) for details of how liquidity is being trapped in banking system. Also, see Figure 2.3 for largely increased banks' reserve in BoE). That is, the reduced price of borrowing for banking system is very unlikely to boost private lending and reduce market risk premium as 'heightened risk aversion reduces the substitutability between government and private assets' (Sharpe and Watt, 2013 quoted Klyuev *et al*, 2009).

Bernanke (2009) tried to distinguish credit easing between quantitative easing by arguing that quantitative easing focuses explicitly (and solely) on the creation of bank reserves whereas the Fed has been concerned with the behavior of a complex range of spreads in the US. This has led it to be more concerned with the nature of the purchases that it made. The result inevitably is an enlarged balance sheet (as with QE) but under the Bernanke definition of credit easing that is a side effect of the range of asset purchases, whose composition is the critical focus of policy.

This argument tries to remove the effect of composition from definition of credit easing that has been summarized by Klyuey *et al* (2009). Bernanke (2009) pointed out that the policy that was run by Bank of Japan during year 2001 to 2006 was a typical example of quantitative easing whereas the policies that have been running by the Fed during the recent financial crisis was credit easing because the aim of the Fed of conducting those policies was to rescue dysfunctional credit markets and reduce the wider spreads. Blinder (2010, p475) commented on quantitative easing in Japan as 'flooding the banking system with excess reserves'. He pointed out that the Japan's case is slightly different because BoJ wanted to flatten yield curve rather than reducing risk spreads as BoE and the Fed.

Trichet (2009), president of the ECB, also tried to separate BoJ's unconventional measures from the Fed's by labeling the BoJ's approach 'quantitative easing'. Also, Bordes and Clerc (2012) pointed out that the measures that have been adopted by the Fed and BoE have been observed as quantitative easing so ECB's, but ECB rejected to the term quantitative easing even though their measures had broadly similar effects as quantitative easing. Cobham (2012) tried to separate measures to supply liquidity from unconventional monetary policy. He treated unconventional monetary policy as measures that are beyond liquidity measures. The unconventional monetary policy he recognized narrows to asset purchase facilities. However, he did mention that the size of central banks' balance sheet expanded as the result of liquidity measures, which falls the feature of quantitative easing. Also, Breedon *et al* (2012) have not applied 'unconventional' to quantitative easing. They treated quantitative easing as an extension of open-market operation involving swap of central bank money for privately held assets with both long and uncertain length.

This discussion shows that there is no universally accepted definition of unconventional monetary policy, quantitative easing and credit easing in terms of operation and effect. However, to summarize the above statements we can have the following features for policies that have been created especially during the crisis by the three central banks:

- Liquidity provision
- Large-scale purchase of long term government bonds
- Target purchase of asset in credit market
- Lead to change of asset composition and expansion of central banks' balance sheet

Despite they hold different views on how to describe those policies; they do not disagree with each other on the above features. Thus, in the study, we use quantitative easing in general to denote unconventional monetary policies because the fundamental for this study is to estimate and test the effectiveness of those policies to reduce risk premia in interbank market, so the way to name these policies does not matter that much. But, the difference between the markets will be considered and reflected in estimation.

The following section first reviews the origins of unconventional monetary policy. Secondly, the implementation of measures in the three markets is presented with reference to design, operation and impact.

2.2.1 Origins of Unconventional Monetary Policy

The unconventional measures that have been discussed is not as unconventional as they seem. King (2009) stated that when the effectiveness of interest rate instrument was impaired the conventional approach to cope with unconventional (market event) was to purchase (long-term) assets such as government bond or Gilts in liquid markets to boost the supply of money given the assumption that banks do not hoard any additional reserves as examples from Japan (see also Bowdler and Radia, 2012). Bean (2009) argued that quantitative easing only distinguished in its current operation by the circumstances under which it is taking place and the scale, which implies that the measures adapted by central banks are just with bigger size of operation. Also, as mentioned in the previous section, Bernanke (2009) classified the unconventional monetary policy in Japan during 2001-2006 as quantitative easing because it had the objective of expanding the monetary base. Woodford (2012) followed that the action (purchase short-term government securities) and the result (expanding the monetary base) of quantitative easing is same as when central banks conduct any open market operation. Thus, it seems that the unconventional measures we talked about are not as unconventional as they seem to be.

Moreover, King (2009) pointed out that what has been described as credit easing by Bernanke (2009) really fits the term unconventional monetary policy. When the disorder of economy starts from dysfunction of credit market, central banks can do target purchase of assets on most affected credit markets to improve liquidity. It is very important for central banks to make the decision on which market they should start such intervention. Both Bernanke (2009) and King (2009) emphasized the importance of selection. Bernanke (2009) advocated that central banks should consider markets that play major roles under normal condition. King (2009, p8) followed by

'… (BoE) need to be satisfied that there is a genuine private demand for an asset in normal conditions before it would be eligible for the asset purchase facility … complement and stimulate private demand, not substitute for it.'

It clearly reveals that quantitative easing should be considered by central banks when malfunctioning of credit market has had an impact on total demand. The target asset to be purchased should be an asset that plays important role in private finance. Moreover, the aim of quantitative easing is to restore the role of intermediation of financial market so that total demand will be boosted.

Similarly, Trichet (2009)[7] described the ECB Enhanced Credit Support as

'… primarily (focuses) on banks as they are the main source of credit in the euro area economy… seeks to provide enhanced support for credit provision through specific policies… constitutes the special and primarily bank-based measures that are being taken to enhance the flow of credit above and beyond what could be achieved through policy interest rate reductions alone.'

Given the constraints on purchasing government bonds on secondary markets, ECB's non-standard measures focus on providing longer-term refinancing options to banks in order to support credit circulation.

Under the situation in the three markets, it becomes clear that the intention for central banks to employ unconventional monetary policy originates from mainly two points.

The first points converge to failure of interest rate as an instrument because there was no interest rate policy possible when the base rate is close to zero, the so-called 'zero lower bound problem' or ZLB. As we have explained, the transmission mechanism of monetary policy under an interest rate regime primarily depends on the link between market rates and the official rate. The link needs two conditions: close relationship and effective response. If the former term breaks, central banks are likely to have reduced power on influence market rates and total demand, as we saw in the previous section. In the extreme case, central banks can lose control of market rates if the spread widens

7 http://www.ecb.europa.eu/press/key/date/2009/html/sp090220.en.html

dramatically and eventually, the–interbank market seizes up as the case after Lehman Brother collapsed. Moreover, Miles (2012) pointed out further potential problems as interest rates approached very low levels: 1) it is hard to predict the impact on the supply of longer-term credit which ultimately influences consumption and investment and 2) profits of banks are likely to be squeezed when base rate lowers because mortgage rates are often contractually linked to base rate – not the cost of their funding. In this area of lending, banks were threatened with falling revenue while their financing costs increased.

The second point is related to dysfunction of credit market. QE is likely to restore credit markets by increase broad money so to boost market liquidity and trading condition, and reactive capital markets. In the aspect of liquidity, King (2009) pointed out that the objective of unconventional measures would be to boost the supply of broad money as well as to increase liquidity and trading activity in credit markets. King (2009) further explained that the effect would be seen as a reduction on illiquidity premium in credit market where central banks have run the intervention. This may lead to restore of capital market and reduce reliance on bank lending. The intermediate result ideally should help the banking system restore its lending function so the flow of credit goes to business (King, 2009).

Certainly, the ECB has held the same view. Trichet (2009) summarized the policies in EMU under two headings, liquidity management measures and covered bond[8] purchase. Both of them aim to provide liquidity to the banking system and credit to households and business. Indeed, monetary measures by the three central banks during the earlier stage of the crisis have shown what the authorities committed – supply liquidity to banks and financial institutions (Banque de France, 2010, No.3).

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[8] Covered bonds are a type of asset-backed securities with less credit risk compared with others in the category e.g. CDOs because coupon and redemption payments are agreed in advance. Covered bonds bear little moral hazard problems because the cover loans remain on the issuer's balance sheet. Covered bonds are seen as substitutes for government bonds in the EMU i.e. market treats covered bonds as risk free asset. Details of credit risk contained in covered bond can be found in Prokopczuk *et al* (2013, p102-120).

Apart from what we have seen above, it is worth mentioning those features of the ECB's response that were due to its own institutional features. Since EMU is neither a federal union nor a nation, the target and approach for ECB to implement monetary policy differs from that of the BoE and the Fed. Cour-Thimann and Winkler (2012) explain that the provision of monetary financing in the EMU does not allow ECB to purchase government bonds in the primary market and its intervention in the secondary market is also restricted because when ECB purchase government bond in the EMU, the money goes to investors not sovereigns (Cour-Thimann and Winkler, 2012). Moreover, ECB (2007) pointed out that banks as one of financial intermediaries particularly take the original feature of transit of money from depositors to borrowers. The statistics (European Central Bank, *Monthly Bulletin*, 2010Oct) shows that nearly 80 percent of financing demand outside financial sector has been fulfilled by banks whereas the figure is opposite in the US i.e. nearly 80 percent of financing is fulfilled by non-bank financial institutions. This shows the fact that banks dominate in the EMU whereas financial markets play a significant role in financing firms in the US. The flexibility of substitution is limited in the EMU. If banks restrict credit, the problems are more serious. If banks fail to play their role of lending, large corporates can switch to other source of finance but SMEs are very unlikely to do so. Therefore, banks take extraordinary role in transmission mechanism of monetary policy in the EMU rather than in the US (Cour-Thimann and Winkler, 2012). It explains the reason that ECB's non-standard measures largely and primarily concentrate on banks (Cour-Thimann and Winkler, 2012).

To summarize, the origins of unconventional monetary policy start with the failure of conventional interest rate policy. This could be observed either as widening spreads or the little response from total demand to low interest rate in long term. Moreover, the concern for stability of financial markets forms another incentive for central banks to employ unconventional monetary policy. As in the recent crisis, the increased concern of uncertainty has led to severe asymmetric information and adverse selection problems for banks, so the lending activity nearly halted at the beginning of the crisis. This may further affect financial stability since banks' activity in interbank market is the primary transit process for credit to the private sector. Thus, unconventional monetary policy may have three elements: 1) massive supply of liquidity support to banks primarily; 2) forward indication of lowest boundary of policy rates over extended period; 3) large-scale purchase of financial assets especially longer-term's (Pattipeilohy *et al*, 2013), so there are mainly two clusters of unconventional policies, liquidity provision tools and large-scale purchase of long term asset mainly government bonds. As a result of these operations, the composition and size of central banks' balance sheet will be altered because the purchase is normally funded by issuance of Treasury bills and monetary base will expand accordingly to increased liquidity in credit market. Bain and Howells (2012) distinguish the effect of quantitative easing and qualitative easing on central banks' balance sheets. Quantitative easing expands the size of balance sheet of the central bank and changing composition of assets is associated with portfolio rebalancing process. Qualitative easing using to increase liquidity in market swaps central banks' liquidity and low risk assets for less liquidity and risker assets, so it results in changing of the composition of the assets. As a result, qualitative easing may increase central banks' exposure to all forms of risk including credit risk. The good example of qualitative easing would be the Special Liquidity Scheme (SLS) operated by BoE in the UK at the beginning of the crisis.

The next section reviews the unconventional facilities in the three markets respectively by looking at design and implementation. Also, we will show the institutional set-up of SLS by BoE to eliminate the credit risk that it may bring to their balance sheet. The impact of these facilities on money market will be discussed in the empirical chapter.

2.2.2 Unconventional Monetary Policy Tools in the UK, the US and EMU

The unconventional monetary facilities can be classified into liquidity provision and asset purchase programs (Trichet, 2009). The timelines of monetary policy events at the BoE, the Fed and ECB websites, show that the liquidity provisions were mostly implemented during the first one and half years of the advent of crisis. Below are the links to timelines:

BoE	http://www.bankofengland.co.uk/markets/Pages/sterlingoperations/timeline/timeline_no_flash.aspx
ECB	http://www.ecb.europa.eu/ecb/html/crisis.en.html
The Fed	http://timeline.stlouisfed.org/index.cfm?p=timeline and http://www.newyorkfed.org/research/global_economy/Crisis_Timeline.pdf

A table summarizing those measures is also provided for each monetary regime in the following subsection.

After the beginning of 2009, central banks with governments support launched large-scale asset purchases, despite some differences in the EMU because the size of the purchase of covered bonds is relatively small compared with the longer term refinancing scheme. The emphasis of policy shifts with movements of the crisis. The crisis was explored as liquidity shortage in interbank market. Here, liquidity refers to cash equivalent assets that can be easily converted in to cash to make payment. After a series of liquidity provisions, the problem moved to trading liquidity in certain credit markets, mainly commercial paper and corporate bond markets. This problem rises from the transfer of liquidity in banking system to credit. Thus, the focus of policy was targeted on the purchase of assets from specific markets at second stage. The section first reviews unconventional monetary policies in the three markets and a comparison of those policies will be discussed accordingly. It is also worth mentioning that there are currency swap lines operated among countries during the crisis in order for domestic firms to fulfill foreign currency liability, but these programs do not have interest on the study so they are not discussed.

2.2.2.1 Liquidity Provision

Bank of England

BoE launched the first term auction facility on September 26, 2007, which was just over a month after the crisis began on August 06, 2007. The BoE (2007) scheduled four auctions on September 26, October 02, 10 and 17, respectively. Those auctions were repo transactions with a three-month term. The amount was £10bn for each of the auctions. The key feature of the auction was the extended range of acceptable collateral (Bank of England, 2007)[9]. Apart from securities that are normally eligible in the BoE's OMOs, the collateral consisted of EEA and G10 sovereign bonds down to BBB/Baa ratings and other high quality market securities including mortgage-backed securities issued in the UK and EEA and commercial paper and senior corporate bonds with A+/A1 ratings (Bank of England, 2007a). The added collaterals are assets that are concerned in the crisis due to the unclear credit risk contained. This term auction facility[10] has attracted little attention from researchers compared with US Term Auction Facility. The reason may be that BoE (2007a) received no bid on the four auctions. Banks may have feared that obtaining funds from such auctions would damage their reputation and raise adverse selection problems since it was the first additional facility with extraordinary tolerance that opened to all banks and building societies in general in the crisis.

[9] Term Auction market notice http://www.bankofengland.co.uk/markets/Documents/money/documentation/statement070921.pdf

[10] The term auction is different from Extended Long-term Repo Operation that BoE first introduced on December 18, 2007. The term auction had more tolerant acceptance of collaterals and it was not scheduled in OMOs.

Table 2.4 Liquidity Measures during the Crisis

Scheme	Launch Date	Finish Date	Relevance to Interbank Spread
First term auction	26/09/2007	17/10/2007	No transactions
Extended collateral three-month long-term repo operation (ELTR)	18/12/2007	14/04/2009	Yes
Special Liqidity Scheme (SLS)	21/04/2008	30/01/2009	Yes
Discount Window Facility (DWF)	20/08/2008	Permanent	No data. Potentially no.
Extended Collateral Term Repo (ECTR)	06/12/2011	BoE can activate whenever it is needed	Potentially yes.

On December 18, 2007, BoE held its first extended collateral three-month long-term repo operation (ELTR). Compared with the previous additional term auctions, ELTR is scheduled as an open market operation (OMO) operating on a monthly basis with an initial amount £10bn. ELTR offers funds of three, six, nine and twelve months maturity. The pricing mechanism uses a 'uniform price' format – all successful bidders pay the lowest accepted spread on official bank rate (Bank of England, 2013)[11]. BoE (2007b)[12] intends to absorb excess liquidity generated in ELTR by reducing the size of the weekly short-term repo OMOs or the issuance of BoE sterling bills. Commercial paper and corporate bonds were dropped from eligible collaterals compared with the previous term auction. Moreover, the minimum rating of accepted sovereign bonds increased to AA- or higher. On October 03, 2008, BoE introduced separate minimum bid rates for

[11] Extract from the Red Book
http://www.bankofengland.co.uk/markets/Documents/money/publications/redbookectr.pdf
[12] ELTR market notice
http://www.bankofengland.co.uk/markets/Documents/money/documentation/statement071214.pdf

narrow and wider collateral, respectively. The narrow set of collateral includes only the securities that are likely to remain liquid in all but the most extreme circumstances, in BoE's view, and the securities need to be issued by sovereigns with sufficiently deep debt markets to facilitate broad access to BoE's operations while the rest of accepted sovereign bonds go into a wider set of collateral (Bank of England, 2010)[13]. Cross *et al* (2010) demonstrated that the accumulated size of ELTR increased rapidly after July 2008 and peaked at £ 180bn on January 2009. The expansion of the BoE's balance sheet was largely the result of these ELTR operations during this time.

The effect of the crisis became more visible in 2008 followed by the closure of some asset-backed security markets in the second half of 2007 (John *et al*, 2012). The fact was revealed by the collapse of Bear Stearns in early 2008. It turned out to be very difficult for banks to use mortgage-backed securities as collateral to borrow in the market. Moreover, the large amount of mortgage-related securities on banks' balance sheet reduced their willingness to lend in the interbank market due to uncertainty about the future value (*ibid*). This seemed likely to reduce credit available to economy. Therefore, it became important to remove those illiquid assets from banks' balance sheets (*ibid*).

BoE announced special Liquidity Scheme (SLS) on April 21, 2008. Compared with the term auction, SLS had more innovative features that were specially designed to tackle liquidity issues in the crisis. Firstly, the concept of SLS was to swap high quality but less liquid assets e.g. mortgage-backed securities that were held on balance sheet at the end of 2007 for high quality and liquid assets e.g. UK Treasury Bills for up to three years (Bank of England, 2012)[14]. That is, banks were given three-year secured loans. The interest was reflected by 'haircut'

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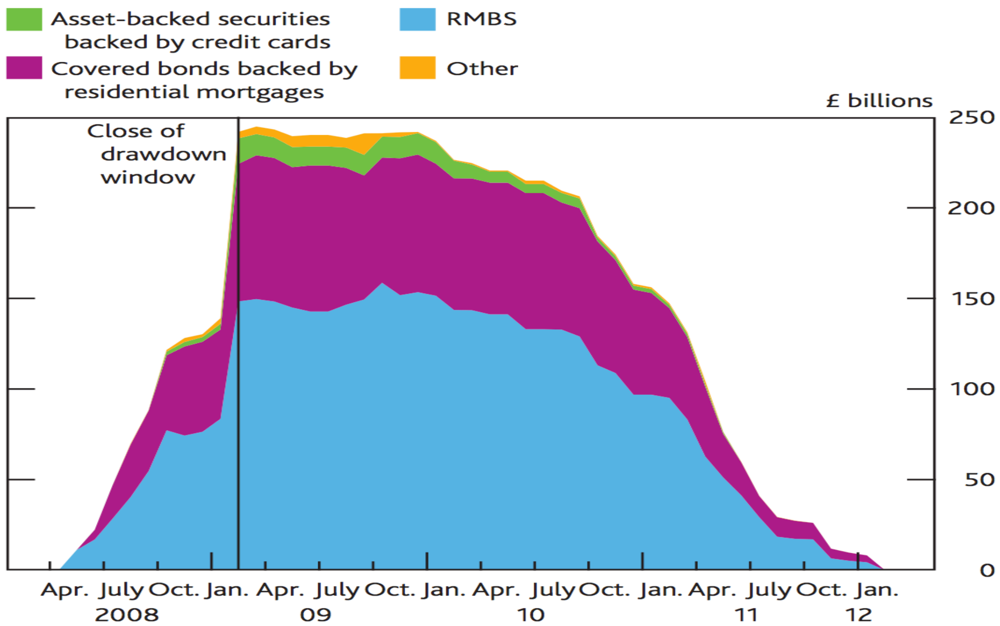
[13] Revisions to eligibility criteria for sovereign, central bank and supranational debt taken as collateral in the bank of England's operations. Link: http://www.bankofengland.co.uk/markets/Documents/marketnotice110211.pdf

[14] http://www.bankofengland.co.uk/markets/Pages/sls/default.aspx

when taking the swap. SLS had recorded £185bn lending of Treasury Bills and 32 participants by its close date on January 30, 2009 and BoE had received £287bn collaterals (Bank of England, 2009)[15]. The statistics (Bank of England, *Quarterly Bulletin*, 2012Q1, p62) reveal that collateral was mainly residential-mortgage-backed securities, covered bonds backed by residential mortgages, and asset backed securities backed by credit cards as well as small amounts of UK government debt, UK government-guaranteed bank debt, government guaranteed agency debt, and other government and supranational debt.

Figure 2.5 Collateral Pledged in SLS



Source: Bank of England *Quarterly Bulletin*, 2012Q1, p62. Used with permission of the publisher.

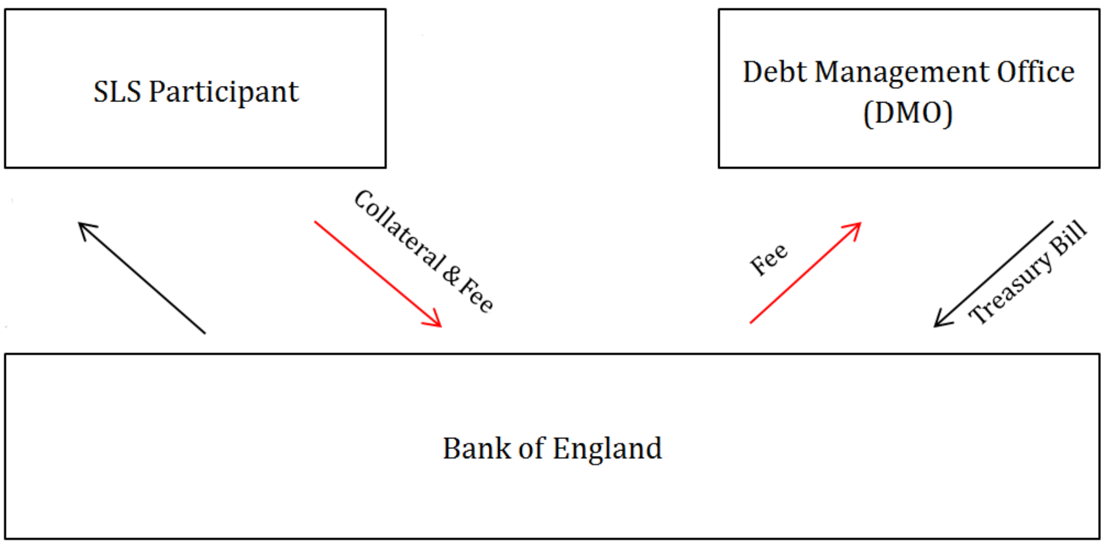
Despite the value of collateral dropping to £242bn at the close date of drawdown window, it still counts an effective haircut of around 16% (Bank of England, 2009). Moreover, there was a fee based on the spread between three-month

[15] Special Liquidity Scheme market notice http://www.bankofengland.co.uk/markets/Documents/marketnotice090203c.pdf

LIBOR and three-month General Collateral (GC) gilt repo (Bank of England, 2009), which represents the credit premium in the credit market (BIS, 2008; Taylor and William, 2009). This fee will be used as credit buffer to cover any loss in the unlikely case of counterparty defaults. Bowdler and Radia (2012) described SLS as an occasional operation to provide high quality and liquidity securities in exchange for lower quality collateral.

According to John *et al* (2012, p57-66), the target of SLS was to inject long-term liquidity to banks as well as reducing concern of credit risk in interbank market. The targets were fulfilled by collateral swap structure.

Figure 2.6 Stylised SLS Collateral Swap Process



Source: modified from John *et al* (Bank of England *Quarterly Bulletin*, 2012Q1, p60). Used with permission of the publisher.

Participant banks and building societies submit their collateral subject to acceptance and fee to BoE in exchange for Treasury Bills at a rate of discount. The BoE pays a fee to Debt Management Office (DMO) and borrows Treasury Bills to lend to participants under uncollateralized stock lending agreement. The Treasury Bills used in transactions were specially issued for SLS with extended maturity of nine months. Allen (2012) argued that SLS boosted direct bank funding, but it was impossible to distinguish the effect from that of quantitative easing. The effects that Allen (2012) pointed out were that the amount of repayment under SLS - £ 60bn in 2010, £ 160bn in 2011, and £ 60bn in 2012, would reduce the growth of liquid assets, apart from those positive effects that have been mentioned.

Despite those illiquid residential-mortgaged securities were removed from banks' balance sheet, the credit risk associated is still within banks' unless under circumstance of default. The temporary removal of illiquid assets from banks' balance sheet does not mean transferring credit risk associated with those assets to BoE's balance sheet because BoE set prudent procedures to eliminate the chance of taking excessive risk on their balance sheet. Firstly, the 'haircut'[16] approach to limit any loss that may have occurred when a participant defaults. The rate of haircut differs between assets and is subject to adjustment. That is, the value of collateral pledge has been discounted twice to get the borrowing value. The first discount is from nominal value to market value. The second discount is the haircut on market value. Secondly, HM Treasury indemnified the SLS. In case of a counterparty default, the transaction fees generated in SLS will first be applied to cover the loss as a buffer prior to HM Treasury's indemnity. As to the worst case, the loss will need to satisfy three conditions all together before it has been passed to private sector, 1) a counterparty defaults; 2) the haircut value of the collateral pledged by the counterparty is smaller than the its market value after the counterparty defaults: 3) the loss is greater than the buffer (John *et al*, 2012). Moreover, Fisher (2010) pointed out that SLS had no direct implications for monetary policy because the supply of central bank money was not affected by the swap of assets.

In addition, BoE also launched other liquidity programs: Discount Window

[16] Haircut is a noun to describe the difference between market value of collateral and borrowed Treasure Bills (John *et al*, 2012)

Facility (DWF) and Extended Collateral Term Repo (ECTR). The DWF launched on August 20, 2008 as a permanent on-demand standing facility, aiming to provide shorter-term liquidity to banks with a broader range of collateral at higher cost compared with SLS. On April 01, 2011, the range of collateral was extended. There are four levels of collaterals classified A – D. Similarly to SLS, DWF aims to help banks under firm-specific or market-wide shock (Fisher, 2010) i.e. liquidity related insurance (Bank of England, 2008)[17] through lending banks high quality and highly liquid asset with collateral pledged. The difference between them, apart from lending assets, is that DWF offers much shorter term (30 days) with higher costs. Participants can roll over the loan subject to acceptance of BoE.

BoE apparently want to use DWF as liquidity provision for banks when market is not under stress – liquidity shortage is not a problem for most of banks in the market. As role of liquidity insurance, BoE (2008)[18] described DWF as

> '… (L)iquidity risk is a standard feature of banking … but it is inefficient for banks to have to self-insure against extreme liquidity risks by holding excessively large stocks of safe liquid assets … In such circumstances, central bank are well placed, as monopoly suppliers of the most liquid means of payment … to act as backstop providers of liquidity to solvent banks: so-called liquidity insurance.'

It is clear that DWF fundamentally focuses on fulfillment of the role of lender of last resort when there is turbulence in the market and an individual bank is affected, but it does not deal with credit risk so banks that want to borrow under DWF need to be solvent and viable (John *et al*, 2012). Moreover, in order to

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[17] Sterling Operations – Liquidity Insurance
http://www.bankofengland.co.uk/markets/Pages/sterlingoperations/liquidityinsurance.aspx
[18] Sterling Operations – Liquidity Insurance
http://www.bankofengland.co.uk/markets/Pages/sterlingoperations/liquidityinsurance.aspx

protect banks' reputation and avoid unnecessary credit risk concerns, the statistics of DWF are revealed with a time lag to ensure any drawing will have ended before information is revealed to pubic (John *et al*, 2012 and Fisher, 2010). According to *BoE Quarterly Bulletin* from 2008 – 2013, there has been no borrowing under DWF since it was introduced. Moreover, the institutional set up of DWF does not exactly fit in the concept unconventional we have discussed in the study but it was newly created during the crisis in the UK so we have mentioned it briefly.

Table 2.7 Collateral Accepted under Discount Window Facility

Level A	High-quality sovereign and supranational bonds
Level B	Other quality debt that is tradable in liquid markets
Level C	Debt, and other transferable instruments, that are not tradable in liquid markets
Level D	'Own name' instruments

Source: Bank of England *Quarterly Bulletin,* 2008Q4, p380

ECTR is a contingency liquidity facility that BoE can activate in response to market turbulence. The aim of ECTR is to 'mitigate risks to financial stability arising from a market-wide shortage of short-term sterling liquidity' (Bank of England, *Quarterly Bulletin*, 2008Q4, p15). It launched on December 06, 2011 carrying very similar features to SLS but the transaction is finished by term repo and with widest range of collaterals. BoE will activate the facility when they believe there is a market wide need for liquidity. The first operation was held on June 15, 2012 and there were another three operations on July, August and September 2012, respectively. The amount of each auction was £5bn. Amount of allocation was reduced subsequently from £5bn to £1.5bn. There were another three operations from October to December 2012, but no amount was allocated.

BoE deactivated ECTR since then indicating the quantity of liquidity was enough in the banking system (Bank of England, *Quarterly Bulletin,* 2012Q3, p193).

On February 13, 2009, BoE started Asset Purchase Facility (APF) by establishing the Commercial Paper Facility (CPF). Since then, the focus of unconventional policy has moved to large-scale asset purchases, which will be discussed separately once we have finished with liquidity provision.

The European Central Bank

The ECB (*Monthly Bulletin* 2010, October) summarized their response to the financial crisis in four stages, the advent, the intensification, the period of temporary improvements in financial market conditions, and the sovereign debt crisis. At the onset of the financial crisis, the ECB first accommodated the needs for banks to build up their liquidity buffers so as to reduce uncertainty about their liquidity position by providing € 95bn on the first day (Cour-Thimann and Winkler, 2012). A few months later, the ECB added a six-month maturity to their normal three-month euro liquidity providing operation ('longer-term refinancing operation', LTRO). The LTRO has similar operational features to the term auctions that were held by BoE and the Fed. It is an open market operation that can be used during normal market conditions, also. On February 07, 2008, the Governing Council renewed another two supplementary LTROs allotted on November 23, and December 12, 2007 with € 60bn of each (European Central Bank, Press Release, 07/02/2008). Despite ECB had not announced officially opening term lending, the extension under LTROs revealed explicitly the intention of ECB to meet liquidity requirement in the money market.

The innovation of LTRO during the crisis was to add longer-term maturities rather than three-month and extend acceptable collaterals. The maturity of funds was three and six months initially and extended to twelve months in June 2009 and three years in December 2011, eventually, when the crisis intensified. The size was over €1 trillion for banks across Europe. However, the aim of LTRO differed from SLS since the ECB announced that LTRO aimed to reduce the spreads between risk-free rates and the cost of funding to banks in order to fix the monetary transmission mechanism (Cour-Thimann and Winkler, 2012) whereas the effect of SLS tends to be short term focusing on liquidity provision of the banking system.

Moreover, the ECB recognized that the extended LTRO was a complement to their interest rate instrument (European Central Bank, *Monthly Bulletin* 2010, October), which means ECB can adjust rates charged on LTRO regardless of the prevailing level of base interest rate, and vice versa, because the indexation of interest rate in LTRO is on the future main refinancing rate over the lifetime of the operations (Cour-Thimann and Winkler, 2012). That is, any increase in the policy rate will be immediately passed to increase costs of the remaining outstanding operations. The feature of indexation was introduced in December 2009. Before introduction of indexation, LTRO responded to the signaling of monetary policy stance through the key ECB interest rates (Cour-Thimann and Winkler, 2012). In addition, a fixed-rate full allotment tender procedure was adopted for all refinancing operations during the crisis to ensure financial institutions in EMU have unlimited access to central bank liquidity at the main refinancing rate subject to collateral (European Central Bank, *Monthly Bulletin* 2010, October).

Furthermore, together with the Fed, the ECB conducted two US dollar liquidity provision operations against ECB-eligible collateral for terms, 28 days and 35 days, respectively (European Central Bank, Press Release, 12/12/2007). The total amount of the two transactions was $20bn. Moreover, on November 08, 2007, the Governing Council extended two supplementary longer-term refinancing operations (LTROs) made on August and September 2007 from

November and December 2007, respectively to February and March 2008, respectively (European Central Bank, Press Release, 08/11/2007).

Table 2.8 Measures taken by ECB during the Crisis

Scheme	Launch Date	Finish Date	Relevance to Interbank Spread
US dollar liquidity-providing operations	12/12/2007	20/12/2007	Potentially yes because the two auctions were in line with US TAF
Six-month refinancing operations with longer maturities (LTROs)	28/03/2008		Yes
Special term refinancing operation	28/09/2008		Yes
Fixed rate tender procedure with full allotment	08/10/2008		Yes
Twelve-month LTRO	07/05/2009		Yes.
Covered Bond Purchase Programme (CBPP)	04/06/2009	30/06/2010	No. The amount of CBPP is very small and its second version aims to fight with sovereign crisis.
Sovereign crisis explores – aid to Greece	25/03/2010	02/05/2010	No
Securities Markets Programmes	10/05/2010		No.
Sovereign crisis – aid to Ireland	21/11/2010	07/12/2010	No.
New mechanism for countries in financial stress	28/11/2010		No.
Sovereign crisis – aid to Portugal	06/04/2011	17/05/2011	No.
Thirty-six-month LTROs	22/12/2011		Yes
Sovereign crisis-second aid for Greece	21/02/2012		No
Sovereign crisis – aid to Spain and Cyprus	27/06/2012	NA	No

While the crisis moved to the third and fourth stage, the ECB adopted asset purchase schemes and particular rescue tools for sovereigns with debt issues. Those responses will be discussed in the subsection regarding asset purchase.

The Federal Reserve

The Term Auction Facility (TAF) was announced December 12, 2007 aiming to provide depository institutions with direct liquidity in order to suppress the elevated risk premium in term lending in interbank market. The Board of Governors of the Federal Reserve[19] (Press Release, 12/12/2007) commented on TAF as

> '(Injecting) term funds through a broader range of counterparties and against a broader range of collateral than open market operations, this facility could help ensure that liquidity provisions can be disseminated efficiently even when the unsecured interbank markets are under stress.'

The TAF originally offered 28-day[20] lending to participants subject to a broader range of collateral than is used in the Fed's normal standing facility Discount Window. The Board of Governors sets the amount that would be offered via TAF and the minimum interest rate accepted equals the OIS rate corresponding to the term of the loan (Taylor and William, 2008). The Fed announced another term, 84 days, of TAF loans on August 11, 2008 but the size of 84-day loan $ 25bn was smaller than 28-day loan $ 75bn (Board of Governors of the Federal Reserve System, Press Release, 11/08/2008[21]).

[19] http://www.federalreserve.gov/newsevents/press/monetary/20071212a.htm

[20] From statistics that are published, some TAF loans had 35 days period e.g. the second transaction on December 27,2012.

[21] http://www.federalreserve.gov/newsevents/press/monetary/20080811a.htm

Table 2.9 Liquidity Measures by the Federal Reserve during the Crisis

Scheme	Launch Date	Finish Date	Relevance to Interbank Spread
Term Auction Facility (TAF)	17/12/2007	08/03/2010	Yes. Lender of last resort.
Primary Dealer Credit Facility (PDCF)	17/03/2008	01/02/2010	Yes.
Term Securities Lending Facility (TSLF)	11/03/2008	01/02/2010	Yes
Commercial Paper Funding Facility (CPFF)	07/10/2008	01/02/2010	Potentially yes if banks bidding in interbank market rely on commercial paper market to obtain credit.
Asset-Backed Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF)	19/09/2008	01/02/2010	Same as above
Money Market Investor Funding Facility (MMIFF)	24/11/2008	30/10/2009	Potentially yes if those beneficial special purpose vehicles (SPVs) are banks off-balance sheet vehicles. The facility would reduce the funding stress of banks.
Term Asset-Backed Securities Loan Facility (TALF)	25/11/2008	30/06/2010	Yes.

Apart from a general liquidity shortage, there were some credit markets made particularly dysfunctional by the crisis. It is important for central banks to help those markets restore their functions to prevent the wide spread of credit panic (King, 2009). Despite central banks in the three markets have all taken actions in specific segmental market, only facilities that have been created by the Fed fall into 'liquidity provision'. The programs that BoE and ECB operate in credit markets involve purchase of asset so they will be discussed in 'asset-purchase' section.

There were five facilities in total that were created by the Fed as liquidity provision to specific credit markets, Primary Dealer Credit Facility (PDCF), Term Securities Lending Facility (TSLF), Commercial Paper Funding Facility (CPFF), Commercial Paper Money Market Mutual Fund Liquidity Facility (AMLF), Money Market Invest Funding Facility (MMIFF) and Term Asset-Backed Securities Loan Facility (TALF). In addition to easing credit market, these facilities were offered to wider range of market participants than just depository institutions.

PDCF and TSLF focused on primary dealers. Primary dealers are principal intermediaries that operate as the trading counterparties for the Fed's open market operations and have a key role in offering liquidity in the market for US Treasury securities (see Arnone and Iden, 2003). Primary dealers are mainly big financial institutions e.g. investment banks that do not have reserve account with the Fed so they can neither enjoy lender-of-last-resort function through the discount window nor benefit from TAF. The Fed had lent $25bn and $112bn through PDCF and TSLF, respectively by February 25, 2009 at subsidized rate i.e. rate that is lower than market rate (Baker and Sherman, 2009).

PDCF started operation on March 17, 2008 in response to the liquidity pressure for primary dealers resulting from frozen triparty repurchase agreement market

(Board of Governors of the Federal Reserve System, 2013a)[22]. The triparty repurchase agreement is a repurchase transaction that a sale of securities coupled with an agreement to repurchase the securities at a pre-set price on a future date (Board of Governors of the Federal Reserve System, 2012)[23]. PDCF offered overnight liquidity to primary dealers, which takes similarity as discount window facility for depositary institutions.

TSLF was announced on March 11, 2008 focusing on promoting liquidity in Treasury and other collateral markets and so on boosting the functioning of financial markets in general because when the markets for the collateral became illiquid, primary dealers had increased difficulty obtaining funding and were less able to support broader markets (Board of Governors of the Federal Reserve System, 2013b)[24]. TSLF offered longer, one-month lending compared with PDCF. Both of them closed on February 10, 2010.

CPFF began on October 27, 2008, one month after the collapse of Lehman Brothers, and finished on February 1, 2010 targeting the three-month commercial paper that was issued by US firms. Operations were done by the Federal Reserve Bank of New York. CPFF facilitated issuers to participate in term lending financed by commercial paper issuance so to boost the ability of financial institutions to extend credit to public (Adrian *et al*, 2010). A month later on September 22, AMLF was launched with similar purpose but open to US depository institutions and bank holding companies.

In order to meet demand for credit by households and small businesses, the Federal Reserve Bank of New York created TALF on November 25, 2008 with size of $ 200bn on a non-recourse basis to lend to holders of certain triple

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22 PDCF background http://www.federalreserve.gov/newsevents/reform_pdcf.htm
23 Glossary of instruments http://www.federalreserve.gov/newsevents/reform_glossary.htm#tripartyrepurchaseagreement
24 TSLF transaction data http://www.federalreserve.gov/newsevents/reform_tslf.htm

A-rated asset-backed securities that are backed by newly and recently originated household and small business loans e.g. student loans, motor loans and credit cards (Board of Governors of the Federal Reserve System, 2008)[25]. The market value of collateral securities is fully considered but subject to a haircut. The context of the launch of the TALF was that new issuance of asset-backed securities shrank dramatically in September and halting in October and the risk premium containing in AAA-rated tranches increased quickly (*ibid*). This damaged credit resources fundamentally for households and small businesses since asset-backed security markets funded a substantial proportion of credit demand in the past. The difference of TALF to the previous liquidity provisions was firstly the term of funding i.e. TALF offers much longer maturity, three to five years compared with TAF, for example. The size of TALF is also much bigger. It starts with $ 200bn with expansion of further $ 1 trillion if market demands (Campell *et al*, 2011). TALF so far is the only running liquidity provision by the Fed (2013).

Moreover, according to the Fed (2013), the above facilities can be divided into two groups. The first group of facilities aims to fulfill the traditional role of central banks as lender of last resort. These facilities involve extended term auctions in the UK and EMU and DWF, SLS and ECTR in the UK, and TAF, PDCF and TSLF in the US. They aimed to meet liquidity demand in the financial market by offering longer terms against a wider range of collaterals. The second group of facilities targeted major credit markets. These are CPFF, AMLF and MMIFF and TALF in the US. Both BoE and ECB have operations in specific credit markets, but it has been done by large scale of purchase. In addition to those facilities, central banks have also set up currency swap agreements with each other to keep liquidity demand of foreign currency in domestic markets.

[25] TALF http://www.federalreserve.gov/monetarypolicy/talf.htm

2.2.2.2 Large-scale Purchase of Assets

The crisis intensified in 2009. Under the previous provision, large increases in banks' liquidity were observed on their balance sheets whereas the flow of credit to the private sector did not respond accordingly. Sharpe and Watts (2013) argued that increased liquidity in the banking system was not necessarily matched by increased credit in circulation because there are other factors that will influence banks' lending activity. In order to improve credit conditions in the economy, central banks started large-scale of purchase of assets targeting the most affected credit markets and the quantitative easing starts. In this section, we do not discuss those purchases under different regions because they share very similar features and have virtually same target in the US and the UK. However, the purchase of covered bond and sovereign bonds in the EMU takes a different purpose and objective compared with the US and the UK. It aims to help sovereigns in the EMU with their debt crisis. Also, the date when the purchase started is outside the period of this study, so we will just briefly refer to the purchase in the EMU.

The Fed (2013)[26] described quantitative easing as

> '… (T)raditional tool of open market operations to support the functioning of credit markets, put downward pressure on longer-term interest rates, and help to make broader financial conditions more accommodative through the purchase of longer-term securities…'

In the UK, the phase 'quantitative easing' was formally introduced on March 05, 2009 whereas the concept and operation to purchase commercial paper started one month earlier on February 13, 2009 through Asset Purchase Facility (APF).

[26] http://www.federalreserve.gov/monetarypolicy/bst_crisisresponse.htm

The first round of quantitative easing ended on June 2010. The purchase amount was £200bn containing mainly government bonds with small amount of commercial papers. The second round of quantitative easing stared on October 10, 2011. The eligible assets remained the same.

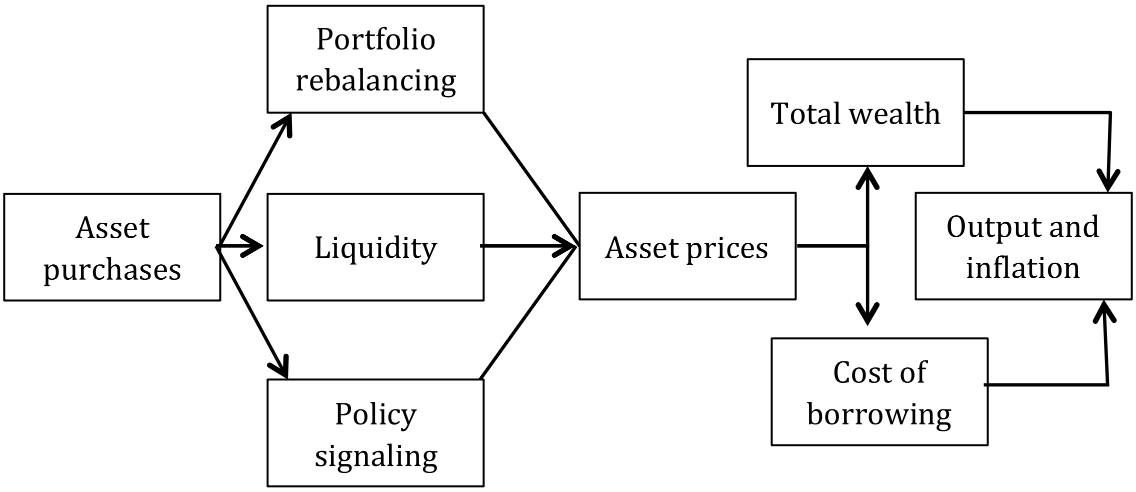
The BoE (2009) stated that the aim of APF was to help funds flow to corporate sector removing obstacles of access to capital market as well as supporting secondary market activity. Furthermore, BoE [27] emphasized the aim of quantitative easing in the UK as to

> '… (I)nject money directly into the economy in order to boost nominal demand … It does not involve printing more banknotes … (and) is not about giving money to banks. Rather, the policy is designed to circumvent the banking system … (electronically created) new money (is used) to purchase gilts from private investors such as pension funds and insurance companies … (through the portfolio rebalancing channel) they tend to use it to purchase other assets, such as corporate bonds and shares. That lowers longer-term borrowing costs and encourages the issuance of new equities and bonds to stimulate spending and keep inflation on track to meet the government's target.'

It implies that the effect of quantitative easing on the economy depends on the transit channels e.g. the portfolio rebalancing channel. Moreover, the ultimate effect the BoE would like to achieve is to lower longer-term borrowing costs and boost activities on primary markets and of course, to meet the inflation target.

[27] Quantitative easing explained http://www.bankofengland.co.uk/monetarypolicy/pages/qe/default.aspx

Figure 2.10 Stylised Transmission Channels of Quantitative Easing



Source: Bowdler and Radia (2012, p608) adapted from Joyce *et al*. (2011)

According to Joyce *et al* (2011), the effect of quantitative easing to stimulate spending and influence inflation relies on agents' activities through five channels. Particularly, portfolio rebalancing, market liquidity and policy signaling take majority function (Bowdler and Radia, 2012), as shown in Figure 2.6. The other two are confidence and money channels. The effect of portfolio rebalancing channel relies fundamentally on the imperfect substitutability of assets as suggested by Tobin (1969) and Brunner and Meltzer (1972). The degree of substitutability between assets can be influenced by duration, credit risk and liquidity (Joyce *et al*, 2011). Therefore, by purchasing long-term[28] government bond from the private sector, the BoE expected the proceeds i.e. cash will be used to purchase other assets which are substitutes to long-term government bond – rebalancing their portfolio until reaching an accepted level of return (Joyce *et al*, 2011). For example, the Fed under their large-scale asset purchases

[28] Woodford (2012) emphasized that purchase of short-term gilt is equivalent to open market operation. However, the assets that have been purchased under quantitative easing facilities are mainly long-term gilts. This made quantitative easing distinctive between normal open market operations.

(LSAPs) bought $600bn mortgage-back securities and agency debt because they are less similar to money (Foerster and Cao, 2013) so that investors will likely get rid of money quickly by purchasing assets with similar maturity and return such as corporate bonds (Bowdler and Radia, 2012). Moreover, pension funds are likely to hold long-term assets to match maturity of their liabilities. The swap of gilts for cash is unfavorable to the maturity structure, so they will probably seek for other assets to replace cash on their balance sheet (Bowdler and Radia, 2012). Given the restricted supply of gilts as a result of quantitative easing, the price increases and yield curve flattens. Moreover, since policy signaling channel aims to influence agents' expectation of policy rate, portfolio balance effects work by reducing the spreads of longer-term interest rates over expected policy rates (term premia) and risk premia – the mark up of return on risky assets to risk free assets (Joyce *et al*, 2011).

Moreover, the large-scale purchase of long-term assets is likely to reduce duration on long-term assets i.e. future movements in interest rates. Hence, investors would require lower risk premia reducing the pressure on longer-term real interest rates (Bowdler and Radia, 2012). They argued that the characteristic of investors' portfolios is altered, as a consequence. Therefore, investors would probably rebalance their portfolio by investing in riskier but cheaper assets e.g. corporate bonds or foreign government bonds etc. The process will be repeated until every investor holds satisfied portfolio (Joyce *et al*, 2011)

The effect of market liquidity premia can be explained by the example of commercial paper market. Commercial paper markets were severely affected during the crisis. Investors were concerned about market liquidity i.e. ease for them to sell and the amount of discount needed to be added on market price (Benford *et al*, 2009; Bowdler and Radia, 2012). That is, increased liquidity risk premia were demanded. This would push up the price for companies to obtain finance in capital market (Bendford *et al*, 2009). The purchase of commercial paper that BoE and the Fed conducted would provide confidence to investors that their holding assets can be easily sold as there is a ready buyer – the central bank. Hence, lower risk premia would be required. Consequently, there should be more investors entering the market and the amount of capital available to companies should increase (Benford *et al*, 2009), accordingly.

Moreover, Joyce *et al* (2011) described the liquidity premia effects in conjunction with the asset price. Appreciation of asset prices is expected when central banks conduct large scale purchases as well as the increase of trading activities of other investors due to the asset purchase of central banks. As a result, this will lower premia for illiquidity. They also pointed out that the transmission effect of quantitative easing should exist only when purchase is running. However, the reduction of illiquidity should be reduced permanently by increased trading activities in the market. However, they also pointed out the effect to reduce liquidity premia was not very important as expected by BoE in the gilt purchase. The effect would be more important in the design of purchases of private sector assets.

ECB has also run an asset purchase programme during the crisis. However, as we mentioned at the beginning of the chapter, those purchases are unlikely to fit the term large-scale purchase of asset i.e. quantitative easing because the size of purchase is very small compared with LTROs as well as size of purchase in the UK and the US. Moreover, the covered bond market is not as functional as government bond market because the size is smaller and the acceptance as collateral is limited when borrowing securely. We therefore discuss the two programmes, covered bond purchase programme and security market purchases only to keep the information complete.

The ECB operated a Covered Bond Purchase Programme (CBPP) from July 06, 2009, after the stage of temporary improvements in financial market conditions. CBPP finished in June 2010 and by the end involved €60bn three- to seven-year maturity euro-denominated covered bonds with 27% in the primary market and 73% in the secondary market. The Beirne *et al* (2011) noted that a significant increase in number of issuers and outstanding amounts was experienced in some national markets, despite the amount was relatively small. The second round of covered bond purchase programme (CBPP2) was launched in November 2011.

In early 2010, the EMU moved to the last stage – the sovereign debt crisis starting with Greece and spreading to Ireland, Portugal, Spain and Italy later on. The prices of government bonds for the stressed countries dropped significantly and yields moved upward, signaling negative market expectation. For example, in early 2010, the spread between Greek bonds to German bonds peaked at around ten percent due to the increased concern of the sustainability of public finances in view of rising government deficits and debt (*ibid*). Some secondary markets for government bonds started to dry up from May 2010 because sovereigns cannot afford the required high return (Cour-Thimann and Winkler, 2012). As a consequence, the ECB established the Security Markets Programme (SMP) to support market liquidity and the transmission mechanism. Since May 10, 2010 CBPP was conducted under SMP. As discussed before, unlike the BoE and the Fed, the ECB had limited power to purchase government bonds. The ECB conducted purchase of government bonds in secondary markets in line with provisions of the Treaty on the Functioning of the European Union (Beirne *et al*, 2011). These purchases are fully sterilized by conducting liquidity-absorbing operations (ECB, 2010).

On August 02, 2012, the ECB announced Outright Monetary Transactions (OMT) to replace SMP. Transactions under OMT focus on the shorter part of one to three-year yield curve of sovereign bonds. Given the credit and liquidity risks that have been produced by the crisis as mentioned above, the EMU faces a unique risk – redenomination risk particularly in sovereign bond market (Cœuré, 2013). Cœuré (2013, p3) stated that redenomination risk rises when 'investors perceived the monetary union as having turned from a single currency area into a fixed nominal exchange rate system cursed with the classic "peso problem"'. The example of redenomination risk is the spread of sovereign bond. The spread is wider when there is more redenomination risk, given all else being held constantly. For instance, the spread between Spanish and Germany ten-year government bonds increased by 2.5 percent in July 2012 compared with one year before. Therefore, Cœuré (2013, p6)[29] stated that the aim of OMT is to

'Eliminate the unwarranted and self-reinforcing fears of a euro area break-up that have undermined (ECB's ability) to effectively conduct monetary policy in the pursuit of price stability.'

It shows that the aim of OMTs is consistent with ECB's previous non-standard measures – maintain soundness of transmission mechanism of monetary policy. OMT will fulfill the purpose by eliminate fears of disasters and remove denomination risk from market by purchase of government bonds on secondary markets. The difference between SMP and OMT is that OMT is strict and effective conditionality attached to an appropriate EFSF/ESM programme in order to preserve the primacy of the ECB's price stability mandate (European Central Bank, 2013)[30]. Moreover, it is important to retain the incentive for national governments to operate required fiscal adjustments and structural reforms. Another difference is that OMTs are unlimited *ex ante*. The ECB will withdraw the programme once they believe the objectives have been achieved or when there is a failure to comply with a programme. The latter provides incentive for nations to keep their fiscal policy in line with monetary union's monetary stance.

[29] Speech by Benoît Cœuré, "The ECB and its OMT programme", 2 September 2013 http://www.ecb.europa.eu/press/key/date/2013/html/sp130902.en.html

[30] Monetary Policy Slide 10 http://www.ecb.europa.eu/ecb/educational/facts/monpol/html/mp_011.en.html

By now, we have discussed the design and purpose of unconventional monetary policies operated by BoE, the Fed and ECB. In the next section, comparison of aims and effects between the three markets is carried out.

2.3 Comparison between Unconventional Policy in the UK, the US and The EMU

As we have shown, the immediate difference between ECB's action and BoE's and the Fed's is the way they name their policies. The ECB named those unconventional policies as non-standard measures under their Enhance Credit Support (ECS) whereas both BoE and the Fed were more aggressively labeling the policies as quantitative easing. Indeed, the ECB has limited power to conduct large-scale purchases compared with the BoE and the Fed due to its institutional set up. Moreover, the purpose of policies differs between the three central banks. As mentioned in ECB October *Monthly Bulletin* (2010, p62), ECS aims to fix the broken transmission mechanism in the EMU. Quantitative easing in the UK focuses on providing liquidity directly into the economy in order to boost nominal demand (Joyce *et al*, 2011) so it is in the US.

Apparently, the purpose of those liquidity provisions was to offer liquidity to financial institutions by lending longer-term liquid assets and to reduce liquidity premia and concern in the money market so that the flow of funds can reach ultimate borrowers in the general economy. In the UK, the representative of such policies is Special Liquidity Scheme (SLS). In the EMU, it is longer-term refinancing operations (LTROs). In the US, there were in total five liquidity provision facilities running since the advent of crisis and it was hard to find a representative since the target and purpose between them was different. Given the important role of interbank market in monetary transmission mechanism, the central banks reacted immediately after the beginning of the crisis by offering term lending to banks with extended collateral and term to fulfill the role of lender-of-last-resort. For example, the Fed had launched TAF in December 2007 offering 28-day and 84-day funds. ECB announced to meet all banks liquidity at the first instance when the crisis explored and offered LTROs on March 28, 2008. The BoE scheduled four term auctions for banks right after the spread on three-month LIBOR and three-month OIS shot up on August 2007, despite no take up for the four auctions. Later on, the BoE established SLS to supply large scale of liquidity to banks by allowing them to temporarily swap quality but illiquid assets for Treasury Bills.

However, apart from liquidity provision to banks, the eligible institutions in the US were broader than in the UK and EMU because the Fed had designed different facilities to target primary dealers and different stressed credit market. Especially in the EMU, the ECB's policies showed a great favor to the banking industry. The reason for the deviation of policy focus was attributed to the different financial structure in the US. According to statistics from *Eurostat*, ECB and the Fed by the first quarter of 2012, nearly 80 percent of funding for corporate sector i.e. non-financial institutions in the euro area fulfilled by banks whereas only about 40 percent of funding is provided by banks in the US. Therefore, the ECB excessively focused on banking industry in their non-standard measures (European Central Bank, *Monthly Bulletin*, 2010, October and Cour-Thimann and Winkler, 2012).

Furthermore, the large-scale purchase of financial instruments operates also differently in the EMU compared with the UK and the US. The asset purchase in the EMU has been operated through SMP. As mentioned, SMP focuses on stabilizing malfunctioning of securities market as a result of sovereign debt crisis whereas the purpose in the UK and US is to go around banking system injecting liquidity directly to investors and economy, thus, the action in the UK and US is referred as quantitative easing. Eser and Schwaab (2013) argued that SMP differs from quantitative easing in three ways. Firstly, the effect of SMP will have little impact on private sector demand because the purchases focused on easing the sovereign debt crisis and the markets that had been affected. Secondly, the process of purchase of SMP e.g. total amount, duration of the program and targeted securities was not as transparent as in quantitative easing and LSAP in the UK and in the US, respectively because it contains resemble foreign exchange intervention. Thirdly, the introduction of the SMP was subject to significant controversy within the Eurosystem. This might be due to the institutional features of monetary union. Each member country will have its own preferred policy, which may not be consistent with such large-scale of purchase of sovereign debts. Foreseeably, the size of SMP should be smaller compared with quantitative easing and LSAP in the UK and the US, respectively. By early 2012, the amount acquired under SMP was €220bn (Eser and Schwaab, 2013). In the UK, BoE announced total accumulated amount £ 275bn by November 2011. In the US, the Fed announced total $ 2,650bn purchase by September 2011.

Moreover, both the BoE and the Fed had purchased wider assets rather than government bonds. For example, APF started with commercial paper purchase and the first round of LSAP announced $600bn purchase in mortgage-backed securities and agency debts and the Fed's liquidity provision tackled the commercial paper market. By contrast, apart from covered bond, which is a close substitute to government bonds in the EMU, ECB did not purchase any assets other than sovereign bonds.

Despite central banks holding different views of unconventional monetary policy, one of the fundamentals of those policies is to temporarily increase liquidity to the banking system to keep stability of interbank lending. The financial crisis raised credit risk and liquidity premia, which are both tackled by those policies, as central banks suggested. In the next chapter, we will review empirical works regarding the effectiveness of those policies to achieve their objectives, respectively.

Chapter 3 Empirical Literature Review of Impact of Unconventional Policy Measures

In Chapter 2, we reviewed the unconventional monetary policies that have been implemented by the BoE, the Fed and the ECB. Given that the interest rate as the primary instrument of monetary policy had nearly reached the zero lower bound, any further monetary stimulus would be limited because holding cash becomes a close alternative for bank deposits resulting in draining bank deposit as well as credit supply (Meier, 2009 and Mortimer-Lee, 2012). In addition, the widening spread between LIBOR and OIS weakened central banks' power to manipulate market rates anyway. That is, monetary policy fails to transmit through its interest rate channel during the crisis. Moreover, reducing and keeping interest rate at as low boundary as possible would cut down banks profit (because the spread between interest rates on banks' assets and banks' liabilities is narrowed). If monetary conditions still remain unfavorable in these circumstances, central banks are bound to consider using unconventional monetary policy tools (Mortimer-Lee, 2012).

Meier (2009) argues that unconventional monetary policy can work in three ways. The first option is to influence expectations of market participants. This might be called the 'signaling' effect. Central banks can form agent's expectation of low interest rate in the future by making announcements backed by concrete policy action. For example, the Fed announced it would keep interest rate low for at least two more years in June 28, 2011 (Reuters, 2011). Indeed, the Fed fund rate was still low at less than one percent in the spring of 2014. The effect of these announcements with commitment has been studied. For an earlier period, Bernanke *et al* (2004) using event analysis and an arbitrage-free term structure model find that the Fed's statements have had significant effect on market expectation of future policy rates. Furthermore, Biefang-Frisancho Mariscal and Howells (2010) used an exponential GARCH model to show that Fed announcements affected both interest rate expectations and the volatility of actual short-rates.

The second way is described as fixed-rate refinancing operations with extended maturity. This is a step further from the first option and is derived from the lender-of-last-resort function of central banks. The ECB's policy responses during the crisis provide a good example of this approach. The ECB offered fixed-rate full allotment subject to collateral to banks in the euro area and the LTROs. The former aims to meet banks' liquidity requirement unlimited at its main refinancing rate and the latter extends the maturity of long-term repo operations to a maximum of three years (Cour-Thimann and Winkler, 2012). Meier (2009) states that the likely outcome of such policies is to ease term premia in the interbank market so as to lower the interbank market yield curve. The risk associated with the approach arises when the central bank breaks the commitment to a low interest rate in the first option because they will pay higher interest rate on its short-term liabilities than they earn on longer-term assets i.e. the lending made to banks. But, this risk in turn can convince banks of the central bank's commitment to keep interest rates low at long-term horizons. Orphanides (2004) warns that central banks should not extend lending to truly long-term horizons due to unforeseen market movements and the exit strategy should be carefully considered prior to pursuing such a policy.

The third possible option is asset purchase, which is normally referred as quantitative easing (QE). The assets being purchased are normally long-term government bonds, although the Fed purchased some Treasury Bills at the beginning of the crisis. QE is financed by an expansion of the monetary base, so the direct result is to increase the narrow money supply. The focus of QE moves beyond the interbank market to the general private sector since it affects the price and yields on government bonds for which there are numerous close substitutes. During the crisis, the ECB has not engaged in asset purchase as heavily as the other two central banks in our study. The reasons summarized from Cour-Thimann and Winkler (2012) and Mortimer-Lee (2012) are 1) the institutional set-up of ECB constrains its ability to purchase government bonds;[31] 2) bank finance takes 80% of lending from private sector so it seems unnecessary for ECB to go beyond the interbank market; 3) the fear of moral hazard because sovereigns may engage less in addressing fiscal deficits, debt levels and structural reform issues[32].

Moreover, Bernanke (2009) classifies the unconventional responses from central banks into two broad groups, liquidity provision and asset purchase. Indeed, the first two options advocated by Meier (2009) mainly focus on restoring liquidity in interbank markets and the last option is asset purchase.

Not surprisingly, there is a substantial literature investigating the effect of central banks' unconventional monetary stimulus in the recent crisis. Martin and Milas (2012) reviewed some remarkable empirical works that examine the effect of quantitative easing on government bond rate, other asset prices and the real economy. For example, they report that Gagnon *et al* (2011), Glick and Leduc (2011), Krishnamurthy and Vissing-Jorgensen (2011), and Meaning and Zhu (2011), used event study analysis to find that QE successfully and significantly reduced ten-year US government bond rates by 80 to 107 basis points.[33] But, there was little evidence of impact of QE on money market rates and on other financial assets (see Neely, 2011). Baumeister and Benati (2010) using quarterly US and UK data in a VAR model found that QE saved both economies from much worse outcomes during late 2008 and 2009.

Martin and Milas (2012) provided a useful summary of empirical work on the

[31] See discussion in Chapter 2.2.1 for details.

[32] Purchase of government bond will lower long-term yield curve so reducing the interest payment on new issues of government debt.

[33] Gagnon *et al* (2011) estimated 91 basis point decrease. Glick and Leduc (2011) and Krishnamurthy found 100 basis point and Vissing-Jorgensen (2011) found around 107 basis point reduction and Meaning and Zhu (2011) found 80 basis point reduction on ten-year bond and 85 basis point drop on five-year bond.

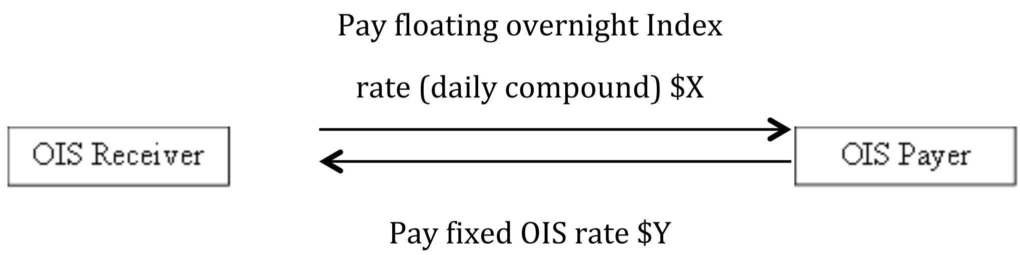
impact of QE, but QE is only part of unconventional monetary policies during the crisis. There are still liquidity provisions that operated prior to QE. Moreover, when we use the phrase 'QE', the ECB's ECS tends to be excluded because the focus of ECS is largely on providing liquidity to the banking system and the amount of asset purchase of covered bonds and sovereign bonds is relatively small. Indeed, Martin and Milas did not include the literature on the ECB's response in their review. Moreover, they argued that QE should have insignificant impact on money market spreads, which is just the question that our study tries to address. If QE does not have a direct significant impact on money market spreads, the question will shift to how else can central banks fix the break in communication between official rate and market rate as shown in Chapter 2 to restore the transmission mechanism of monetary policy. Fortunately, our study in Chapter 5 shows that QE *does* significantly reduce the risk premia in interbank markets in the UK and the EMU.

Therefore, this chapter looks next at the limited empirical literature that investigates interest rate behavior in interbank markets during the crisis. Those works tend to fall into two broad groups. The first group identifies itself with variation of data e.g. Michaud and Upper (2008) applied trading volume in the money market from eMid that is a system that is not widely available to researchers and innovative measure of credit/liquidity risks. Their results draw on how credit risk and/or liquidity risk contained in risk premia shift during the crisis in interbank markets without saying much about the impact on policy. They provide preliminary evidence to evaluate efficacy of unconventional monetary policy to influence money market. The second group investigates the communication between central banks' interventions and interbank market by looking at the change in risk premia. The remainder of this chapter proceeds as follow. Firstly, section 3.1 reviews work on the movement of interbank market before the interventions. Then, section 3.2 looks at literatures investigating impact of interventions in interbank market.

3.1 The behavior of risk premia components during the crisis

We showed in Chapter 2 that the crisis started with an obvious and sudden increased LIBOR rate. The obvious interpretation was the increased risk premium in interbank markets. Sarkar (2009) points out that an understanding of the prevailing risk environment may facilitate the evaluation of effectiveness of central banks' unconventional policies. BoE (2007) firstly attempted to decompose the LIBOR spread into credit risk and non-credit risk premia. The LIBOR spread refers to the difference between LIBOR rate and the rate on overnight index swaps (OIS), which is used as a proxy for the risk-free rate.

According to Hull and White (2013) and Sengupta and Tam (2008), Overnight Index Swaps (OIS) are interest rate swaps that entitle a bank to receive fixed interest rate from the counter party i.e. OIS rate and in exchange, the other bank in the swap is getting a floating rate of interest that is the geometric mean of a daily overnight rate, based on a notional amount. That is, OIS is a contract (or agreement) between two parties (normally, the two parties are banks.) who want to exchange fixed and floating short-term interest rates. The floating rate is also called reference rate. In the US, the overnight effective Federal funds rate is used as the floating rate. The reference rates are the Euro Overnight Index Average (EONIA) and Sterling Overnight Index Average (SONIA) in the EMU and the UK, respectively. As seen below, the party, the OIS payer, pays fixed OIS rate that is agreed in the contract to the counterparty, the OIS receiver, in exchange for a floating rate on daily compounded and based on the agreed notional amount.



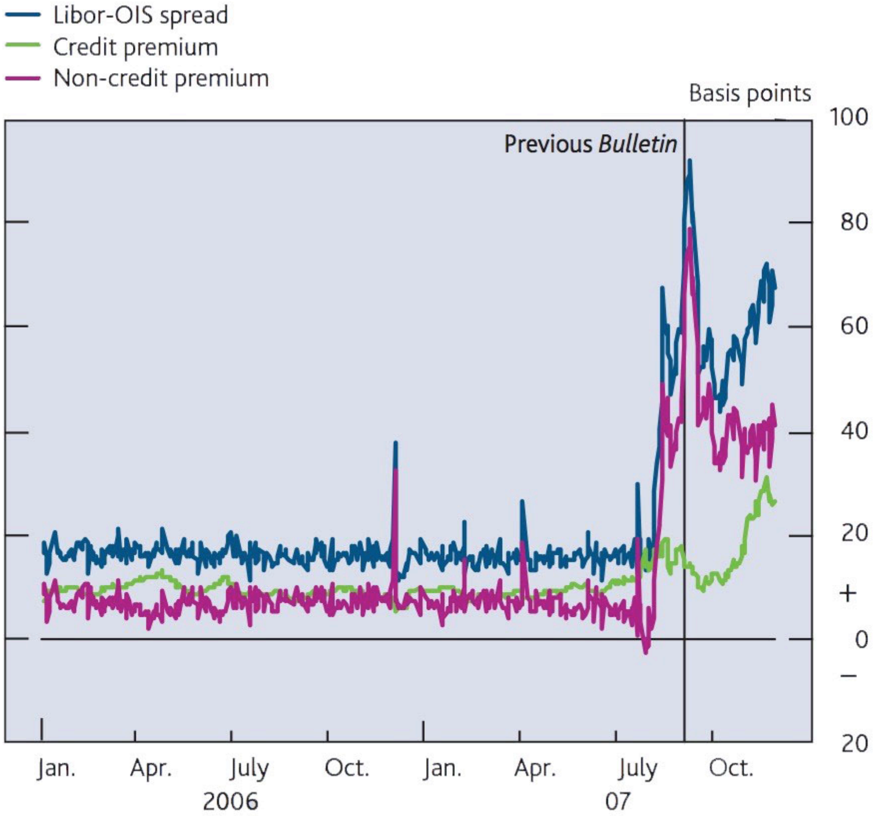
OIS has very little exposure to credit risk and it is used as a proxy of risk free rate as well as agents' expectations of the future interest rate (Sengupta and Tam, 2008; Hull and White, 2013; Michaud and Upper, 2008; BoE, 2007; Taylor and Williams, 2009; Reserve Bank of Australia, Bulletin June, 2002 and Poskitt, 2011). Firstly, the credit risk in the overnight borrowing is very small (Fabozzi, 2012 p.1473). For example, by mid of 2007, the spread between overnight rate of repos that are backed by U.S. Federal government securities (secured overnight lending rate) were only 5 to 10 basis points below the federal funds rate (unsecured lending rate and it is used as the reference for floating rate in the US OIS.) (Hull and White, 2013). During the crisis, the gilt repo rate fell relative to the federal funds rate, but for other repos that rate rose relative to the federal funds rate (*ibid*). These cross-sectional variations indicate that market microstructure may have contributed to the spread between unsecured and secured overnight lending rates more than the credit risk factor in the US (*ibid*), because if the credit risk factor mainly explains the spread between unsecured and secured lending, the spread should perform the same way during the crisis. Secondly, given the structure of OIS, there is no exchange of principal (notational amount) between the two parties and the final payment is the net interest e.g. $X - $Y to OIS Payer from OIS receiver if $X is greater than $Y, and *vice versa*. Also, OIS contracts have short maturity i.e. 1 week to 12 months normally although there are 2-year SONIAs. In our study, we use short maturity OIS in the three markets i.e. three-month OIS. Therefore, the net interest i.e. the difference between the fixed (the OIS payer pays) and floating interest (the OIS receiver pays) is very small leaving little credit and liquidity risks, respectively, in the swap.

OIS also reflects agents' expectation of the future policy rate. Firstly, the calculation of floating interest rate assumes rolling over a sequence of daily loans at the overnight rate until the maturity of OIS, which reflects the forward overnight interest rate (Hull and White, 2013). Secondly, the calculation of the fixed rate is derived from the government bond yield representing an average of the forward rates (Fabozzi, 2012, p1473). Therefore, we employ OIS as the proxy of risk free rate in our risk decomposing model by taking the difference between three-month LIBOR and three-month OIS. The spread should mainly show the risk premium contained in the LIBOR rates. Moreover, in the previous discussion, we have not distinguished the three interbank markets for the US, the UK and the EMU because these markets are similar.

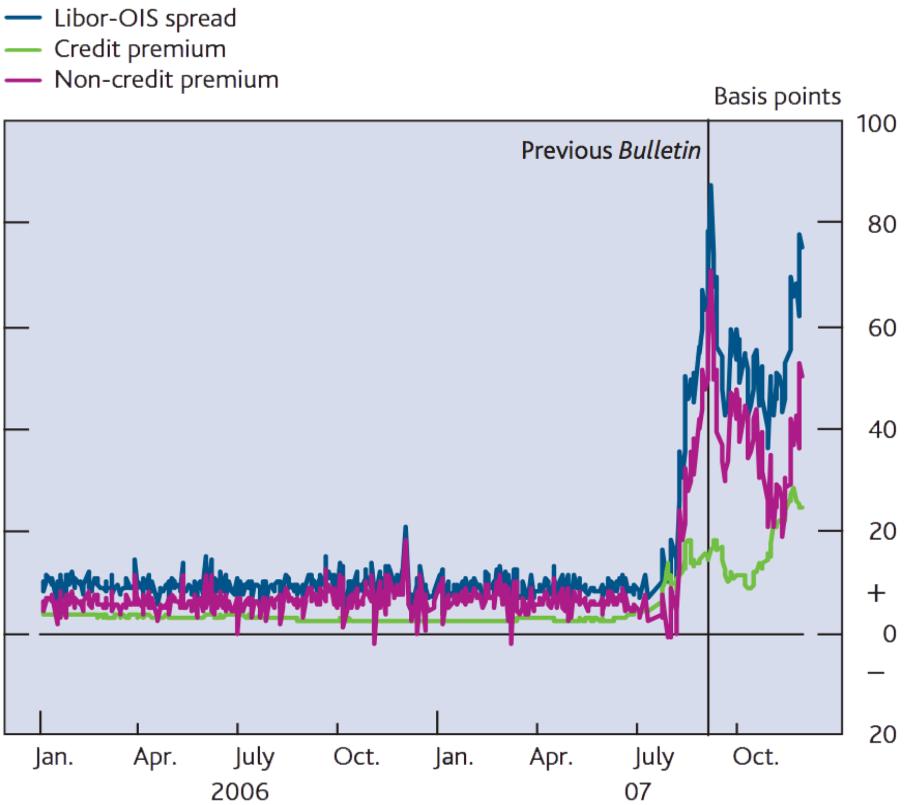
Using CDS as proxy for measure of default risk of banks they abstracted credit risk from the LIBOR and OIS spread because credit risk mainly arises in unsecured interbank lending activity so it is easier to be captured compared with non-credit premia, which may include various structural factors. Using event study analysis, BoE assumed that any deviation between LIBOR – OIS spread and CDS (credit default swap) price should reflect non-credit premia. The problem associated with this assumption is that credit risk and non-credit risk premia tend not to be independent. For example, a bank that finds it difficult to borrow in the interbank market (and thus faces raised liquidity risk) may be regarded as more likely to default and therefore experience greater credit risk. Figure 3.1 is a set of plots that BoE represented based on the above statement.

Figure 3.1 Bank of England Decomposition of 12-month LIBOR-OIS Spread

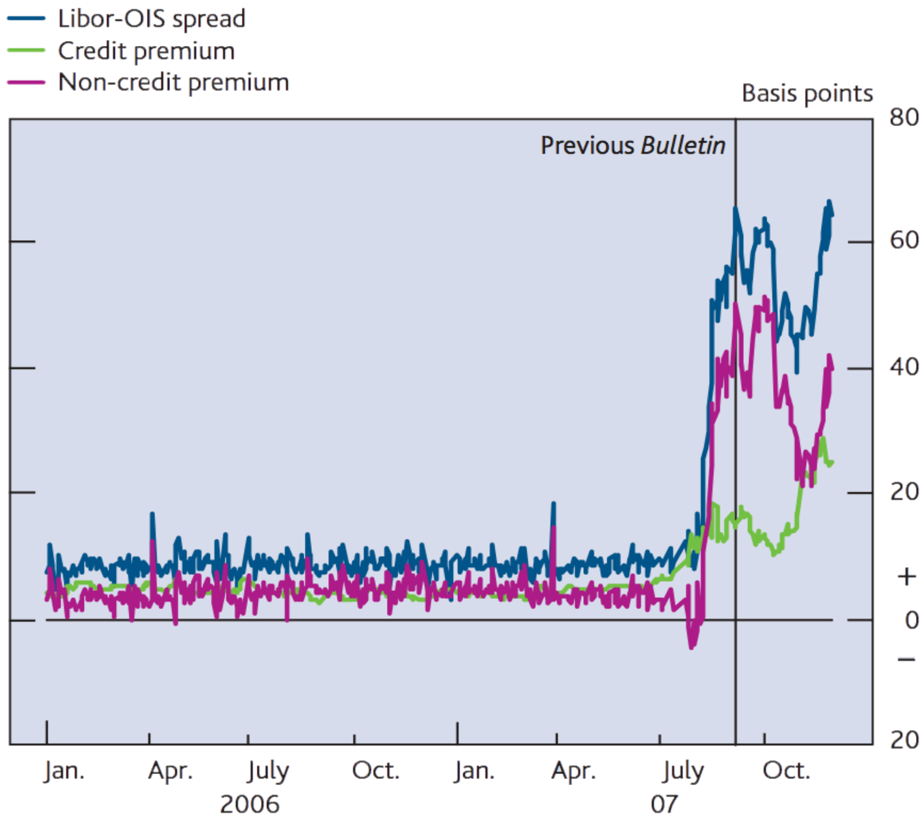
a. Sterling Pound



b. US Dollar



c. Euro



Source: Bank of England *Quarterly Bulletin*, 2007Q4, p498. Used with permission of the publisher.

The BoE's results, published at the beginning of the crisis, provided preliminary evidence for researchers to develop the topic. Their findings were mixed. It seems that they tried to express the change of credit factor and non-credit factor contained in the risk premium spread are highly related to market events. BoE broadly decomposed risk premium into credit and non-credit factors. The vague definition of non-credit factor ignores the possible reaction between elements in the credit factor and non-credit factor. There may be various components included in the non-credit risk factor e.g. liquidity risk, microstructure of market and term premium etc. These components may have positive effect on elements that influence credit risk i.e. elements contained in the credit factor may depend on the elements in non-credit factor. Particularly, BoE used twelve-month LIBOR in the research so the term premium might not be too small to be ignored. Thus, the vague definition of non-credit component may lead to over estimation on the effect of credit risk component in risk premium.

Following the BoE study, Michaud and Upper (2008) made a similar decomposition of the LIBOR – OIS spreads for G10 countries. Firstly, the contribution of their work was to clearly label spread of LIBOR – OIS as risk premium. Secondly, they argued that risk premium in the interbank particularly may be affected by two sets of variables, bank-specific variables and market variables which should reflect market condition and structure. The banking-specific variables contain risk of default i.e. credit risk and funding liquidity of the borrowing bank. The market variable include term premium which reflects the uncertainty about the path of expected overnight rates, market liquidity i.e. the ease of trading, and factors in the LIBOR fixing process and the microstructure of the market. In other words, Michaud and Upper argued that there are mainly two components in the risk premium, credit risk and liquidity component. The liquidity component includes the funding liquidity of the borrowing bank and market liquidity. The other elements that may influence risk premium are treated as residuals.

Thirdly, they introduced additional measures to proxy credit and liquidity risk components. For the credit risk, apart from CDS, they used the spread between secured and unsecured loans. The rationale underlying the measures is that both of them can represent risk of default as well as the compensation for bearing credit risk. The most significant development since BoE (2007) is the attempt to measure the liquidity component. Market liquidity was measured by quantities and prices observed on the electronic trading platform e-MID. They collected the number of trades, trading volume, bid/ask spreads and the price impacts of trades.

Other influencing components were treated as residuals because there is hardly financial data that can measure them. Moreover, Michaud and Upper applied both an econometric approach, using panel data, and event study analysis to the data and found at higher frequencies that liquidity has played a more important role while credit risk factors were traceable at lower frequencies.

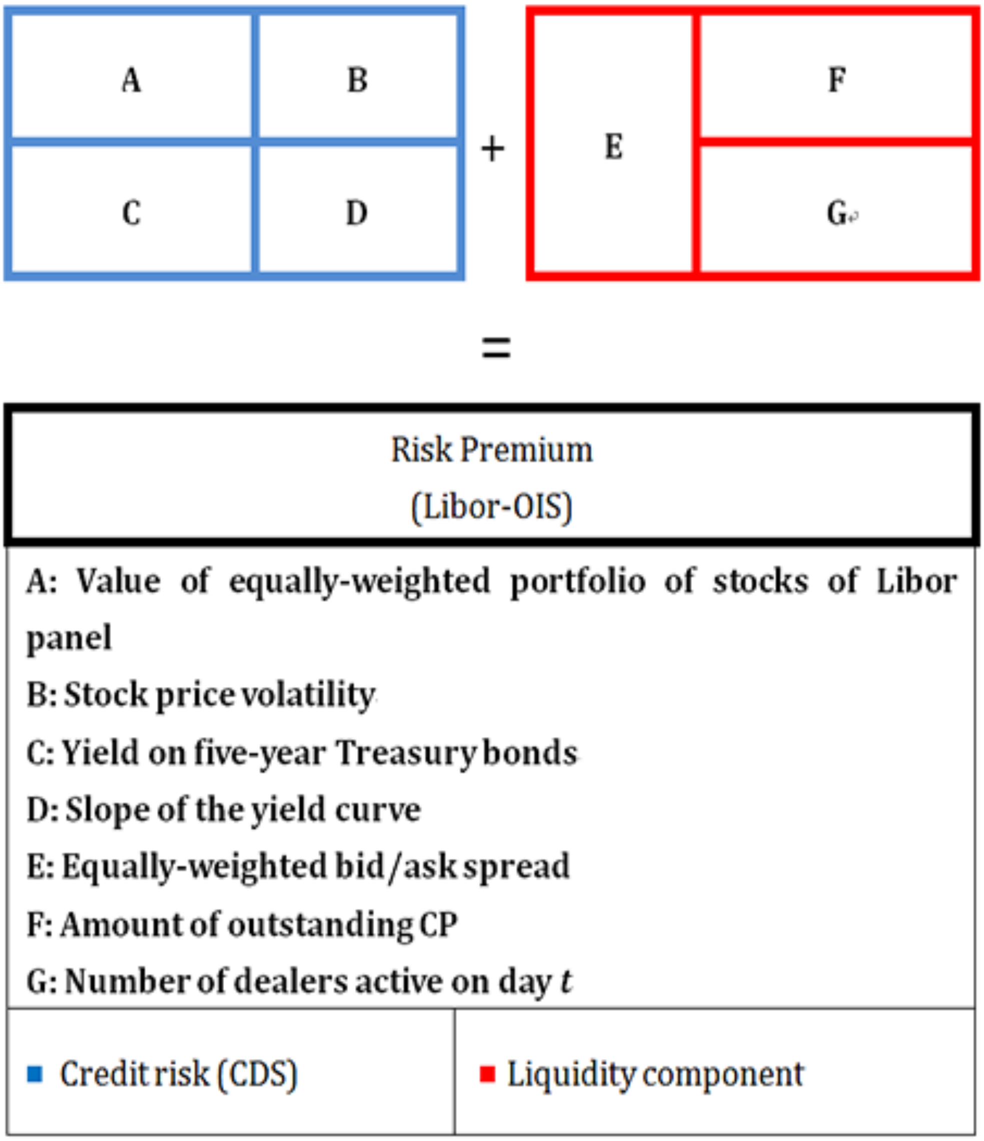
Based on their investigations, it seems clear that risk comes in many forms and from many sources. There may be a range of labels to denote these risks. In the interbank market, however, these risks are unlikely to be strictly separable. The risk-decomposing model is quite well defined theoretically, but the empirical evidence to address the problem – if credit risk or liquidity component or both of them played major role in pushing up risk premium in interbank market, may depend on selection of measurement of these risks as well as application of econometrics models. This may be one of the reasons that many later studies used different financial instruments for measuring of these risks with different econometric approaches.

Poskitt (2011) developed a system that contains a structural model of credit risk and liquidity component, respectively, and applied OLS regression on the mean equations with data from the US interbank and financial market. The system starts with the risk-decomposing model by labeling credit risk by CDS. The framework of the structural model is applied to establish a relationship between CDS/liquidity component and underlying elements that explains CDS and liquidity component. Poskitt found four explanatory structural variables for CDS, the value of an equally-weighted portfolio of stocks of the LIBOR panel, stock price volatility, the yield on five-year Treasury bonds and the slope of yield-curve of which is from Collin-Dufresne *et al*, 2001. The structural model of the liquidity component is constructed in a similar approach as Michaud and Upper (2008) by looking at observed interbank trading data, which are equally-weighted bid/ask spread of nineteen dealers and the number of dealers active on the day. In addition, the amount of outstanding commercial paper issued by financial institutions in the US commercial paper market is also used as an explanatory variable to identify the liquidity component.

The advantages of this system are 1) it allows diversified inputs from a wider range of financial markets e.g. commercial paper and stock market; 2) it measures the term premium using the difference on slope of one-year and ten-year Treasury bond yield curve; 3) it provides the opportunity to reveal how elements in CDS influence the risk premium; 4) the interaction between each element in CDS and liquidity component, respectively, is also investigated. Poskitt (2011) applies static OLS as econometric model for regression in this system. However, OLS regression requires variables to be stationary and is very sensitive to assumptions of residuals. Without satisfied unit root test result, OLS may lead to spurious regression, which might be the case for Poskitt (2011) because CDS price has been very volatile since the onset of the crisis.

Poskitt's results found that liquidity seems to be the major component of the LIBOR – OIS spread in the US market. The result also points out, as we suggested earlier, that a bank finding it difficult to raise funds is also in greater risk of default and the difficulty of raising funds will likely be factored into credit default swaps (CDS) premia and higher interbank rates. Similarly, the uncertainty over creditworthiness of banks could lead some banks to withdraw from the interbank market, thereby raising liquidity premia. The problem is widely recognised and the Bank of England (2007) warns that liquidity and credit risks may not be independent and sometimes shies away from the specific term 'liquidity risk' in favour of the vaguer 'non-credit risk' when referring to residual influences behind the LIBOR-OIS spread. Interestingly, however, the Bank also uses its market contacts to corroborate the implications in the data and these do confirm, at least for the period leading up to the crisis, that market participants felt that the credit premium was driven by risk of default unconnected with liquidity and that the residual premium was accounted for largely by liquidity factors (Bank of England, 2007).

Figure 3.2 Illustration of Poskitt (2011) Framework of Structural Model



The Figure 3.2 represents the framework of Poskitt (2011) structural model that attempts to decompose risk premium i.e. the spread between LIBOR and OIS. The structural model starts with the same theoretical ground as our model by decomposing risk premium into two components, credit risk and liquidity components. The distinctive contributions of Poskitt structural model are that the two components are explained by the underlying elements. Firstly, Poskitt applies the framework of a structural model of default to identify the variables that can influence the credit risk component that is denoted by the spread on the credit default swap (CDS). According to Ericcson *et al* (2009), the set of determinants that can change the CDS premium are financial leverage, firm-specific volatility and the risk-free rate. Therefore, Poskitt creates a structural model of CDS that identifies variables for the above three determinants, which are value of equally-weighted portfolio of stocks of LIBOR banks[34], stock price volatility that is measured by the implied volatility of put options written on the stocks of LIBOR panel banks[35], yield on five-year treasury bonds and slope of the yield curve. Similarly, the liquidity component is divided in two broad categories, trade-based measures, amount of outstanding commercial paper and number of dealers active on the day, and order-based measures, the equally-weighted bid/ask spread. The three explanatory variables of liquidity component reflect the market liquidity of the interbank market in the US.

Nobili (2009) studied liquidity risk in money market spreads using EMU data. The first approach to measuring liquidity risk is similar to that of the BoE (2007). The second approach adopts a simultaneous model to estimate the variables that may influence the liquidity component. Those variables are unsecured interbank deposit rates, zero coupon yields on financial bonds and zero coupon yields on Treasury bonds. The result appears that both credit and liquidity risks pushed up the money market spread (Euribor) and credit risk becomes more influential on the spread whereas liquidity risk had the lion's share initially.

Supporting these views, Berrospide (2012) tests liquidity hoarding (which is believed to be one of the reasons for increased liquidity premia in the money

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[34] The list of banks that bid in LIBOR market is provided in Appendix 1.

[35] Poskitt (2011) justified that according to Merton (1974), if the volatility of the firm's assets increases, there is a greater probability of default. Also, the increases in implied volatility of put option reflect a higher volatility of firm value. Therefore, the implied volatility of put option is a measurement for firm-specific volatility.

market by Bank of England, 2007) in the US, using a panel containing balance sheet data of approximately 6,750 financial institutions from the period between 2005 and 2010. Liquidity risk is used to measure the precautionary motive to hoard liquidity. The results suggest that banks held more liquid assets in response to increased risks in their asset portfolios and liquidity hoarding occurred across all banking institutions regardless of their size. This implies that liquidity risk for banks tended to increase during the crisis due to the precautionary motive of liquidity hoarding – the result indicates a quarter of the contraction in lending is due to the precautionary motive.

Schwarz (2010) employs microstructure measures of market liquidity and credit risk in EMU data. Market liquidity is measured by the spread between German federal government bond rates and KfW (Kreditanstalt fur Wiederaufbau) agency bonds by assuming both types of bonds are equally high quality but KfW agency bond are less liquid. The credit measure, indicator of credit tier differs from the previous literature. It is defined as the difference between actual unsecured interbank borrowing rates paid by banks that have good credit rating versus that have low credit rating. The result supports that market liquidity effects explain more widening of one- and three-month LIBOR and OIS spread than credit risk.

However, Angelini *et al* (2011) found that the elevated LIBOR-OIS spread was mainly driven by aggregate factors e.g. risk aversion and accounting practices. Funding liquidity and capital shortage do not appear to be the main determinants. Prior to the crisis, the LIBOR-OIS spread was not as sensitive as it reacted during the crisis to borrowers' creditworthiness. These findings can be interpreted as supportive evidence for the effect of credit risk on risk premium.

Overall, most studies agree that the risk premium in money market can be represented by the spread between LIBOR and OIS (In the EMU, Euribor substitutes for LIBOR.). Although they attempt to label each component differently in the risk premium, credit risk and liquidity are agreed to be the two main components. Measures for the two components are not easy because there are different factors that may influence credit and liquidity risks and it is not possible to find a single financial instrument to measure them all. CDS and the difference between unsecured and secured interbank lending rates are generally the two measures for credit risk. Poskitt (2011) developed the framework of structural model of CDS, which includes elements that may influence CDS price, according to the previous literatures. Schwarz (2010) measures credit risk uniquely using credit tiering. For the liquidity component, researchers tend to agree that there are market liquidity funding risk and bank-specific funding risk. There are mainly two approaches to measure liquidity component, residual approach and collection of market trading information. Schwarz (2010) used spread between German federal government bonds and KfW agency bonds to proxy liquidity. These different measures of credit risk and liquidity component lead to very similar conclusion that both of them contributed to increase of risk premium but the liquidity component tends to be the main driver initially and credit risk started to take over during the development of the crisis.

Knowing the performance of credit and liquidity components, it would be interesting to see how central banks have changed them using unconventional policy tools because the disorder of credit risk and liquidity components have caused significant negative impact on trading activity in money markets and damaged the transmission mechanism of monetary policy. The next section looks at the studies that focus on how the unconventional monetary policies have changed the behavior and relationship between credit risk and liquidity component during crisis.

3.2 How Credit and Liquidity Components Respond to Central Banks Unconventional Intervention

As we explained earlier, central banks' unconventional monetary interventions consist of liquidity provision and asset purchases. We first look at the effects on liquidity provision; then, we move to the effects of asset purchase.

The sudden widening of the unsecured interbank lending rate had a severe impact on banks' liquidity position. Banks as a special type of firm, face liquidity problem regarding the moment of withdrawal of deposits or payments to the public sector. The existence of interbank liquidity reduces the banks' exposure to liquidity risk and prevents bank runs (Freixas *et al*, 1999; Pablo, 1999; Brighi, 2002). The access to interbank credit lines not only helps bank cope with liquidity risk but also reduces maintenance cost of reserves (Freixas *et al*, 1999). Aglietta (1996) argued that liquidity problems could entail systemic risk in banking system with spillover effect from the uncertainty about credit risk assessment and change of price under conditions of stress. The arguments from previous literature provide the rationale for central banks to start intervention with liquidity supply during the crisis.

The study that is often cited by other researchers regarding this crisis is by Taylor and Williams (2008, 2009). It seems to be the first econometric empirical paper published regarding the influence of a central bank's unconventional policy on risk premia. They believed that there should be little liquidity premia contained in LIBOR - OIS spread and they found that counterparty risk was the main driver of the widening of the LIBOR spread. They were sympathetic to the argument that liquidity had been reduced in the money markets by the rise in counterparty risk, but they could not find any convincing evidence of liquidity risk when they compared the LIBOR market with the market for certificates of deposit (CDs). They used the TAF facility to explore the liquidity factor because TAF was intended as a liquidity facility. The TAF impact is measured by dummy variables equal to one since the first day of a TAF auction until the settlement day. Their sample covers sixteen TAF auctions from December 17, 2007 to July 28, 2008. Various efforts to find significant reductions of the LIBOR spread by the TAF proved futile. To this end, research that explored the effectiveness of extra liquidity provision by central banks to reduce the liquidity premium in the interbank market has provided controversial results. For example, Brunetti *et al.* (2009) used reported trades and quotes of the e-MID regulated interbank market and, similar to Taylor and Williams, found that central bank interventions create greater volatility rather than enhance liquidity. Also, in a recent study Angelini *et al.* (2011) found supporting evidence for Taylor and Williams.

Contrary to the above, several articles reached a different conclusion concerning the effectiveness of liquidity injections by central banks: McAndrew *et al.* (2008), Wu (2008), Christensen *et al.* (2009), Hesse and Frank (2009) and Nobili (2009) found that central bank intervention reduced liquidity risk on money market rates. Cecchetti (2009) points out that TAF, TSLF and PDCF helped in reducing the risk of a short-run financial crisis, but the Fed did not prevent the crisis spreading to the real economy as they wished.

The more recent studies tend to develop the problem by considering different aspects. For example, In *et al* (2012) focused particularly on the spillover effect of TAF among different credit markets i.e. interbank, commercial paper and jumbo mortgage markets. The three markets used to be independent before the crisis, but they developed multidirectional lead-lag relations during the crisis, which means, if policies focusing on money market have an effect, it should be transmitted to other credit markets. They find that TAF is successful as a signal policy tool rather than reducing three-month LIBOR and OIS spread because there is no short-term funding effect captured. Thornton (2011) also finds that the announcement of TAF did not reduce risk premium in LIBOR rates instead it increased the risk premium because the announcement was read by market participants as a negative signal for worsening market conditions.

Abbassi and Linzert (2012) used the main refinancing operations (MRO) and LTROs as proxies for liquidity provision in the EMU to estimate the response of money market rates to such massive liquidity injection. They point out that the loss in effectiveness of monetary policy to influence interbank market rates may be due to the higher liquidity premia and increased uncertainty about the future interest rates. The results show that the non-standard monetary operations reduced the Euribor rate by more than 80bps. However, the econometric model employed is a short-run dynamic model because the variables suffer from unit roots in levels. From these results, it is difficult to derive long run implications.

Moving to review work that studies the responses of credit and liquidity components to central banks' asset purchase. Joyce *et al* (2011) depict the transmission channels of QE (see Figure 2.10). One of the important channels is through portfolio rebalancing triggered by changes in asset prices. Portfolio rebalancing is indirectly influenced by credit risk and liquidity because they influence the degree of substitutability, which influences the process of portfolio rebalancing between assets, but credit and liquidity risk refer to specific assets, not the same as we have used previously. However, the normal transmission mechanism of monetary policy affects asset prices through an interest rate channel, which depends on the role of money markets because the official rate first communicates with money market rate in this channel (see Figure 2.1). This difference makes the topic of this subsection hard to develop because the policy of QE is designed to bypass the role of money market in the transmission mechanism (Mortimer-Lee, 2012), so its impact on money markets is not the immediate concern of the policymaker. The Martin and Milas (2012) survey reviews twenty studies spanning the period 2009 to 2011 regarding the impact of QE but only two of them - from Neely (2011), investigating the US and other eight advanced countries including UK, and Szczerbowicz (2011), concerning the effect of US LSAP on LIBOR and OIS, are concerned with money market impacts. Both suggest there is no significant impact of QE on LIBOR and OIS spread.

Literatures researching the impact of QE on asset prices tend to focus on corporate bond rate, exchange rate and equity yields. Krishnamurthy and Vissing-Jorgensen (2011) and Neely (2011) find QE significantly reduced interest rate of corporate bond from rating A to B. The amount of reduction becomes smaller with lower quality bonds. Glick and Leduc (2011) study the effect of US LSAP on exchange rate and find negative impact on USD exchange rate to other major currencies.

However, literature focusing on the EMU market appears to have more discussion on our topic. As we have seen, the ECB's non-standard monetary policy consists of liquidity provision and asset purchase and liquidity provision takes greater share of the policy tools. But, both of them are under OMO, so the estimation for the EMU cannot clearly be grouped in either liquidity provision or asset purchase, especially when the measure of non-standard monetary policy is OMO.

Cassola and Morana (2012) assess the Euribor – OIS by studying the persistence properties of the mean and variance of the spread in the framework of a FI-HF-VAR model[36]. This approach removes the imperfection on selection of measures for components in risk premium. They point out that there are two waves of stress and shocks in the interbank market following BNP Paribas on August 09, 2007 and Lehman Brothers on September 16, 2008. This confirms

[36] Fractionally Integrated Heteroskedastic Factor Vector Autoregressive model is developed by Morana (2011). It deals with the persistent structural break that is observed during the crisis period in the OIS interest rate.

our selection of a boundary for the EMU sample when we distinguish pre-intervention and intervention period. Mortimer-Lee (2012) also confirms the finding by mentioning that the ECB was the first central bank to announce an immense supply of liquidity into the banking system. These two waves of shocks produced permanent effects on changing level, volatility and persistence of the Euribor and OIS spread, implying the long lasting effect on credit and liquidity risks and confidence, which is the new term that does not appear in the previous literature. An error correction term on risk premium is captured but the value is very small. The interest rate cut and non-standard measures together appear to have formed the path for credit and liquidity risk to decrease. They also find credit risk denoted by iTraxx index did not fall although the risk premium showed a downward trend, so they interpret that liquidity risk or confidence factors may also be relevant during the crisis. Their result is similar to our EMU result.

Moreover, for the benefit of knowledge, we review some literature regarding the impact on government bond rates because flattened long-term yield will indirectly influence short-term interest rate. There are many studies of the impact of QE on government bond rates by taking event studies and econometrics analysis. The results are very similar that QE reduced government bond rates but the amount of reduction depends on the data and empirical approach selected. For example, from event study analysis, Joyce *et al* (2011) found around 100 basis point drop in ten-year UK government bond as the result of QE, whereas Meier (2009) finds a reduction of between 40 and 100 basis points. Neely (2011), taking the econometric approach, analyzes the effect of US LSAP on other five foreign ten-year government bond yield and found significant negative impact e.g. the US LSAP reduced UK ten-year government by 65 basis points. To finish this Chapter, we provide a summary table of literature reviewed in this chapter.

Table 3.3 Summary of Literature

Authors	Objectives	Methodology	Findings
Abbassi and Linzert (2012)	To exam the effectiveness of LTROs on money market rates in the Euro area	First difference OLS	The ECB's net increase in outstanding open market operations effectively reduced 3-, 6- and 12-month Euribor rates, respectively.
Angelini *et al* (2011)	To examine the drivers of the LIBOR spread in the EMU	Panel data	Aggregate factors e.g. risk aversion and accounting practices also mostly contributed to the elevated LIBOR spread.
Bank of England (2007)	Decomposition of LIBOR spread. US dollar, Sterling pound and Eur LIBOR data.	Spreads on LIBOR and Credit Default Swap (CDS) and charts	At the beginning of the crisis, non-credit premia played major role and credit risk premia became more dominant.
Berrospide (2012)	To examine liquidity hoarding behavior of UK banks	Panel data	Liquidity risk for banks tended to increase during the crisis due to the precautionary motive of liquidity hoarding.
Brunetti *et al* (2009)	To examine whether the ECB's intervention improved interbank liquidity during the crisis.	Event study	Standard (and special) interventions that did not specifically tackle the issue of asymmetric information in the interbank market failed to improve market liquidity.

Cassola and Morana (2012)	To find out the features of sudden increase of interbank lending rate in the euro money market during the financial crisis.	Vector Autoregressive model	The stress in the money market caused the non stationarity in the OIS spreads and led to permanent changes in levels of OIS spreads.
Cecchetti (2009)	To exam the Fed conventional and unconventional responses to the crisis.	Event study	Conventional instrument was ineffective. The unconventional policies helped to ease market condition.
Christensen *et al* (2009)	To test the announcement effect of TAF in term interbank lending.	Kalman filter estimation	TAF helped reduce the liquidity premium in term interbank rates.
Glick and Leduc (2011)	To investigate the effect of QE in the US and the UK to lower long-term interest rates and commodity prices	Event study	QE successfully reduced long-term interest rates in both countries and markets.
Hesse and Frank (2009)	To exam the effectiveness of central bank interventions, LTROs in the EMU and TAF in the US, on interbank market.	VAR & GARCH	LTROs and TAF eased stress in interbank markets, respectively in the two markets.

In *et al* (2012)	To find out impact of TAF on interbank and mortgage markets.	Error correction model with TAF dummy	TAF reduced the risk spreads in the interbank and mortgage markets and there were multidirectional relations between the markets.
Joyce *et al* (2011)	To explore the impact of QE in the UK economy and financial market.	Review	QE successfully reduced the assets prices.
Krishnamurthy and Vissing-Jorgensen (2011)	To exam the effect of QE on the US interest rates.	Event study	QE worked through signaling and inflation channels. It lowered MBSs yields as well as credit risks.
Martin and Milas (2012)	To review the effect of QEs in the UK, US and EMU	Review	QE had significant effect on reducing long-term yield and risks in the three markets, respectively.
McAndrew *et al* (2008)	To examine the announcement and operations effects of the TAF on the US LIBOR.	OLS regression	TAF worked to reduce the US LIBOR.
Michaud and Upper (2008)	To exam the drivers of the increased spread of risk premium during the crisis. G10 countries.	Event study	Liquidity factors played a more significant role than the credit risk component.
Mortimer-Lee (2012)	To identify risks associated with QE. The UK, EMU and US data.	Event study	Numerous risks associated with QE, timing to entry and exit, conflict of interests and managing expectations.

Neely (2011)	To exam the announcement effect of US large-scale asset purchase (US QE) on international long bond yields and exchange rates.	Event study	The US QE substantially reduced international long-term bond yields and the spot value of the dollar.
Nobili (2009)	To find out if liquidity risk in the EMU money market had pushed up the risk premium i.e. EURIBOR – OIS.	Simultaneous equation model	Both liquidity and credit risks pushed up the EURIBOR spread and credit risk over took liquidity risk to be the more influential element.
Poskitt (2011)	To exam the major driver(s) of the US interbank risk premium i.e. LIBOR – OIS during the crisis.	OLS regression on structural model of credit risk and liquidity component	Liquidity seemed to be the major component of the risk premium spread. The liquidity component can have an impact on the credit risk component.
Sarkar (2009)	To test the effectiveness of the Fed's innovative liquidity providing monetary tools (up to 2009) to reduce liquidity and credit risks in the US.	Survey of the previous literatures	In the earlier stage, liquidity primarily contributed to the risk premium. Credit risk became increasingly prominent during 2008.

Schwarz (2010)	To measure microstructure that may influence market liquidity and credit risk and estimate the relationship between liquidity and credit risks in the risk premium spread. EMU data.	Time-series regression	The market liquidity contributes to the widening one- and three-month risk premium spreads (LIBOR – OIS), respectively, more than the credit risk.
Szczerbowicz (2011)	To find out the effect of conventional and unconventional monetary policies on the risk premia in the US.	Event study	The unconventional monetary policy was proved to be effective to reduce the risk premia.
Taylor and Williams (2008 and 2009)	To test if Term Auction Facility (TAF) effectively reduced the risk premium. US data	OLS regression based on non-arbitrage model	No empirical evidence that the TAF has reduced the risk premium spreads (LIBOR – OIS).
Thornton (2010)	To discuss the downside of quantitative easing. US data.	Economic Synopses from The Federal Reserve Bank of St. Louis	QE increased the liquidity in the money market.
Wu (2008)	To examine the effectiveness of liquidity provisions run by the Fed on reducing risk premium.	OLS regression on non-arbitrage model	TAF had particular effect on reducing risk premium through relieving liquidity concerns of financial institutions

Chapter 4 Methodology

As we saw in the literature review, the conventional links between official interest rates and market rates virtually broke in the UK, US and Euro zone, during the recent financial crisis. The demand for a risk premium in interbank lending increased dramatically due to the uncertainty of the credit position of counter parties. This resulted in excessive LIBOR rates, especially in the UK. This dried up the liquidity in the interbank market and resulted in a worsening lending environment to commercials. To ease liquidity conditions, central banks put into effect a series of unconventional operations aiming to inject money directly into the economy. To understand the effectiveness of these polices, BoE (2007) and BIS (2008) developed a risk decomposition model trying to study the balance of credit risk and liquidity risk in the risk premium. This risk-decomposing model together with a non-arbitrage model provides the theoretical framework for our research.

Our research questions explore the effectiveness of those unconventional policies to reduce risk premium and how they affected the relationship between liquidity and credit risks during the crisis. This chapter presents the research plan of the study, definition of variables, the data collection process and econometrics approaches. Section 4.1 reviews the aspects that the research covers. Section 4.2 represents the theorectical framework. Section 4.3 presents definition of variables and the static model of the study that is derived from theorectical framework. Section 4.4 defines the sample period and section 4.5 shows the econometric approach.

4.1 Research Plan

The research focuses on the evaluation of effectiveness of central banks' innovative interventions to reduce LIBOR spreads and how the relationship between liquidity and credit risks were changed in the crisis. There are three main approaches.

The first is to study the factors(s) that drove up the spread. Current work regarding this question suggests that credit risk and liquidity risk were the two possible sources of this increase. However, there is no explicit and identical empirical evidence to support this hypothesis. For example, Michaud and Upper (2008) suggested that the liquidity premium contributed to the spread by decomposing the risk premium whereas Taylor and Williams (2009) argued that liquidity factors played no additional role, using a no-arbitrage model. Moreover, as the crisis developed, some researchers e.g. Eisenschmidt and Tapking (2009) and McAndrews and Skere (2009) tended to agree that credit risk alone couldn't drive up the spread dramatically. There should be a role for liquidity factor – banks funding liquidity or payment liquidity shocks. These conflicting results may largely be due to the continuing unfolding event and the consequent short period of available data, when those researches were carried out. Therefore, it is worth further investigation in this question.

The second aspect is to study the liquidity interventions that central banks used to save markets during the crisis. By investigating the nature and features of each facility, it will help on not only in identifying the type of risk premium contained in the spread but also give the opportunity to evaluate the strengths and weakness of the techniques for future use. Interventions can be split into conventional and unconventional. The conventional actions are those of reducing the official rate of interest and increasing the length and amount that banks can borrow from the discount window. The unconventional interventions are, for example, in the US, to establish new lending facilities both to inject massive liquidity to banking system (Term Auction Facility, TAF) and to provide high quality collateral for the markets (Term Securities Lending Facility, TSLF). Moreover, since investment banks and brokers are unable to access the discount window so to TAF, Fed created Primary Dealer Credit Facility (PDCF) for primary borrowers and creditors. From the data collected by the Fed, these facilities seemed to reduce the spread yet it still remained wider than when the crisis was developing. Therefore, it is necessary to examine the efficiency of these interventions, to study the implications and evaluate their weakness and strength for future use.

The third aspect is to study the changing relationship between liquidity and credit risks during and after the recent financial crisis. Mayes (2009) stressed that crises cannot be avoided in financial system because the system is given the ability to take risk so that it can undertake role of intermediation. An understanding of the relationship between liquidity and credit risk is necessary for central banks to establish a rescue package in the future. Moreover, after the financial crisis, the transmission of risks may become a concern of central banks since the large amount of lower quality bonds that were purchased remained on central banks' own balance sheets.

Therefore, the research questions are:

i) Why did the spread on official-interbank rates matter in terms of transmission of monetary policy?

ii) What are the factors i.e. credit, liquidity or both that drove up the risk premium in the interbank market in the UK, US and Euro zone?

iii) How effectively did the quantitative easing policies i.e. unconventional credit support facilities reduce the risk premium?

iv) How did the relationship between liquidity and credit risks change during the crisis?

4.2 Theoretical Framework

4.2.1 The Risk Decomposition Model

According to the expectations hypothesis of term structure of interest rate, overnight lending should be close substitute for term lending because the rate of interest paid on term lending should be same as rolling over overnight lending over the same period. However, Michaud and Upper (2008) pointed out that there are factors that may drive a wedge between the two types of lending and the corresponding rates. The factors are mainly nested in the term structure of interest. They include counterparty (credit) risk, liquidity factors and term premium that may be paid due to uncertainty about the future movement of short-term interest rates. This is to say that under the normal market condition, a small spread between the two types of rates is likely to be observed. However, when market conditions worsen, the spread may widen due to the increased credit risk, worse liquidity condition or both.

BoE (2007) tried to decompose the spread between 12-month LIBOR and OIS in the pound, US dollar and Euro into credit premia and non-credit premia using an adjusted ten-day moving average during the period January 2006 to November 2007. LIBOR is an unsecured lending rate because it is not collateralized. It reflects current and expected future interest rates, credit premia, and liquidity and other premia that have been created by market structure and trading procedures. Therefore, the spread LIBOR – OIS contains credit and non-credit premia. The Bank used the CDS spreads for LIBOR banks as proxy of credit premia so the difference between CDS spread and LIBOR – OIS will reflect the non-credit premia. The results indicated that across all currencies, non credit-premia had contributed to the widening risk premium at the beginning of the crisis i.e. end of August to September 2007 because the funding requirements for banks' off balance sheet vehicles were unclear so that banks were hoarding liquidity due to the uncertainty about both their own and counterparties' funding position. However, since October 2007, credit premia across currencies had increased alongside the increase in LIBOR – OIS spread[37]. The BoE argued that this movement appeared to be attributed to the large write-down of mortgage-backed securities and leveraged loan commitments for banks. It was also consistent with the market concerns about capital adequacy of banks after large write-downs.

Following BoE's research, Michaud and Uppers (2008) decomposed interbank risk premium spread into bank specific and market factors. The bank specific factor contains risk of default i.e. credit risk and funding position/liquidity relating to the borrowing bank. It is clear that the two elements in the bank specific factor are not completely independent because a bank with higher risk of default will find it more difficult to obtain funds in the market so its funding position tends to be worse. The market factor includes uncertainty about the path of expected overnight rates i.e. the term premium, trading conditions i.e. market liquidity and elements attached to the fixing process in interbank market and the microstructure of the market.

4.2.2 The Non-Arbitrage Model

The model shows how long-term interest rates (here: Libor with maturity n and denoted as $i_t^{(n)}$) are related to short-term interest rates (here: the overnight rate denoted as $i_t^{(1)}$). The model was developed by Ang and Piazzesi (2003) and was used by Taylor and Williams (2009) to model the effect of TAF on the interbank spread in the US.

The model can conveniently be summarized by four equations which take

[37] BoE (2008) mentioned that the spread of LIBOR – OIS first observed decrease from its peak at the beginning of October 2007 and then increased on November 2007. However, the spread still remained elevated compared with pre crisis period.

interest rate expectations and risk into account in the determination of long-term yields. The continuously compounded yield (or spot rate) of an n-period discount bond at date t is denoted as $i_t^{(n)}$ and defined by equation 1). The price of a discount bond in period t of maturity (n+1) is the expected discounted cash flow (which is here the discounted price) of the bond in t+1 as shown in equation 2). The stochastic discount factor[38] is denoted by m_{t+1} and is determined by equation 3). This equation conveniently introduces the overnight interest rate $i_t^{(1)}$ and the market price of risk λ_t into the discount factor and thus into long-term yields. Furthermore, ε_{t+1} is a random variable with mean zero and the market price of risk is associated with sources of uncertainty ($\lambda_t \varepsilon_{t+1}$). If the price of risk is zero, then the stochastic discount factor is equal to the overnight interest rate $i_t^{(1)}$. In this case, only expectations of future short-term interest rates matter for the current yield of long-term bonds. When λ_t is not equal to zero, then risk factors also determine the yield of long-term assets.[39] Lastly, equation 4) determines the price of risk in relation to a vector x_t which contains variables that may influence risk. These four equations imply that LIBOR at maturity n depends on expectations of future overnight rates and risk factors. Following Taylor and Williams (2009), we use the overnight index swap (OIS) to measure the average of expected overnight interest rates.[40] Thus, the difference between Libor and OIS, the Libor spread, measures the risk in the Libor rate.

$$1)\quad i_t^{(n)} = -n^{-1} log\left(P_t^{(n)}\right)$$

[38] The stochastic discount factor is a random variable and depends on the state of the economy. For instance, the stochastic discount factor in state 1 of the economy equals the price of the asset in state 1 divided by the probability of state 1. Thus, the price of an asset over all states is the expected product of the discount factor and the payoff of the asset across all states as described in equation 2).
[39] The functional form of this equation is assumed by Ang and Piazzesi (2003), page 759.
[40] The reasons for OIS to be used as proxy of risk-free rate are discussed in Chapter 3.1.

2) $P_t^{(n+1)} = E_t[m_{t+1}P_{t+1}^{(n)}]$

3) $m_{t+1} = exp\,(-i_t^{(1)} - 0.5\lambda_t^2 - \lambda_t\varepsilon_{t+1})$

4) $\lambda_t = -\gamma_0 - \gamma_1 x_t$

Having established that risk plays a role in determining the LIBOR spread (LIBOR – OIS), we follow Michaud and Upper (2008) in the risk decomposition of the LIBOR spread. So, the spread between three-month LIBOR and OIS i.e. LIBOR – OIS (LMO) can be written as:

5) $LMO = credit\ risk\ premium + liquidity\ premia$[41] $+ \ others$

The variable '$others$' represents elements that have impacts on the risk premium but are difficult to be quantified and proxied i.e. the bank-specific funding liquidity and the market microstructure of LIBOR market (Michaud and Upper, 2008)[42]. According to Michaud and Upper, it is not possible to quantify the above elements and literatures delegate this variable to the residuals (BoE, 2007; Michaud and Upper, 2008; Taylor and Williams, 2009), so we follow this procedure. The Equation 5) proves the BoE's indicative risk decomposing model and links the two bodies of theories together.

To facilitate the theoretical model i.e. Equation 5), selection of proxy for the components is very important. For example, this model does not consider term premium (which is an element to influence LIBOR rate according to term

[41] The liquidity premia include both market liquidity and banks' themselves funding position.

[42] Michaud and Upper (2008) further distinguish liquidity premia in terms of funding liquidity of banks and market liquidity of trading, but they adjust that banks-specific funding liquidity is hard to measure (e.g. by liquidity ratios and the size of potential commitment) systematically at a relevant frequency, so they treat banks-specific funding liquidity and microstructure effects as unobserved variables whose effects will be captured by the residuals in the regression. If the coefficients of regressors are significant, it implies that the effects of the two elements should be very small.

structure of interest rate) so instruments employed are ideally to have same term to maturity in order to offset term premium. The next section defines the variables to substitute the credit and liquidity components.

4.3 Definition of Variables

The theoretical model tells that the aggregate risk premium in interbank market is driven by credit risk associated with the participating banks, the liquidity condition of both the market and banks themselves, and market microstructure whose effect is included in the residuals. It is worth mentioning that the risk premium may also contain a term premium related to the uncertainty of the future path of short-term interest rates. In our research, the term premium should be very little because we use short-term instruments with same maturity.

The risk premium is measured by the spread between three-month LIBOR and three-month OIS (LMO).[43] It is the indicator of the health of the banking system (Thornton, 2009). The interbank lending rate, LIBOR, reflects both credit risk concern for the lending party and the liquidity factor effect e.g. the liquidity for the lending and borrowing bank and the liquidity of funding condition in the market. The LIBOR rate also contains agents' expectation of future interest rates. OIS is a financial derivative. It does not contain credit risk because the contract is collateralized. The liquidity premium underlying an OIS contract is also very slight because it does not require the exchange of principle at the beginning and only the amount of interest difference will be exchanged at the end of contract. The main determinant in OIS is likely to be agents' expectation of movement of future bank rate, which fits the terms from the non-arbitrage model. Therefore, the difference between LIBOR and OIS is employed to represent the risk

[43] In the EMU sample, we take European interbank offered rate (Euribor) in Euro currency instead of using LIBOR in Euro panel, because banks bidding Euribor are very different from banks bidding in LIBOR Euro panel so Euribor will reveal specific information of the EMU interbank market. The symbol to denote the Euribor – OIS spread is EMO.

premium in the money market in our research.

There are two measurements for credit risk, Credit Default Swap (CDS) and LIBOR – Repo (LMR).[44] CDS is an insurance policy on corporate debt i.e. bond or loan where the buyer of CDS pays a quarterly premium and the seller promises to cover the loss in case of default. In the research, the data contains the median of 5 year CDS rates for LIBOR banks. Therefore, the CDS index of LIBOR banks used in this research is an indicator of long-term credit risk. However, CDS as a credit risk measurement has disadvantages when it comes to explaining the LIBOR and OIS spread. The first is due to the mismatch of maturity with risk premium, which is noted in Michaud and Uppers (2008). The second is mainly due to the rules of trading of CDS. To hold a company's CDS, traders are not necessary required to hold the company's debts. Therefore, speculators can purchase CDS without holding a company's debt when they believe the credit concern for the company becomes an issue. Therefore, the price of CDS may augment the real level of credit risk of a company. We use CDS as a complimentary measure of credit risk.

The other credit risk measurement LMR represents the short-term credit risk by selecting three-month LIBOR and three-month Repo. Repo rate is a rate of lending contract backed by government bonds. It is a representative of interest rates on high quality secured lending. The spread between LIBOR and Repo reflects the risk of default repayment on loans in the interbank market. It is therefore another type of measure for credit risk premia (Taylor and Williams, 2009 and Angelini *et al*., 2011) i.e. the difference between unsecured and secured lending rates.

[44] In the EMU sample, the measure is calculated as Euribor – Repo and both are European interbank instruments. The symbol to denote is EMR.

We use Repo – OIS (RMO) as a proxy for liquidity risk. This measure is a market-based measure and it need some justifications, because it is not used as proxy of liquidity premium in the literature on interbank lending spreads.

Both Repo and OIS are secured lending. Like any other financial market, the repo market is subject to a variety of risks, such as credit risk, liquidity risk and operational risk[45] (BIS, 1999). A major potential for the development of counterparty risk exposure is the volatility of the price of the collateral and the quality of the collateral. However, counterparty risk is minimised through a variety of risk management tools, including initial margins, daily marking-to-market of the collateral, position limits with counterparties and concentration limits for specific securities (Hördahl and King, 2008). Therefore, the risk embedded in the repo spread may be regarded as mostly liquidity in nature.

Liquidity risk affects the repo spread through the following channels. A typical repo trader is specialised and focused on a limited number of bonds in a particular segment of the yield curve. Therefore, traders may not be well diversified and their trading positions may be exposed to idiosyncratic liquidity shocks, giving rise to a liquidity risk premium in the repo spread. Other types of liquidity risk may arise in the repo market. One type of liquidity risk may be related to re-financing difficulties and can arise from over-reliance on very short-term funding resources and an institution may find it difficult to roll over maturing repos. Another source of liquidity risk is associated with the liquidation of collateral, as for instance in the event of default of the counterparty. If markets become illiquid, for instance, due to market stress, the exposure may become under-collateralised if the collateral can only be sold at a discount. Repo rates reflect these liquidity premia. Empirical evidence is provided by Buraschi

[45] Operational risk is related to the transaction structure and legal procedures. Operational risk will be incorporated in the repo rate, but due to its institutional character, we can assume that it is constant over the time period we are considering here.

and Menini (2002), who show that the deviation from the expectations hypothesis is due to a time-varying risk premium which they relate to liquidity risk being still embedded in the repo spread.

Therefore, based on the above definitions of variables, the Equation 5) can be proxied as

$$LMO = LMR\ (and\ CDS) + RMO + Others$$

where LMO = Total risk premium, LMR = short-term credit risk premium and CDS = long-term credit risk premium, and RMO = liquidity premium. Note we have two measurements for credit risk premium, LMR (LIBOR – Repo) and CDS (5-year LIBOR bank CDS median). We use the short-term credit risk premium LMR as the main proxy of credit risk premium and use the long-term credit risk premium CDS as the complement.

Ratio variable is used as the proxy for the QE operations. The Ratio variable for the UK and the US samples, respectively, is defined as the accumulated amount of purchase of QE with respect to the total bank assets. And, the Ratio variable for the EMU sample is calculated as the amount of liquidity that had been provided under Open Market Operation (OMO) and Covered Bond Purchase Programme (CBPP) with respect to total banks assets. The way that we construct the Ratio allows us to say by how much percentage liquidity to credit risk change in response to a one percent change in the Ratio.

4.4 Data Collection

Our sample of the three national markets starts from the first day on January 2004 for which data on all instruments are available. This provides sufficient data for pre-crisis periods. The end date is different among markets because the operation of intervention varies in the three countries. The data in this study was collected from mixed sources. The LIBOR and repo rates and LIBOR bank CDS premia were collected from Datastream. The data of OIS was collected from Reuters 3000 Xtra. Both data bases are reliable and are widely used by researchers. The data are real historical trading data (not for LIBOR due to the nature of LIBOR). We have used daily data in the study to allow for more degrees of freedom in the statistical tests as well as reflecting the fast moving speed of money market.

For the UK, the data set ends on September 30, 2012. The sample was divided into three periods, pre-crisis, crisis and post-crisis periods. The crisis period was then split into pre-QE period and QE period. The key is to determine the start date of 2007 financial crisis but it is not easy to define precisely when the exact start date of the financial crisis hit. The spread between term lending and overnight lending started to widen on July 18, 2007 from 11 basis points and kept climbing rapidly to 300 basis points on November 16, 2008. Two months later after the observed break on term and overnight lending, Victoria Mortgage Funding became the first UK mortgage company that failed in the crisis on September 10, 2007. Then, Northern Rock requested lender of last resort help from BoE three days later. Moreover, the Credit Condition Survey published by the BoE on September 26, 2007 pointed out that lenders reduced the funding to corporates over the last three months and they forecast that the recent market movements would significantly weaken banks' capacity to roll over corporate credit in the following three months. This tells us that severe credit conditions for corporates would be expected in the future. On the same day, BoE announced the first term auction. It was to lend cash against broader range of collaterals i.e. not only highest quality securities than those used in conventional market operations. Based on Moody's scale the qualified securities extended to G10 and EEA sovereign paper with rating down to BBB, the bond issued by the government guaranteed agencies with rating down to A3 and other marketable senior corporate debt and commercial papers with rating A1 or higher.

The onset of the financial crisis seemed to appear earlier in the US and Europe. On June 22, 2007 the American investment bank Bear Stearns failed. On August 09, 2007, BNP Paribas suspended calculation of three of their assets that were exposed to subprime mortgage and halt the redemption. On the same day, the ECB provided €95 billion of overnight liquidity, which was the first emergency injection in the financial crisis.

However, alongside those market events and BoE's special term auctions, the Monetary Policy Committee (MPC) voted to raise the Bank's base rate by 25 basis points to 575 basis points on July 05, 2007 and maintained it until December 06, 2007 when it cut the base rate for the first time since August 2005 by 25 basis points to 550. Following the first cut, the BoE gradually reduced the base rate during the whole of 2008 and beginning of 2009 when it reduced the rate to 50 basis points on March 05, 2009. The largest cut of 150 basis points happened on November 06, 2008, the same day as the widest spread on term and overnight lending happened. On March 05, 2009, BoE also announced a £75 billion Asset Purchase Programme to directly purchase high quality public and private assets

Therefore, there are four possibilities for the start date of 2007 financial crisis, July 18, 2007, August 09, 2007, September 13, 2007 and December 06, 2007. In the research, the start date was chosen on August 09, 2007 when BNP Paribas signal the sign of failure and ECB injected the first liquidity. The reason is that the break on term and overnight lending could be induced by a temporary exogenous or endogenous disturbance. Once the shock has been absorbed by the market the spread could go back to normal naturally without triggering further turbulence. Thus, the day July 18, 2007 is not convincing as the start date of the financial crisis. However, the day December 06, 2007 is too late to be the start date because the BoE had already implemented operations to ease market conditions on September 2007. This is consistent with one of the characteristics of financial crisis. Therefore, it makes sense to treat the day August 09, 2007 as the start date of 2007 financial crisis in the UK because it can be seen as a trigger for BoE to implement unconventional market operations to prevent spread of bank run in the system and help ease funding conditions. The day August 09, 2007 is also set to be start date of crisis in the US and Euro zone as literatures suggested (see Taylors and Williams, 2009, Michaud and Upper, 2008 and Schwarz, 2010). This conditions the comparison of results between countries.

Furthermore, the end date of the crisis period is arguable. For example, Trichet argued in his speech on December 03, 2010 (Trichet, 2010), since the sovereign debt crisis continued and government bonds acted as a benchmark for the pricing of other financial contracts and were an important and prime source of collateral in interbank secured lending. The increasing market concerns about the sustainability of the public finances in May 2010 implied deterioration of banks' funding position as well as the transmission process of monetary policy (*ibid*). The BoE quantitative easing programme was still running to relieve trading and credit condition in the UK in late-2013. Therefore, it seems that the residual effect of financial crisis has not yet gone, although the spread between term and overnight lending in the UK started to fall gradually since reaching its peak on November 06, 2008 and eventually settled at 20 basis points on September 29, 2009 and remains around 20 base points with small deviation, as in the pre-crisis period. However, the first round quantitative easing finished on June 24, 2010 in the UK. Therefore, the end day of financial crisis is set on the day for the UK leaving the rest of period in the sample as post-crisis period.

The EMU sample ends on May 5, 2010 – before the introduction of SMP on May 10, 2010 - because the SMP was aimed at the sovereign crisis, which is not within the scale of our research. According to Trichet (2010), there are only two periods in the EMU sample, pre-crisis and crisis period. The crisis period runs from

August 09, 2007 to May 06, 2010 containing two sub periods, pre-intervention period and intervention period. The boundary is set a day before the collapse of Lehman Brothers on September 15, 2008. After the failure of Lehman Brothers the ECB stepped further to intervene in the money market by providing extra non-standard measures (see Mortimer-Lee, 2012). Moreover, the consensus is that the collapse of Lehman had a significant and persistent impact on European interbank markets (see Cassola and Morana, 2012 and Abbassi and Linzert, 2012). Therefore, the pre-intervention period runs from August 09, 2007 to September 12, 2008 and intervention period starts from September 15, 2008.

4.5 The Econometric Model

Therefore, we now turn to the econometric model

$$6)\ \ RMO = \alpha_0 + \alpha_1 LMR\ (+\alpha_2 CDS) + \varepsilon_t$$

Note that instead of directly testing the equation

$$LMO = LMR\ (and\ CDS) + RMO + Others$$

we test the Equation 6), which directly looks at the relationship between the two components i.e. credit risk and liquidity risk premia contained in the risk premium. If they have a positive relationship, it implies the increase of the total risk premium (LMO) in the interbank market. Also, the $(+\alpha_2 CDS)$ means that we first test the relationship between liquidity premia and the short-term credit risk premium as

$$RMO = \alpha_0 + \alpha_1 LMR\ + \varepsilon_t$$

Following, we include the long-term credit risk premium CDS in the regression as

$$RMO = \alpha_0 + \alpha_1 LMR + \alpha_2 CDS + \varepsilon_t$$

Moreover, we switch the position of RMO and LMR to test for the Granger causality.

This approach is new and its advantages 1) it allows the estimation of interaction between two main components in the risk premium; 2) switching position of RMO and LMR/CDS does not destroy the theoretical model and facilitates the estimation of causality between credit risk and liquidity component; 3) allow estimation of effect of QE on credit and liquidity components.

At the beginning of the crisis, Taylor and Williams (2009) estimated and tried to establish the relationship between risk premium and liquidity and credit risk by imposing a US TAF dummy as a liquidity proxy. They employed a simple OLS and AR(1) model. However, their approach has been criticised because the estimation had overlooked the unit root problems on variables (see McAndrews *et al*, 2008). Theoretically, interest rates should be stationary having the property of mean reversion over a long period of time. This was the case before the crisis. Since the crisis hit, interest rates became extremely turbulent. Interest rates could show evidence of non-stationarity. Therefore, it is necessary to test for unit roots before proceeding to our estimation. This section shows the unit root test procedures. Then, the cointegration and error correction models are discussed.

4.5.1 Unit Root

The assumptions of classical OLS regression require both dependent and independent variables are stationary, that is, the mean and variance are constant in the sample period and covariance between any two values is not time varying. Granger and Newbold (1974) proved that as a result of non-stationary, the OLS regression result could be spurious, because the residuals of such regressions are non-stationary and non-stationary variables do not have the property of mean reversion (Hill *et al*, 2007, p328). For example, if there is a stochastic trend, any deviation in period t is not going to eliminate so it becomes permanent and the estimated value shifts away from mean value in the long run. According to literatures, for example, Enders (2004, p158) showed that short- and long-term interest rates are likely to be random walk variables because there is neither obvious tendency to increase or decrease nor the pronounced tendency to revert to their long-run mean. Therefore, the characteristics of variables necessitates unit root test in the research.

The following of this subsection reviews three unit root test procedures, Dickey Fuller (DF), Augmented Dickey Fuller (ADF) and Phillips-Perron. ADF test is an extension of the DF and is robustness with the serial correlation in residuals. High frequency financial data show time-varying volatility and therefore Phillips-Perron test is also used.

Dickey-Fuller Test

The procedure starts with an AR (1) process of a non-stationary variable, *y*, i.e. the first-order autoregressive of a stochastic or random process. The Equation 7 below represents that the value of *y* at the present period, *t*, depends on its value on the previous period, *t-1*, and a white noise, ε_t.

$$7)\ y_t = a_1 y_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim IID(0, \sigma^2)$$

If variable y has unit root i.e. integrate to order 1, the coefficient a_1 will equal to one. To test the null hypothesis, the re-arrangement is to subtract y_{t-1} from both sides of Equation 7.

$$8)\ y_t - y_{t-1} = a_1 y_{t-1} - y_{t-1} + \varepsilon_t$$

$$9)\ \Delta y_t = (a_1 - 1) y_{t-1} + \varepsilon_t$$

Equation 9 is the simplest form of DF unit root test with no intercept and no trend. The null hypothesis is to assume that 'there is unit root'.

$$H_0: \gamma = 0$$
$$H_1: \gamma < 0$$

where $\gamma = (a_1 - 1)$. The critical value used in the hypothesis test is τ statistics. If the empirical t-statistic is greater than the critical tau value, the null hypothesis cannot be rejected and that is, the variable is non-stationary.

Either a constant drift or a deterministic trend, or both can be included in the DF test. Therefore, DF test considers all the possibilities by adding in those deterministic elements, but the null hypothesis remains same. For instance,

$$10)\ \Delta y_t = a_0 + \gamma y_{t-1} + \varepsilon_t$$
$$11)\ \Delta y_t = a_0 + \gamma y_{t-1} + a_2 t + \varepsilon_t$$

Equation 10 and 11 represent the constant drift and linear trend and intercept, respectively. a_0 is an intercept or drift term. t is a linear trend. The critical tau value changes with the inclusion of deterministic terms (Enders, 2004, p182). The critical value applied is τ, with neither intercept nor linear trend, $a_0 = a_2 t = 0$. With only intercept, $a_2 = 0$, the critical value τ_μ need to be used. With both intercept and linear trend, τ_τ should be applied as the critical value (Enders, 2004, p182).

Augmented Dickey-Fuller Unit Root Test

Despite the innovation of τ distribution, DF test has some problems. First, the models are the first-order autoregressive process whereas time series variables are very likely to be integrating to higher orders. Secondly, the ignorance of the possibility of higher order integrating will produce the problem of serial correlation of residuals, which invalidates the DF distribution (Harris and Sollis, 2005, p48). Therefore, it is necessary to consider an AR (p) process allowing the possibility of higher order integration. In this case, the Equation 7 can be extended as

$$12)\ y_t = a_0 + a_1 y_{t-1} + a_2 y_{t-2} + a_3 y_{t-3} + \cdots + a_{p-1} y_{t-p+1} + a_p y_{t-p} + \varepsilon_t$$

$$\varepsilon_t \sim IID(0, \sigma^2)$$

Repeatedly add and subtract the element $a_p y_{t-p+1}$, it will reach the equation below

$$13)\ \Delta y_t = a_0 + \gamma y_{t-1} + \sum_{i=2}^{p} \beta_i \Delta y_{t-i+1} + \varepsilon_t$$

Equation 13 is the augmented Dickey-Fuller model considering the p^{th} order of autoregressive process with only intercept. Same as DF test discussed above, ADF model can also be added in a linear trend. The null hypothesis is same as DF test i.e. $\gamma = 0$.

Although ADF model attempts to remove the possible serial correlation problem in residuals that is produced by higher order of integration of variables, the components of moving average that may contain in the data generating process still remains untreated (Enders, 2004, p190). To deal with the moving average process, the infinite-order autoregressive model that is derived from mixed autoregressive/moving average, MA, process can be applied.

$$14)\ \Delta y_t = \gamma y_{t-1} + \sum_{i=2}^{\infty} \beta_i \Delta y_{t-i+1} + \varepsilon_t$$

Despite Equation 14 requires an infinite sample so it cannot be applied to a finite sample, Said and Dickey (1984) found that the infinite ARIMA model forms similarity to an ARIMA (n, 1, 0) model where n needs to be no greater than $T^{1/3}$. Therefore, samples bearing moving average process could employ Equation 14 as the model to test unit root.

Moreover, both Harris and Sollis (2005) and Enders (2004) pointed out that it is very important to choose the right order of autoregressive process i.e. length of lags because the test statistics will be larger when fewer lags are involved, so the null hypothesis may be rejected mistakenly. If more lags are included, the presence of unnecessary nuisance variables weakens the power and efficiency of test (Banerjee *et al*, 1993).

In practice, the methods used to find the right lag length is based on the *t*- and *F*-tests and the information criterion of AIC and SBC. Enders (2004, p192) summarized a general-to-specific approach using t-test and F-test. The approach starts with a long lag length for Equation 13 i.e. the general model and use t-test and F-test to examine the significance of the coefficients. If the coefficient on the last variable is insignificant individually or jointly with the second last variable, the model should omit the insignificant variables until the coefficients on variables are significantly greater than zero. Additional, information criterion of AIC and SBC can be used to select the right model with appropriate lag length. Harris (1992) suggested a formula that was introduced by Schwert (1989, p151), $l_{12} = int\,\{12\left(\frac{T}{100}\right)^{\frac{1}{4}}\}$. Ng and Perron (1995) argued that the sequential t-test for the significance of coefficient on the last lag in general-to-specific approach has the ability to yield higher values of p rather than standard lag length selection criteria (Harris and Sollis, 2004, p51). Moreover, Weber (2001) advocated a specific-to-general approach by setting the value of p at a very low level. We

Furthermore, the issue of structural break is not well treated in ADF model. Enders (2004) pointed out that structural breaks could be mis-defined as a stochastic trend in ADF model. Perron (1989) also stated that the ignorance of consideration of structural break would weaken the power of unit root test because a permanent change of slope of a deterministic time trend could be treated as a constant innovation to a non-stationary trend. For example, if a variable is stationary during the two-subperiods around different means (let us simulate two diversified values of mean, 0 and 10), respectively, in one sample, ADF test is very likely to conclude that the variable has unit root by forming a random walk process (possibly with a drift) because the intercept is biased towards 1 due to different value of mean. The solution to structural break is to add dummy variables. The number of dummy variables depends on the number of times that structure breaks. By adding in dummy variables, it makes sure that there are always same number of deterministic regressors and deterministic trends in the DGP (Harris and Sollis, 2004, p57). By giving a value to a dummy variable when structure changes, the dummy will fix and control the permanent effect on the level of the variable due to change of mean. However, if the break of structure is not permanent, it would be useful to simply separate the period of sample.

Phillips-Perron Unit Root Test

Phillips (1987) and Perron (1988) and Phillips and Perron (1988) had developed Phillips-Perron type unit root test by modifying the *t*-statistics of coefficient γ in Equation 9, 10 and 11 (Asteriou and Hall, 2011, p344). The development was based on DF unit root. Due to the restrict assumption of residuals in DF test i.e. residuals have to be statistically independent and have a constant variance, any serial correlation may invalidate DF test. ADF test deals with the serial correlation problems by allowing more lags of dependent variables in the model while Phillips-Perron (1988) made a non-parametric correction by correcting the *t*-statistics to count for bias that may be produced by serial correlation in the residuals (Harris and Sollis, 2004, p50), but the asymptotic distribution of the Pillips-Perron test follows the DF distribution. This correction weakens the assumption placed on distribution of residuals (Asteriou and Hall, 2011, p344). Phillips and Perron defined the biased variance of the true population was $\sigma^2 = \lim_{T\to\infty} E(T^{-1}S_T^2)$ and the variance of residuals in the AR (1) autoregressive equation was $\sigma_u^2 = \lim_{T\to\infty} T^{-1}\sum_{t-1}^{T} E(u_t^2)$. The consistent estimators of σ_u^2 and σ^2 were

$$15)\ S_u^2 = T^1\sum_{t=1}^{T}(u_t^2) \qquad S_{Tl}^2 = T^{-1}\sum_{t=1}^{T}(u_t^2) + 2T^{-1}\sum_{t=1}^{l}\sum_{t=j+1}^{T} u_t u_{t-j}$$

The parameter l is the term to capture the serial correlation in residuals that are produced by misspecification of order of autoregressive process. If there is no serial correlation on residuals, the second element in S_{Tl}^2 will be zero, so it necessitates $\sigma_u^2 = \sigma^2$. Therefore, when the variable is in higher order of integration than AR (1), the test of coefficient $a_1 = 1$ or $\gamma = 0$ in Equation 9 is computed by Phillips Z-test.

4.5.2 Cointegration and Error Correction Model

There are mainly two approaches to resolve the problem of spurious regression that is produced by non-stationary time series, in practice (Asteriou and Hall, 2011). The first approach is to difference a non-stationary variable until it becomes stationary. The number of differences depends on the order of integration. The higher order of integration, the more times of difference are needed i.e. the number of times of difference before reaching stationary equals to the order of integration. The first potential problem of this approach is that the residuals that are obtained from regressions using differenced variables will also be differenced. This brings the problem of non-invertible moving average error process in a regression (Asteriou and Hall, 2011, p356), which is a serious estimation problem.

Moreover, by regressing on differenced variables, the result is losing long run information, that is, the coefficients will not present the long run relationship between dependent and independent variables. If y_t and x_t are both I (1) variables, the first difference of them, $(y_t - y_{t-1})$ and $(x_t - x_{t-1})$ will be I (0) variables, respectively. Therefore, if assuming the relationship between y and x is $y = 2x$, given any value of x, the value of y is computable and the value is unique. However, the situation is changed if y and x are replaced by their first difference, respectively i.e. $(y_t - y_{t-1}) = 2(x_t - x_{t-1})$. Given a value of x_t, without knowing the value of x_{t-1} and y_{t-1}, it is not possible to get a unique value of *y*. In the field of econometrics, it is very important to obtain long run equilibrium relationship between variables because economics theories are always presented to the long run relationship rather than short run (Gujarati and Porter, 2009, p762).

The second approach to estimate non-stationary variables is cointegration. The concept of cointegration was introduced by Granger (1981) first and developed by Engle and Granger, and Engle and Yoo on 1987, Johansen (1988, 1991, and 1995), Stock and Watson on 1988, Phillips and Ouliaris (1995) and Phillips (1986 and 1987) (Asteriou and Hall, 2011, p308). Cointegration describes a combined linear relationship between two or more I (1) variables that produce stationary residuals (cf. Enders, 2004, Harris and Sollis, 2004 and Gujarati and Porter, 2009). The advantage of cointegration approach is that it reveals both short- and long-run relationships between dependent and independent variables, which is in favor of economic models. Also, estimation of cointegrating equation is introducing simultaneous interactions without the condition of stationarity (Hill *et al*, 2008, p348).

The relationship of cointegration can be presented mathematically as

$$16)\ y_t = \alpha_0 + \alpha_1 x_t + e_t$$

where both y_t and x_t are I (1) variables and e_t is error term. So, equation 16 can be estimated and re-arranged as a function for e_t as

$$17)\ \widehat{e_t} = y_t - \widehat{\alpha_0} - \widehat{\alpha_1} x_t$$

y_t and x_t are cointegrated if $\widehat{e_t}$ is stationary. The coefficient α_1 is the cointegrating parameter. If two variables are cointegrated, error correction model should be applied in order to obtain both short- and long-run relationship.

There are variants of Equation 16 to test cointegration. For example, variable y and x can be replaced by two vectors that are conducted of a series of I (1) variables, respectively. Then, α_1 is called cointegrating vector. Moreover, since test of cointegration is normally followed by error correction model, if there is cointegration relationship, the system of error correction model is often discussed with cointegration. In the following, we introduce Johansen cointegrating test, residual based Engle-Granger procedure, Banerjee single-equation cointegration and ECM and vector error correction model (VECM).

Johansen Cointegrating Test

The Johansen cointegration test in EViews is a VAR-based cointegration tests, which allows input options of a constant and a deterministic trend. If the VAR of order p is defined as follows

$$18)\ y_t = A_1 y_{t-1} + \cdots + A_p y_{t-p} + B x_t + \varepsilon_t$$

where y_t is a k-vector of non-stationary I(1) variables, x_t is a d-vector of deterministic variables, and ε_t is a vector of residuals. Equation 18) can be re-parameterised as an error correction model

$$19)\ \Delta y_t = \Pi y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta y_{t-1} + Bx_t + \varepsilon_t$$

where

$$20)\ \Pi = \sum_{i-1}^{p} A_i - I,\ \Gamma_i = -\sum_{j=i+1}^{p} A_j$$

Johansen's cointegration test is to investigate the Π matrix from an unrestricted VAR and to test if it is possible to reject the restrictions implied by the reduced rank of Π. This gives the number of cointegration relations r for variables conditional on the assumptions made about the trend and constant. The programme proceeds sequentially from r = 0 to r = k-1 (Π has reduced rank of $r < k$) until it fails to reject.

Residual Based Engle-Granger Approach

If variable Y_t and X_t are integrated to order 1, there may be a vector $\{\theta_1, \theta_2\}$ that makes the linear combination of Y_t and X_t to stationary. If this is the case, Y_t and X_t are said to be cointegrated to order (1, 1). It is possible for a higher order of cointegration to exist e.g. two I (2) variables may be cointegrated to of order (2, 1), that is, there is one linear combination for the two I (2) variables to become stationary. In general, literatures using the term cointegration refer to order (1, 1). According to Enders (2004, p322), Engle and Granger (1987) defined the model of cointegration as follow: If a) all elements of vector x_t are integrated to the same order, d; b) there are a vector $\beta = (\beta_1, \beta_2, \beta_3, \dots, \beta_n)$that can form a linear combination of x_t as $\beta x_t = \beta_1 x_{1t} + \beta_2 x_{2t} + \beta_3 x_{3t} + \cdots + \beta_n \beta_{nt}$, a vector of $x_t = \{x_{1t}, x_{2t}, x_{3t}, \dots, x_{nt}\}$ are cointegrated of order d, b, i.e. the

$x_t \sim CI(d,b)$ when b > 0. The vector β is the cointegration vector. The main problem remaining is to estimate the cointegrating vector that reveals the long-run equilibrium. Engle and Granger (1987) proposed a three-step approach to examine the relationship. Firstly, the order of integration of variables needs to be tested using unit root tests that were discussed. If both variables are integrated of the same order e.g. order 1, the step moves to estimate the long run equilibrium between variables, which is represented by equation 16. If the two variables are cointegrated, the coefficients a_0 and a_1 will converge faster than in OLS regression using stationary variables (Stock, 1987). Thus, the OLS regression of the long run relationship will return a 'super-consistent' estimator of the cointegrating parameters a_0 and a_1 because the effect of stochastic trend on the two variables will dominate the stationary process (Ender, 2004, p336). To conclude the cointegration relationship, the stationary process of residuals in equation 16 need be checked, normally, using DF or ADF unit root test. If the test statistic rejects the null hypothesis, the two variables are cointegrated. Engle and Granger (1987) suggested the ADF with the form

$$21)\ \Delta\hat{e_t} = \beta\widehat{e_{t-1}} + \sum_{i=1}^{p-1}\beta_i\Delta\widehat{e_{t-\iota}} + \mu + \delta t + \omega_t \qquad \omega_t \sim IID\ (0,\sigma^2)$$

to be applied on the residuals. The residuals are obtained from Equation 16. It is worth to note that deterministic elements can be included in either Equation 16 or Equation 21, but not to both (Harris and Sollis, 2004, p80). Thirdly, once cointegration relationship is reached, an ECM model should be carried out to obtain both short- and long-run relationship.

The core of ECM is the parameter of speed adjustment of the disequilibrium (α_2 in Equation 22)) moving back to its long run mean. The process refers to error correction. The ECM takes form

$$22)\ \Delta y_t = \alpha_1 + \alpha_{2y}\widehat{e_{t-1}} + \sum_{i=1} \alpha_{11}(i)\Delta y_{t-i} + \sum_{i=1} \alpha_{12}(i)\Delta x_{t-i} + \varepsilon_{yt}$$

$$23)\ \Delta x_t = \alpha_1 + \alpha_{2x}\widehat{e_{t-1}} + \sum_{i=1} \alpha_{21}(i)\Delta y_{t-i} + \sum_{i=1} \alpha_{22}(i)\Delta x_{t-i} + \varepsilon_{xt}$$

where the error correction term $\widehat{e_{t-1}}$ is the lag of residual saved from Equation 16. The coefficients on $\widehat{e_{t-1}}$ are also the error correction parameters and reveal the long run relationship between y and x (Enders, 2004, p337).

Finally, procedures to assess if ECM is an adequate model need be carried out. There are three aspects to check (Enders, 2004, p338). Firstly, the diagnostic check of residuals obtained from ECM equation should be carried out. The residuals ε_{yt} and ε_{xt} need to be white noise. Secondly, the error correction parameter i.e. the speed of adjustment coefficients should be carefully examined. The ECM model should also satisfy the feature of weak exogeneity. Thirdly, the issue of contemporaneous is also to be checked.

Particularly referring to the second aspect, weakly exogenous variables do not respond to the deviation from the long-run equilibrium relationship, so the speed of adjustment coefficient on weakly exogenous variables is zero. This feature facilitates the estimation of error correction models when using the reparameterized autoregressive distributed lag (ADL) model, which benefits Banerjee single equation ECM mechanism that is discussed in the following paragraphs.

Single Equation ECM Banerjee Approach

The Banerjee ECM model for cointegration was introduced on 1998 based on the parameter of the lagged dependent variable in an autoregressive distributed lag model that was developed by Hendry and Richard (1982) and Hendry (1987). The advantage of Banerjee ECM model is that 1) the parameters in the conditional ADL models are asymptotically efficiently estimated given weak exogeneity of regressors for the parameters of interest in an (Engle *et al*., 1983); 2) in both normalized bias and t-ratio versions, the limited distribution neither depends on nuisance parameters nor being dimension-invariant because the limited distribution shifts with the increased number of regressors; 3) Compared with EG single equation ECM model, the ECM does not bear the problem from imposing potentially invalid common-factor restrictions in finite samples, which can result in poor power of properties if the restrictions are not satisfied (Banerjee *et al*., 1998). Moreover, Banerjee *et al* also point out the form of t-ratio ECM may have better power properties than the normalized form especially when the common-factor restrictions are grossly violated. In our research, we adapt the t-ratio form of the ECM.

Our discussion of Banerjee single equation ECM approach starts with how to pare a general ADL model down to a specific error correction model i.e. general-to-specific modeling process, because Banerjee ECM is nested in a general ADL model.

The ADL model regresses a dependent variable against its own lags and independent variables and their corresponding lags. The two-variable first-order ADL provides a good example of the model:

$$24)\ y_t = b_{11}y_{t-1} + b_{12}x_t + b_{13}x_{t-1} + u_t$$

In the error correction model, variables concerned are I(1) variables and the first difference of y_t is used as the dependent variable, so it is helpful to transform Equation 24) by subtract y_{t-1} on both sides of the equation and subtract $b_{12}x_t$ on the left side as well as add $b_{12}x_t$ simultaneously to obtain first difference of variables. The Equation 24) becomes (the bold terms are those newly added)

$$y_t - \boldsymbol{y_{t-1}} = b_{11}y_{t-1} - \boldsymbol{y_{t-1}} + b_{12}x_t - \boldsymbol{b_{12}x_{t-1}} + \boldsymbol{b_{12}x_{t-1}} + b_{13}x_{t-1} + u_t$$

To rearrange the above equation, it gives

$$25)\ \Delta y_t = \alpha(y_{t-1} - \beta x_{t-1}) + \rho \Delta x_t + u_t$$

where $\alpha = (b_{11} - 1)$, $\rho = b_{12}$, and $\beta = \frac{b_{13} + b_{12}}{1 - b_{11}}$.

Equation 25) is a general ADL model with two variables at their first-order case. To get the specific error correction model, we need to impose the appropriate restriction. Assuming the two variables are cointegrated of order (1, 1), the reduced form of error correction model can be written as

$$26)\ \Delta y_t = \alpha_1(y_{t-1} - \beta x_{t-1}) + e_{1t}$$
$$27)\ \Delta x_t = \alpha_2(y_{t-1} - \beta x_{t-1}) + e_{2t}$$

α_2 is the coefficient of long-run deviation adjustment of x_t. If $\alpha_2 = 0$, x_t is said to be a weakly exogenous variable. That is, x_t does not respond to the disequilibrium from the long run relationship, which will benefit our discussion later. The variance and covariance matrix of error terms e_{1t} and e_{2t} can be denoted as

$$\Sigma = \begin{bmatrix} \sigma_{11} & \sigma_{12} \\ \sigma_{12} & \sigma_{22} \end{bmatrix}$$

If σ_{12} does not equal to zero, the error terms are correlated. Then, the relationship between the two error terms could be written as

$$28)\ e_{1t} = \rho e_{2t} + \varepsilon_t$$

where $\rho = \frac{\sigma_{12}}{\sigma_{22}}$ and ε_t is a white noise error term. If firstly substituting

Equation 28) then substituting Equation 27) to Equation 26), we can get (the bold term is the replacing term)

$$\Delta y_t = \alpha_1(y_{t-1} - \beta x_{t-1}) + \boldsymbol{\rho e_{2t}} + \boldsymbol{\varepsilon_t}$$

$$\Delta y_t = \alpha_1(y_{t-1} - \beta x_{t-1}) + \rho[\boldsymbol{\Delta x_t} - \boldsymbol{\alpha_2}(\boldsymbol{y_{t-1}} - \boldsymbol{\beta x_{t-1}})] + \varepsilon_t$$

$$\Delta y_t = (\alpha_1 - \rho\alpha_2)(y_{t-1} - \beta x_{t-1}) + \rho\Delta x_t + \varepsilon_t$$

Therefore, if we set $\alpha = (\alpha_1 - \rho\alpha_2)$, the above equation becomes

$$29)\ \Delta y_t = \alpha(y_{t-1} - \beta x_{t-1}) + \rho\Delta x_t + u_t$$

Comparing Equation 29) with Equation 25), we can see that Equation 29) is the reparameterized equation of Equation 25) i.e. the error correction model defined in Equation 26) and 27) is a specific model of general ADL model by considering the restriction – the correlation between error terms in the error correction model i.e. $Ee_{1t}e_{2t}$. Therefore, testing Equation 29) using OLS is same as testing the error correction model set in Equation 26) and 27). In the OLS regression, Equation 29) needs to be written as

$$30)\ \Delta y_t = \beta_1 y_{t-1} + \beta_2 x_{t-1} + \beta_3\Delta x_t + \varepsilon_t$$

where $\beta_1 = \alpha = (\alpha_1 - \rho\alpha_2)$, $\beta_2 = -\alpha\beta = -(\alpha_1 - \rho\alpha_2)\beta$ and $\beta_3 = \rho$, according to Equation 29). In the error correction model, the coefficients of interest are α_1 and β. Knowing the value of β_1, β_2 and β_3 by regressing Equation 30) will not give value of α_1 and β. However, if x_t is a weakly exogenous variable ($\alpha_2 = 0$), the value of α_1 and β can be easily obtained from regressing Equation 30) i.e. $\alpha_1 = \beta_1$ and $\beta = -\frac{\beta_2}{\beta_1}$. Moreover, the feature of exogeneity makes the effect of contemporaneous correlation ρ between error terms in the error correction model on coefficients α_1 and β irrelevant in the OLS for Equation 29), so we can test the unrestricted ADL model using OLS to get the long-run adjustment β and the normal distribution can be applied to construct confidence intervals for coefficients of interest. However, the test statistics becomes non-standard because variables y_t and x_t are I(1) variables in the ECM. This is the reason that we use Banerjee critical values of the t-ratio in our estimation.

The data generation process (DGP) in the Banerjee ECM starts with the ADL model in Equation 25) - $\Delta y_t = \alpha(y_{t-1} - \beta x_{t-1}) + \rho\Delta x_t + u_t$. They define ρ and β are $1 \times k$ column vectors of parameters. α is a scalar and x_t is a $k \times 1$ column vector of independent variables that are assumed to be strictly exogenous. T is the size of sample. In this DGP, y_t and x_t are I (1) variables and they are cointegrated, if $-2 < \alpha < 0$. When $\alpha = 0$ (the null hypothesis), they are not cointegrated. Given the assumption strictly exogenous, estimation of parameters ρ, α and β can be obtained by regressing Equation 25) using non-linear least squares method. Alternatively, based on results from Kiviet and Phillips (1992), Banerjee *et al* (1993) prove that regressing Equation 25) with inclusion of x_{t-1} by OLS can reach a parameter-free distribution for the coefficient of interest, α, because the alternative hypothesis of cointegration, the slope of β is implicitly estimated. Therefore, the ECM equation that can be regressed by OLS is

$$31)\ \Delta y_t = \rho\Delta x_t + \alpha y_{t-1} + \theta' x_{t-1} + u_t = \rho\Delta x_t + \pi' w_{t-1} + u_t$$

where $w_t' = (y_t, x'_t)$ and $\pi' = (\alpha, \theta')$ (Banerjee *et al*, 1998). The null hypothesis $\alpha = 0$ implies $\pi = 0$ because $\alpha(1, -\beta) = \pi'$[46] so the ECM test can

[46] This is obtained when multiply out bracket $\alpha(y_{t-1} - \beta x_{t-1})$ in Equation 25.

rely on the OLS estimator of α (*ibid*).

However, the assumption of strictly exogenous variables is a very strong assumption. To make OLS an asymptotically efficient estimation method for Equation 31), the assumption needed for variables is only weakly exogenous (Engle *et al*, 1983). This allows for the inclusion of lags of first order of both independent and dependent variables. Thus, Equation 25) can be extended as

$$32)\ \gamma(L)\Delta y_t = \rho'(L)'\Delta x_t + \alpha(y_{t-1} - \beta x_{t-1}) + u_t$$

where $\gamma(L)$ and $\rho'(L)'$ are polynominals in the lag operator L. According to Banerjee *et al* (1998), the Equation 32) may suffer serial correlation because the assumption of weakly exogeneity will not guarantee the long-run variance/covariance matrix of errors equals to zero. Therefore, they augment the Equation 32) as suggested by Phillips and Loretan (1991) and Saikkonen (1991), so we get our econometric model

$$33)\ \Delta y_t = a'\Delta x_t + \alpha y_{t-1} + \theta' x_{t-1} + \sum_{j=1}^{S} a'_j \Delta x_{t-j} + \sum_{j=1}^{S} b'_j \Delta y_{t-j} + u_t$$

The coefficient of interest is α. If $\alpha < 0$, the two variables are cointegrated and y_t error corrects in the long run. The sum of lags of first order of both independent and dependent variables are augmented term that helps on serial correlation problems that may produce by weak exogeneity of x_t.

To summarize, Equation 33) is the form of single equation cointegration and ECM system that is advocated by Banerjee *et al* (1998). It allows the weak exogenous of independent variable, which is not concerned by the Engle-Granger model. The critical values of *t*-ratio that are computed by Banerjee et al (1998) for the ECM test are represented in Appendix. For the ease of illustration, we do not add intercept and trend terms, but this model allows deterministic terms i.e. intercept and/or linear trend.

The two systems that have been mentioned above are both single equation ECM for a pair of variables. It can be problematic e.g. contradictory problem when they are applied on more than two variables (Pesaran and Pesaran, 1997, p291), because the number of cointegrating vector allowed in single equation is only 1 whereas when more than two variables are involved, there is possibility for more than 1 cointegrating vectors (Asteriou and Hall, 2007, p319). The number of cointegrating vectors can be up to (n-1) that n is the number of variables included. Therefore, vector error correction model is discussing in the next section to overcome the problems.

Vector Error Correction Model

The Johansen cointegrating test discussed above investigates the Π matrix from an unrestricted VAR and to test if it is possible to reject the restrictions implied by the reduced rank of Π. The vector error correction model (VECM) is a multivariate autoregressive model allowing more than two variables in an unrestricted vector autoregression (VAR) process and count for the number of cointegrating vectors.

$$34)\ z_t = A_1 z_{t-1} + A_2 z_{t-2} + \cdots + A_k z_{t-k} + \mu_t \qquad \mu_t \sim IN\ (0, \Sigma)$$

where z_t is an m x 1 vector containing jointly determined endogenous variables and A_i is an m x m matrix of parameters. The residual μ_t have zero mean and a time-invariant conditional variance matrix Σ. The latter necessitates the assumption of homoscedasticity (Pesaran and Pesaran, 1997, p122). The DGP was first advocated by Sims (1980) and has been represented in many textbooks and literatures (cf. Harris and Sollis, 2004, p110, Pesaran and Pesaran, 1997, p121.). Allowing the impact from an intercept and/or a linear time trend, equation 24 can be extended as follow

$$35)\ z_t = a_0 + a_1 t + A_1 z_{t-1} + A_2 z_{t-2} + \cdots + A_k z_{t-k} + \Psi w_t + \mu_t$$
$$\mu_t \sim IN\ (0, \Sigma)$$

Being others same, t is a linear time trend and a_0 is the drift. The vector w_t has order q x 1 containing exogenous I (0) variables. Equation 35 is the augmented form of Equation 34, so it is the augmented vector autoregressive model of order k i.e. AVAR(k).

The cointegrating VAR (VECM) for a vector containing three variables is therefore written as

$$36)\ \Delta z_t = a_0 + a_1 t + \Pi z_{t-1} + \sum_{i=1}^{k-1} A_i \Delta z_{t-i} + \Psi_y w_t + \mu_{ty}$$

where $z_t = [Y_t\ X_t\ V_t]$ and A_i is an order of 3 × 3 matrix of parameters. $\Pi = -(\mathrm{I} - A_1 - A_2 - \cdots - A_k)$ is the cointegrating vector containing the speed of adjustment to disequilibrium α and a matrix of long-run relationships β', so Π can be expressed as $\alpha\beta'$. Using the algebra of matrix to compute Πz_{t-1}, the term $\beta' z_{t-1}$ can be obtained. It is the error-correction element in VECM including up to (n-1) vectors in a multivariate system. In the case of three variables, the term contains up to 2 cointegrating vectors. Moreover, as the ground of the relationship of cointegration to exist, Π needs to have reduced rank because the variables in z_t are stationary when Π has full rank, whereas when the rank of Π equals to zero, it implies there is no cointegration relationship among variables. Therefore, the parameter of interest in VECM is Π. Johansen (1988) developed a system to find the rank of Π as well as the estimates of α and β.

Similar to the single equation approach, Johansen VECM starts with test for order of integration of variables. Then, the lag length and deterministic elements needs to be decided. The distinctive of Johansen approach is to use maximal eigenvalue statistic and trace statistic to find the rank of Π. The null hypothesis is that there are r cointegration vectors existing. The maximal eigenvalue statistic obtains n characteristic roots $\lambda_1 > \lambda_2 > \cdots > \lambda_n$. If there is no cointegrating relationship i.e. r = 0, the rank of Π is zero and all the roots will be zero. Therefore, Johansen approach tests how many of the numbers of the roots are significantly different from zero us the statistic $\lambda_{max}(r, r+1) = -T\ln(1-\hat{\lambda}_{r+1})$ (Asteriou and Hall, 2007, p324). The second approach, trace statistic, is based on likelihood ratio test. The statistic is computed as $\lambda_{trace}(r) = -T\sum_{i=r+1}^{n}\ln(1-\hat{\lambda}_{r+1})$ (Asteriou and Hall, 2007, p325). Unlike the maximal eigenvalue statistic test, trace statistics tests the rank r by adding in more eigenvalues beyond the r^{th} eigenvalue. Therefore, the null hypothesis is that there is up to r numbers of cointegrating vectors.

Followed by test of rank, Johansen approach concerns weak exogeneity of variables because there should be at least (n – r) columns of α equal to zero, if the value of r is smaller than n. Finally, Johansen approach allows the testing for linear restrictions in the Π. It is quite important feature because an econometric model need satisfy economic theory.

In this chapter we have presented the DF, ADF and PP unit root test procedures and the Johansen cointegrating, Engle-Granger and Banerjee single equation ECM and VECM econometric models. In our study, we reported the ADF statistic of the unit root test because it is widely used in applied studies and the augmented term helps deal with serial correlation, which is a common issue for high frequency financial data. We apply all the variations of cointegrating and ECM introduced in the chapter in our empirical analysis because data performs differently across countries.

Chapter 5 Empirical Analysis of Credit Risk and Liquidity Premia during the Financial Crisis in the UK, the US and the EMU

The persistence of high interbank rates in the UK, the US and the EMU signaled the prologue to the recent financial crisis. Medium- and long-term interbank lending and borrowing virtually stopped, resulting in distress of other credit markets e.g. the commercial paper market in the US. Asymmetric information resulted in great uncertainty of asset valuations, counterparties' creditworthiness and liquidity position. Given these uncertainties, risk premia in interbank lending increased dramatically and adverse selection problems made financing even more difficult for banks, other financial institutions and the private sector. In principle, the risk premia can be decomposed into credit risk and liquidity risk premia, respectively (Bank of England, 2007). A temporary liquidity shortage can induce credit default, particularly for banks; this will cause collapse and threaten financial stability. So, there is interaction between the components in the risk premium although they can be measured individually. Moreover, monetary policy is nowadays largely transmitted through an interest rate channel. The elevated interbank rates weakened the power of central banks to stimulate the economy by reducing the policy rate. That is, the transmission mechanism of monetary policy is severely damaged. Central banks need recourse to other policy tools to implement their targets.

Therefore, in order to boost market liquidity, reactivate credit markets and fix the transmission mechanism, central banks of major economies undertook a range of unconventional interventions during the crisis. These unconventional interventions firstly fulfilled the function of lender-of-last-resort of central banks by providing liquidity to banks. For example, the BoE implemented a 'Special Liquidity Scheme' (SLS), swapping high quality treasury bills for illiquid securities to ease uncertainty on banks' balance sheet and boost their ability to refinance. Secondly, the interventions involved direct purchase of long-term assets, treasury bills and government bonds during the crisis. The interventions that purchase long-term assets are referred as QE in general in this study. The label QE may not be an entirely accurate for the EMU sample because the size of asset purchase in the EMU is very small compared with the total easing amount. Most of monetary easing has been done under LTROs, which is under OMO. However, we believe the labeling of interventions is not very important for our purposes because the measure of interventions for each sample is considered subject to their policies and market operation.

The aim and purpose of QE in the UK and the US were to provide liquidity directly into economy so as to boost nominal demand whereas ECB set the aim of those unconventional interventions in the EMU to fix the broken transmission mechanism. However, fundamentally, QE should have an effect on reduction of credit and liquidity premia since they are the primary causes of increased risk premia and uncertainties, which were in turn the triggers of this crisis. Also, a restoration of the transmission mechanism was of interest to BoE and the Fed, as well.

As discussed in Chapter 3, given the observed jump in risk premia and the implementation of unconventional monetary policy tools, earlier studies looked at the contribution of credit risk and/or liquidity premia in the risk premia and how central banks liquidity provisions worked on the risk premia (see Taylor and Williams, 2009; Michaud and Upper, 2008; McAndrews *et al,* 2008 and Sarkar, 2009). Since 2008, the crisis worsened in economies worldwide after a series of remarkable market events e.g. failure of Bear Stearns in March 2008 and bankruptcy of Lehman Brothers in September, 2008, the BoE, the ECB and the Fed stepped in further to stimulate national economies by introducing quantitative easing[47]. The interests of studies then shift to how quantitative

[47] We have identified in the Chapter 2 that the policies ran by the ECB do not fit the definition of quantitative easing perfectly, but the implementation of LTROs have intensified since August 2008.

easing influences long term economic indicators e.g. inflation, GDP, and government bond yields (Martin and Milas (2013) provide a comprehensive survey of literatures in the field). Indeed, quantitative easing aims primarily to bypass the money market and transit (monetary intervention) through portfolio rebalancing, liquidity and policy signaling channels to intermediately influence asset prices changing the total wealth and cost of borrowing and ultimately to work on output and inflation (see Figure 2.10 for the transmission mechanism of quantitative easing). Changing of cost of borrowing (after changing of asset prices) likely impacts on the money market rates on the short end. The possible impact on money market rates is also worth studying because the spreads between them are measures of risk components, which are one of the key drivers of the crisis.

In this chapter, we focus on credit risks and liquidity premia contained in the interbank markets in the UK, the US and the EMU by investigating the relationship between these components in the interbank rates and how the relationship developed during the crisis. Moreover, the effect of QE on these relationships is also investigated. The results show that the credit risk premium played a major role in the widening spread of risk premium in the UK's interbank market before the operation of QE and credit risk also caused the increase in liquidity premium whereas the relationship reversed during the operation of QE. Moreover, we find evidence that QE successfully reduced liquidity premia and ultimately, indirectly, reduced credit risk premium. In the EMU, the causality remains throughout from credit risk to liquidity premia. Long-term credit risk CDS had greater effect on widening liquidity premia so it is tempting to conclude that the long-term credit risk was the main driver for the widening Euribor-OIS spread. The ECB's OMO and CBPP reduced the liquidity spread significantly, but it proved hard for such operations to decrease credit risk because there is no causality from liquidity component to credit risk spread. In the US, both the long-term credit risk and liquidity premia contributed to the widening of risk premium and there is dual causality between the two premia throughout the sample period. The US LSAP has reduced both long-term credit and liquidity premia significantly.

The remainder of the chapter consists of three sections. The first section, 5.1, describes the variables and unit root test results. The second section, 5.2, discusses the empirical results of cointegration and the VECM. Finally, section 5.3 compares the results and summarizes findings in the chapter.

5.1 Basic Statistics and Unit Root Results

Tables 5.1 and 5.2 summarize the period of data, and variables and their abbreviations, respectively. Broadly, the study looks at three periods, pre-crisis, crisis and post-crisis. The definition of the pre-crisis period follows same criteria for the three markets i.e. finish one day before the widely recognized beginning date of the crisis. During the crisis period, we test the relationships separately for pre-QE ('pre-QE-crisis') operation and QE operation[48]. For the UK and the US, the boundary of pre-QE-crisis and QE periods is set according to the announcement date of operation of QE, which we believe fairly reflects the market movement in respect to policies. The split of pre-QE-crisis and QE period in the EMU sample poses a problem. We define the pre-QE-crisis period from August 09, 2007 to September 12, 2008 when Lehman Brothers filed for bankruptcy because the data for the liquidity ratio seems to indicate that after the market event, the ECB stepped in more determined than before. The QE period therefore runs from September 15, 2008 to May 06, 2010, which date is also the end date of data of the EMU. Due to the sovereign crisis, the spreads in EMU did not settle in our sample period so there is no post-crisis period for the EMU estimation. Also, the operation of ECS has not stopped during the sample

[48] Again, here QE is just the name of the label, as stated before. The definition of period fully considers the development of operation of policies in each sample.

period indicating the lasting of crisis in the EMU. On May 10, 2010, ECB introduced the SMP in response to the severe sovereign debt crisis. The sovereign debt crisis is outside our research scale so the sample stops before the operation of SMP. Moreover, the preliminary estimations beyond the chosen end date have been unable to explain the relationship. The selection of date is also more comparable with the UK and the US results. Then, the post-crisis period in the UK and the US starts after the end date of the first round QE and finishes a day before the second round of QE, respectively.

In the US, the Fed first signaled the second round of QE on August 10, 2010 by stating they will reinvest principal payments from agency debt and agency mortgaged-backed-securities in longer-term Treasury securities[49] (The Fed Monetary Policy Press Release, August 10, 2010). On November 03, 2010, the Fed formally announced the further purchase of $600 billion of longer-term Treasury securities at a pace of $75 billion per month[50] (The Fed Monetary Policy Press Release, November 03, 2010). The end date of the US sample is set to be one day before the signal date i.e. August 09, 2010 to exclude any impact from the second round of QE.

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[49] Press release August 10, 2010
http://www.federalreserve.gov/newsevents/press/monetary/20100810a.htm#fn1
[50] Press release November 03, 2010
http://www.federalreserve.gov/newsevents/press/monetary/20101103a.htm

Table 5.1 Summary of Period of Estimation

		Whole Period	Pre-Crisis	Crisis	Post-Crisis	Pre-QE	QE
UK	**B**	1/1/04	1/1/04	9/8/07	25/6/10	9/8/07	19/2/09
	E	30/9/10	8/8/07	24/6/10	30/9/10	18/2/09	24/6/10
EMU	**B**	2/1/04	2/1/04	9/8/07	NA	9/8/07	15/8/08
	E	6/5/10	8/8/07	6/5/10	NA	12/8/08	6/5/10
US	**B**	1/1/04	1/1/04	9/8/08	31/3/10	9/8/07	25/11/08
	E	9/8/10	8/8/07	30/3/10	9/9/10	24/11/08	30/3/10

B: Beginning E: End; QE represents intervention period in the UK, the EMU and the US. In the EMU, the period QE refers to the period of enhanced credit support.

Table 5.2 Summary of Variable and Abbreviation[51]

	Liquidity Risk	Short-term Credit Risk	Long-term Credit Risk	QE Measurement
UK&US	Repo – OIS	LIBOR – Repo	5-year Interbank CDS Index	Accumulated QE Amount / Total Bank Assets
	(RMO)	(LMR)	(CDS)	(Ratio)
EMU	Repo – OIS	Euribor – Repo	5-year Interbank CDS Index	(OMO[52] + CBPP) / Total Bank Assets
	(RMO)	(EMR)	(CDS)	(Ratio)

OMO: Open Market Operation; CBPP: Covered Bond Purchase Programme
Maturity of Euribor, LIBOR OIS and Repo, respectively, is three month. LIBOR represents LIBOR (£) in the UK and LIBOR ($) in the US. The same applies to the OIS and repo for the UK and US samples.

In the rest of this section, we first present and discuss the basic statistics of these variables including mean, skewness and kurtosis, and standard deviation, and then move to correlation. Then, we present unit root test results as evidence of

[51] The explanation of variables in Table 5.2 can be found in Chapter 4.3.
[52] Open Market Operation (OMO)

the selection of econometric model.

5.1.1 Basic Statistics

This sub-section looks at basic descriptive statistics and plots of variables. The discussion starts with the UK sample followed by the EMU sample and the US sample. Unless otherwise stated in the following paragraphs, the chapter proceeds in this order. Moreover, the spreads used in this research are in basis points in the three data sets, but we changed the EMU sample to percentage in the regression for easier interpretation of the coefficients. The change is only made in the regression section for the EMU sample and it does not apply to descriptive statistics and correlation.

Table 5.3 Descriptive Statistics of Variables[53]

	UK				EMU			
	LMR	**RMO**	**CDS**	**Ratio**	**EMR**	**RMO**	**CDS**	**Ratio**
				Pre Crisis				
Mean	14.7	-2.51	11.09		6.52	-0.93	11.6	27.8
Std.dev	1.51	1.74	3.75		1.03	1	3.76	1.18
Skewness	0.29	-0.83	2.19		0.65	0.19	1.53	-0.63
Kurtosis	4.5	14.01	15.57		5.15	9.17	8.22	3.35
Jarque-Bera	94.53	4548.7	6502.5		247.31	1497.39	1433.67	66.07
Probability	[0.00]	[0.00]	[0.00]		[0.00]	[0.00]	[0.00]	[0.00]
				Pre QE Crisis				
Mean	94.27	9.75	88.9		62.88	0.31	67.01	23.58
Std.dev	49.41	10.55	37.83		13.88	2.55	28.86	2.2
Skewness	1.14	1.2	0.2		-0.36	-0.05	0.57	1.24
Kurtosis	3.35	6.46	2.21		2.83	5.46	3.15	5.56
Jarque-Bera	82.91	276.58	12.34		6.37	71.88	15.49	150.99
Probability	[0.00]	[0.00]	[0.00]		[0.04]	[0.00]	[0.00]	[0.00]
				Crisis QE				
Mean	36.97	12.69	118.19	0.02	64.2	2.56	107.48	26.21
Std.dev	35.15	6.96	37.61	0.01	44.17	3.89	25.08	2.7
Skewness	1.22	1.32	0.91	-0.93	1.3	0.69	0.83	-1.32

[53] For the time period of each sample, please refer to Table 5.1 in Chapter 5.

Kurtosis	3.32	3.58	2.73	2.48	3.57	3.84	3.38	4.69
Jarque-Bera	85.85	102.98	47.97	52.83	127.04	46.76	51.74	175.61
Probability	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]	[0.00]
					Post Crisis			
Mean	18.14	7.95	115.02	0.03				
Std.dev	0.61	0.45	15.21	0				
Skewness	0.32	-0.59	0.9	-0.04				
Kurtosis	2.12	4.26	2.93	1.75				
Jarque-Bera	3.39	8.62	9.27	4.48				
Probability	[0.18]	[0.01]	[0.01]	[0.11]				

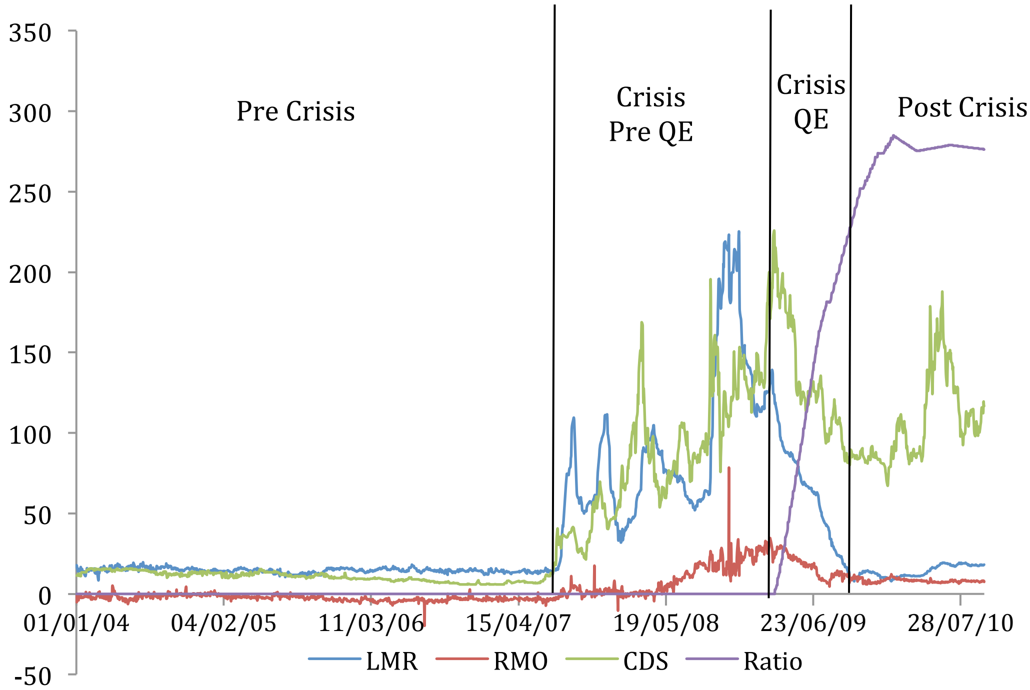
		US		
	LMR	**RMO**	**CDS**	**Ratio**
		Pre Crisis		
Mean	0.22	-11.32	11.6	6.5
Std.dev	0.05	8.44	3.76	0.05
Skewness	0.04	1.17	1.53	-1.18
Kurtosis	4.29	5.51	8.2	3.35
Jarque-Bera	65.42	461.08	1424.51	36.71
Probability	[0.00]	[0.00]	[0.00]	[0.00]
		Pre QE Crisis		
Mean	1.14	-20.92	74.97	4.73
Std.dev	0.64	22.86	33.38	1.12
Skewness	2.45	-1.26	0.43	0.14
Kurtosis	9.61	6.73	2.56	1.24
Jarque-Bera	954.39	285.22	13	44.46
Probability	[0.00]	[0.00]	[0.00]	[0.00]
		QE Crisis		
Mean	0.55	-4.03	106.11	4.89
Std.dev	0.44	5.64	25.47	1.03
Skewness	1.13	1.26	0.95	-0.38
Kurtosis	3.56	4.92	3.65	1.4
Jarque-Bera	78.8	146.97	59.05	45.57
Probability	[0.00]	[0.00]	[0.00]	[0.00]
		Post Crisis		
Mean	0.31	-6.78	126.05	5.86
Std.dev	0.08	2.82	26.96	0.02
Skewness	-0.58	-0.36	0.06	-0.36
Kurtosis	1.79	3.01	2.21	2.02
Jarque-Bera	10.95	2	2.53	5.78
Probability	[0.00]	[0.37]	[0.28]	[0.06]

In the UK, during the pre-crisis period, the variables LMR, CDS and RMO were stable and calm representing the reduced macroeconomic volatility during the 'great moderation' period. Both short- and long-term credit risks (LMR and CDS, respectively) remained low. Liquidity premia (RMO) wandered around zero depicting ample liquidity in the interbank market and favourable trading environment. The low standard deviations given in Table 5.3 of these variables imply low volatility of credit and liquidity risks in the period.

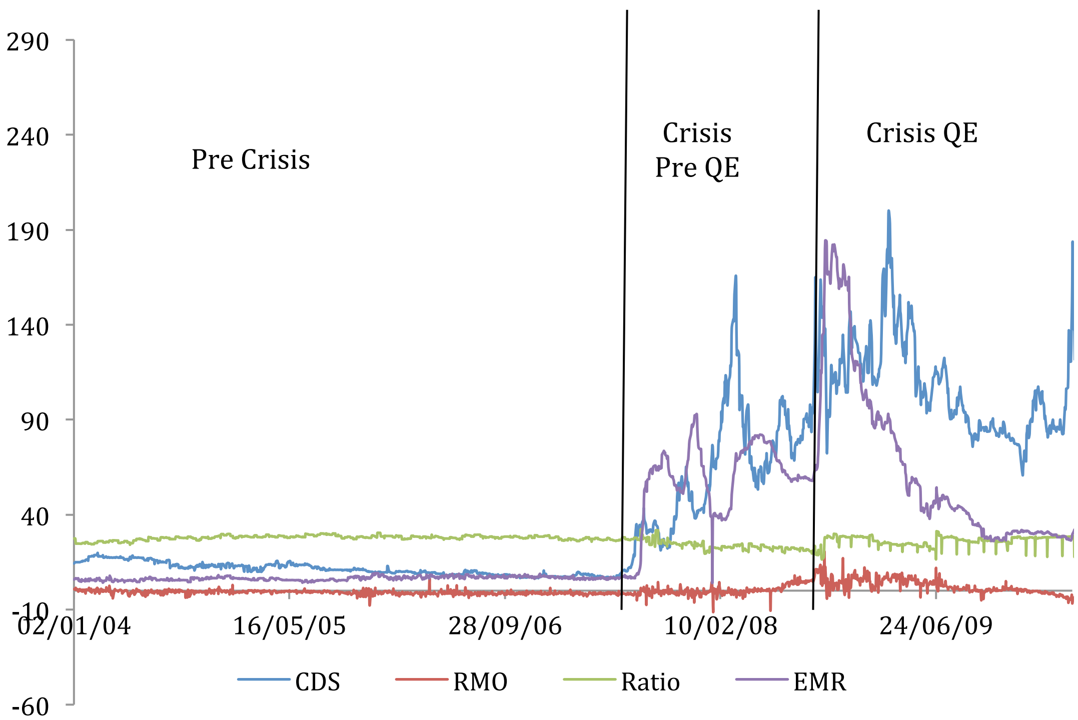
Turning first to the UK and Figure 5.4a, it can be seen that after the financial crisis was triggered, both credit risks and liquidity premia grew dramatically and wandered with an upward trend. Prior to the operation of QE, the three variables kept increasing even after a series of liquidity provisions (see Chapter 2 for more detail), possibly implying that credit risk premia caused by uncertainty played more important role in the interbank market at the beginning of the crisis. The reason is that those liquidity provisions that are discussed in chapter 2 aimed to fulfill the lender-of-last-resort function of BoE so they did not directly deal with uncertainties that were raised by difficulties of asset valuation. Particularly, around half year before the collapse of Northern Rock and Lehman Brothers, short-term credit risk spread LMR dropped considerably. This does not necessarily mean a decrease of credit risk because the decline of LMR can be a result of increase on repo rate reflecting market demand for secured repo used under repo agreement transaction. The long-term credit risk measure CDS increased rapidly during the period reflecting negative market expectation of banks' ability to meet their debt obligation.

Figure 5.4 Plot of Variables in Basis Point

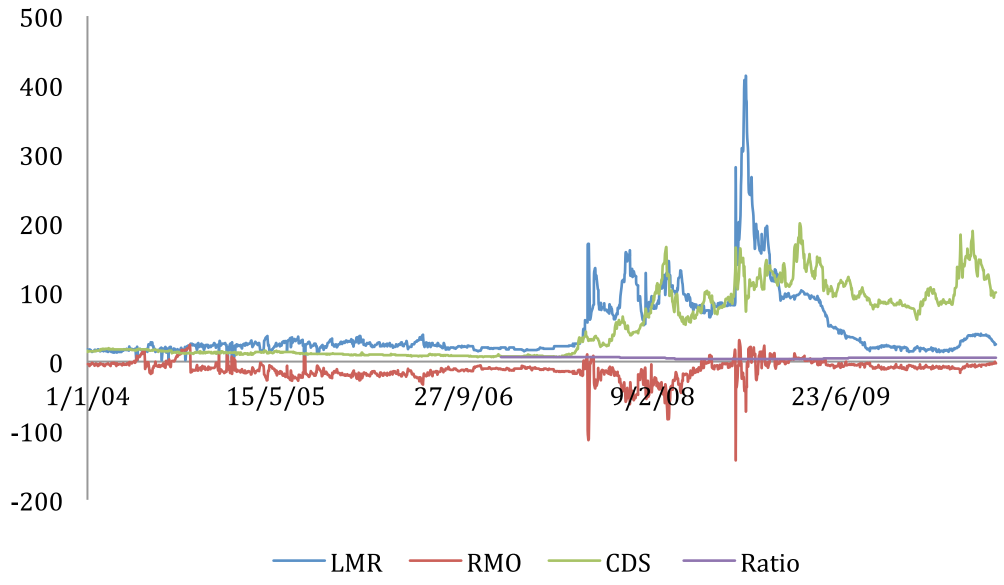
a. UK (January 01, 2004 – September 30, 2010)



b. EMU (January 02, 2004 – May 05, 2010)



c. US (January 01, 2004 – August 09, 2010)



In the meantime, the liquidity indicator RMO remained quite low until the Northern Rock and Lehman Brothers events. This might explain that the BoE's liquidity intervention had successfully boosted the interbank market. Banks themselves were well liquid (see Figure 2.3 in Chapter 2). They would like to lend securely but were reluctant to lend insecurely. This, in turn, gives evidence of the dominant role of credit risk during the pre-QE crisis period. After these events, RMO remained persistently high in the period. This may be explained as 1) the expectation of future movements of asset prices, especially those that were distressed during the crisis e.g. CDOs and MBSs became even more passive due to the low ebb of trading condition and close down of some credit markets; 2) banks therefore protect themselves by hoarding excessive reserves on their balance sheet resulting in rise of liquidity premia.

Moving to the crisis QE period, the short-term measure LMR continued to drop in tandem with the increasing amount of QE purchases. This could be evidence for the effectiveness of QE in reducing the credit risk premium. The liquidity premium RMO dropped gradually in the period. However, the absolute level of

RMO did not go back to its pre-crisis level. This might reveal banks' cautiousness about the market and economy so they may have run tighter criteria in making lending decisions and this can result in less liquidity in the market.

CDS spread fell significantly during the QE period but still remained at a much higher level compared with the pre-crisis period. Interestingly to note, the long-term credit spread (CDS) stayed close to short-term credit risk LMR during pre-crisis and pre-QE-crisis periods, but they started to depart because LMR dropped significantly more than CDS. This shift seems to be consistent with the purpose of QE. QE is a temporary monetary policy tool and the facilities under QE aim to have a short-term effect rather than achieving a long-term goal. The short-term effect is mainly on the improvement of liquidity in the market. This may reduce the credit risk that is associated with inability to borrow (see Bank of England, 2007, p498), but it would have little impact on reducing the risk of default that relates to other factors e.g. capital adequacy or composition of assets. In other words, QE facilities are designed to produce a buffer for financially sound banks to survive during the crisis, but banks have to adapt their own strategies to correct the bugs in their business models in order to perform in the long run. Therefore, QE would possibly reduce some default concerns raised by temporary shortage of liquidity for banks, but not eliminate probability of default raised on the long-run elements. That is, sound banks remain sound.

During the post crisis period, the short-term credit spread LMR nearly dropped back to its pre-crisis level and liquidity premia RMO stayed low and stable despite still being twice its level in the pre-crisis period and stayed close to LMR. This could mean that banks may have started to consider liquidity factors more seriously in their asset valuation models. The CDS rate remained at an elevated level at the beginning of the period and then increased suddenly, also showing greater volatility.

Turning to the descriptive statistics for the UK in Table 5.3, we see that the means of the spreads have risen considerably since the pre-crisis period, indicating generally elevated levels of credit risk and liquidity premia during the pre-QE-crisis period. The standard deviation of the spreads also shows sharply the increased uncertainties and greater instability in the interbank market. Skewness measures asymmetry of the distribution of a variable around its mean. The positive value of skewness shows that the distributions of the variables have a long right tail. This is not so for RMO whose small negative skewness shows a longer left tail. This means that for RMO the mass of the distribution is towards the right – at the higher values of RMO. This might explain that liquidity was hardly a problem before the crisis and that market participants tended to be very optimistic about market conditions. Kurtosis is a measure of peakedness of the distribution of a variable. The values of kurtosis show that each variable has a distribution that is peaked relative to the normal distribution in the pre-crisis period and in the pre-QE-crisis period except variable CDS, which has a slightly smaller kurtosis. Finally, Jarque-Bera statistics also suggest non-normality of these variables in the three periods.

The mean values of LMR dropped after the crisis QE period, but the means of CDS and RMO increased during the same period. The standard deviation of LMR and RMO fell dramatically during the post-crisis period, indicating that the interbank market had started to settle.

During the post-crisis period, firstly, the mean (18.14 basis points) of short-term credit risk premium LMR is very close to its pre-crisis mean (14.70 basis points) confirming the contribution of asset purchases to removing credit risk that had been caused by uncertainty of asset valuation. The Jarque Bera test statistics do not reject the null hypothesis of normality for LMR, but they do so for RMO and CDS. As we saw in the Figure 5.4a, the mean of liquidity premia (7.95 basis points) is much higher than its pre-crisis mean (-2.51) despite the standard deviation being much smaller (0.45). This seems to imply that liquidity conditions in the interbank market were quite settled after the interventions by the BoE. The raised mean of liquidity premia might reflect the change of banks' awareness of risk.

We turn now to the discussion of the risk premia in the EMU sample. During the pre-crisis period, short- and long-term credit risk measurements, EMR and CDS, respectively and liquidity premia RMO performed very similar to the UK's market. The level of short-term credit risk is smaller than in the UK whereas the mean of long-term credit risk is about the same in both markets. The standard deviations for the corresponding variables are close, as well, indicating a similar trading environment in the two markets. The size of OMO in proportion to total bank assets is 27.80 percent in the pre-crisis period, on average.

On August 09, 2007, the ECB reported a liquidity shortage worldwide using Euribor data (European Central Bank, *Financial Crisis Timeline*, 09/08/2007). From August 09 to August 14, the ECB injected €335 billion into the interbank market to ensure the orderly functioning of money markets (European Central Bank, Press Release, 14/08/2007). Then, a series of liquidity interventions was carried out during the crisis period. Furthermore, RMO varied positive and negative over the whole sample period so that on average RMO is close to zero. Since it is the absolute size of the spread that measures the degree of liquidity risk, a better measure of the average may be the absolute mean, which is equal to 0.01 during the pre-crisis period. Moreover, the relatively calm RMO spread may show that the main issue in the EMU is likely to be credit default rather than short-term liquidity problems. In the pre-QE period, the spread of EMR and CDS increased dramatically. The mean of EMR increased by nearly ten times in the crisis pre-QE period compared with pre-crisis period. The mean of CDS increased about six times. Interestingly, the Ratio showed a slight downward trend in the period.

During the crisis QE period, with the crisis intensifying after the collapse of Lehman Brothers, on October 08, 2008, the ECB decided on taking unconventional liquidity measures to banks as well as commitment to meet banks' liquidity request subject to collaterals with sufficient quality (European Central Bank, Press Release, 08/10/2008). In this period, the variables show some divergence from those of the UK market. The mean of all variables increased compared with the pre-QE period in the EMU and variables showed an upward trend. The long-term credit risk measure CDS reached its peak at this period in the EMU whereas it continuously reduced in the UK. In the middle of the period, CDS started to drop but the mean was still double its value in the pre-QE period. It also showed signs of increasing toward the end of the sample period. Short-term credit risk did not decrease from the pre-QE period but increased slightly. Moreover, short-term credit risk seemed to settle at a level that was much higher than its pre-crisis period i.e. 64.20 basis points versus 6.52 basis points whereas it went back quite closely to its pre-crisis level in the UK. The standard deviation increased significantly implying market instability whereas we observed a decline of standard deviation in the UK sample during the period. The Ratio increased slightly as expected. The spikes in the figure may be due to the maintenance period of OMO.

In the EMU, the variable 'Ratio' has values for the whole sample period because of the way it is computed (see Table 5.2). A large proportion of EMU's ECS scheme was carried out through LTROs in different maturities under OMO. Therefore, prior to the operation of CBPP in the QE period in the EMU sample, 'Ratio' is the proportion of OMO to total bank assets. Its pre-crisis values provide a benchmark for the size of ECB's OMO in relation to bank assets.

Turning to the result of the US, before the crisis hit, in a manner similar to the UK and the EMU, all variables stayed low with small fluctuation. Particularly, the short-term credit risk premium LMR wandered very close to zero and the liquidity risk premium RMO was below zero on average. This shows the favourable market trading conditions in the US money market prior to the crisis.

Despite the Fed voting to maintain the bank base rate at 5.25 percent on August 7, 2007 (a day before the widely recognized start date of the crisis), they announced on August 10, 2007 that banks may experience unusual funding needs due to dislocations in money and credit market and they will always provide liquidity as necessary to promote trading[54]. In Figure 5.4c, the obvious signal is the sudden increase in the long-term credit risk premium proxy, CDS. The short-term credit risk and liquidity premia did not increase as dramatically as they did in the UK and the EMU, but we can still observe the rise in the two variables. This phenomenon might indicate that the short-term credit risk and illiquidity are not the main drivers in the crisis. Market participants in the US market are likely to consider the long-term credit worthiness of their counterparties when they make their lending decisions. This is also consistent with the regression result shown in the later part e.g. the long-term credit risk premium appears to have more significant influence on the liquidity premium compared with short-term credit risk premium.

Moreover, a series of immediate responses to ease market liquidity conditions and to provide liquidity directly and quantitatively may have also pushed down the liquidity premium in the US money market although RMO became volatile during the period. For example, eight days after the crisis hit, August 17, 2007, the Fed reduced fifty basis points of the primary credit rate making it only fifty basis points higher than the bank base rate i.e. 5.75 percent. On September 18, 2007, the Fed reduced the bank base rate by fifty basis points to 4.75 percent as well as another fifty basis point reduction on the primary credit rate. On December 12, 2007, the first (in our sample) unconventional liquidity provision

[54] Reference from Federal Reserve Bank of St. Louis website. The financial crisis: A timeline of events and policy actions. http://timeline.stlouisfed.org/index.cfm?p=timeline

TAF was launched to provide massive liquidity to the US banking system (There are another two bank base rate cuts before the launch of TAF, twenty-five basis points on October 31, 2007 and twenty-five basis points on December 11, 2007).

On November 25, 2008, the Fed revealed their intention to purchase a total of $600bn market securities - $500bn was used to purchase mortgaged backed securities. On March 18, 2009, the Fed announced a further $1.15tn purchase, $850bn for agency debt and $300bn for longer-dated government bonds. From Figure 5.4c, the long-term credit risk premium CDS reacts to the measures positively. CDS fell significantly during the period of QE, especially after the announcement of further purchases. The short-term credit risk premium LMR also fell. The liquidity premium RMO narrowed and flattened indicating a lower standard deviation.

By the end of March 2010, the Fed has used up the total $1.65bn budget. On March 16, 2010, the Fed revealed their confidence in the economic recovery by stating that 'although the pace of economic recovery is likely to be moderate for a time, the Committee anticipates a gradual return to higher levels of resource utilization in a context of price stability'[55] (The Federal Reserve, Press Release, March 16, 2010). This ends the first round of QE presumably indicating an improved market condition. In Figure 5.4c, both short-term credit risk and liquidity premia have dropped and formed smoothed curves, respectively, but the CDS remained elevated. This is the same as in the UK and the EMU. Also, it fits the intention of QE – to provide liquidity to economies directly.

Moving to the descriptive statistics in Table 5.3, the statistics for the US firmly confirm the information revealed by the plot of variables. The mean and standard deviation of LMR, RMO and CDS are low, respectively during the

[55] Press release March 16, 2010
http://www.federalreserve.gov/newsevents/press/monetary/20100316a.htm

pre-crisis period whereas the values increased dramatically during the period of crisis prior to QE, especially for the liquidity premium RMO and long-term credit risk premium CDS. The standard deviation and mean of RMO is 8.44 for the pre-crisis period and it increased to 22.86 during the period of crisis before the unconventional quantitative intervention showing the strong demand for liquidity and the shortage of liquidity in the money market. The mean and standard deviation of CDS is 11.6 and 3.76 during the pre-crisis period, respectively and they increased to 74.97 and 33.38, respectively, since the onset of the crisis. This confirms that uncertainty of valuation and value of assets on banks' balance sheet has triggered the concern of credit worthiness in the long run. The mean and standard deviation of LMR increases slightly implying that short-term credit risk may not be the main concern from market participants.

During the period of QE intervention, the liquidity effect has been apparently reflected in the value of standard deviation of RMO – it dropped to 5.64, which is smaller than the value during the pre-crisis period. This reveals that the large amount of purchase of longer-dated securities swaps for an ample liquidity in the money market pushing down the liquidity premium in the risk premium.[56] However, although we observe a downward shift of CDS during the period of QE intervention, the mean of CDS increases during the period, but standard deviation falls. This might explain that banks become clearer on the identification of the creditworthiness of counterparties i.e. the QE eliminates the probability of default that is triggered by the illiquidity. Therefore, the standard deviation of CDS drops. The high value of the mean then shows the high probability of default in the long term with little influence from the liquidity position. Therefore, it indicates the long-term credit risk concern in the US money market.

[56] The ample liquidity indeed pushed down the liquidity premium but if the liquidity has been converted into credit that ultimately benefit the economy is another issue.

Looking at the post crisis period, the statistics do not vary too much from their QE period value except the standard deviation of RMO – it decreases to 2.82 i.e. about a 50 per cent decrease from its value during the QE period. This further proves the ample liquidity in the money market.

Overall, the basic statistics of variables in the UK depicted the relationship as expected according to market events, but they showed some ambiguity during the crisis-QE period in the EMU. Presumably, these risk measures should decrease during the operation of intervention but they tended to increase in the EMU sample. This might result from a lagged effect. In the US sample, the statistics shows comparability with the UK result, but the short-term credit risk premium LMR seems not to have much impact (on the risk premium) in the crisis in the US. In the next sub-section, the correlation table will shed more light on these relationships.

5.1.2 Correlation between Variables

Correlation is a numerical measure of the degree to which patterns in one variable and another variable correspond. The squared correlation measures the proportion of the variability in the variable that is explained by the variance in the other variable density. But, correlation does not necessarily identify causality. The correlation between two variables is the same as the correlation when they reverse their places. To establish causality in our study, we need to employ the econometric models whose results are presented in section 5.2. In this sub-section, we look at the pairwise correlation between variables.

In the UK, during the pre-crisis period, the correlation between credit risks and liquidity premia was quite low especially between short-term credit risk LMR and liquidity premia RMO i.e. the correlation is only -0.08. This low correlation may represent the great moderation period when liquidity was never an issue in the banking system in the short run. The short-term and long-term credit risk were positively related indicating a trading day yielded high LMR spread tend to have high CDS figure *vice versa*, despite the figure was quite low at 0.30. The variables, CDS and RMO had a higher positive relationship at 0.36. This might reveal that liquidity premia tend to be higher in the interbank market for banks with greater default probability in the long run.

During the crisis period, the correlation in the UK increased rapidly and showed significant changes in the relationship between short-term credit risk and liquidity premia. Prior to the QE period, the correlation between RMO, and short- and long-term credit risks was positive at 0.58 and 0.65, respectively. Both figures were significantly greater than their pre-crisis value. Thirty-four percent (forty-two percent) of the variance in LMR (CDS) can be explained by variance in RMO, and *vice versa*.[57] This most likely reveals that the probability of default of banks who faced greater liquidity problems tended to be particularly higher during crisis period, and *vice versa*[58] – we need more evidence to find the precise causality. Moreover, the greater correlation between short- and long-term credit risk showed stronger connection between credit risks in short and long terms.

During the QE period, the correlation further increased compared with pre-QE-crisis period. The correlation between short-term credit risk and liquidity premia was nearly perfectly positive at 0.91, showing an extremely high tendency for banks with liquidity problem to tend to default in the short run. The market's perception of high default risk due to low quality assets and asymmetric information leads to a liquidity shortage in the system because banks may tend to hoard cash. This would reflect the urgency for the BoE to

[57] $0.58 \times 0.58 = 0.3364 = 34\%$ is for LMR and RMO. $0.65 \times 0.65 = 42\%$ is for CDS and RMO.

[58] As mentioned in the previous paragraph, correlation does not reveal causality. Therefore, we have estimated causality in the econometric model. To avoid repeating, the phase 'vice versa' is not added while discussing correlation relationship.

intervene in the market in a stronger way i.e. asset purchase. If it was the case, 1) the correlation between Ratio, and LMR and RMO, respectively should be negative; 2) the variable Ratio should weaken the correlation between LMR and RMO. The latter cannot be revealed by the correlation in this section and it will be examined in the empirical result section. For the former, the correlations indeed showed near-perfect negative relations (-0.97 and -0.93) for the two pairs of variables, respectively. Moreover, the correlation between Ratio[59] and CDS also showed large negative relation, -0.71. This provided the evidence that QE effectively reduced credit risks and liquidity premia during its operation period.

Table 5.5 Correlations between Variables

Variable	UK			EMU			US		
Pre-Crisis									
	LMR	**CDS**		**EMR**	**CDS**	**Ratio**	**LMR**	**CDS**	**Ratio**
RMO	-0.08	0.36		-0.35	0.25	-0.11	-0.89	-0.49	0.76
CDS	0.3	1		-0.3	1	-0.34	0.76	1	-0.79
Ratio				0.19	-0.34	1	-0.87	-0.79	1
Crisis									
Pre-QE	**LMR**	**CDS**		**EMR**	**CDS**	**Ratio**	**LMR**	**CDS**	**Ratio**
RMO	0.58	0.65		-0.1	0.22	-0.25	-0.17	0.09	-0.4
CDS	0.55	1		-0.16	1	-0.53	0.44	1	-0.65
Ratio				-0.01	-0.53	1	-0.31	-0.65	1
QE	**LMR**	**CDS**	**Ratio**	**EMR**	**CDS**	**Ratio**	**LMR**	**CDS**	**Ratio**
RMO	0.91	0.71	-0.93	0.49	0.62	-0.35	0.69	0.71	-0.78
CDS	0.78	1	-0.71	0.48	1	-0.23	0.73	1	-0.83
Ratio	-0.97	-0.71	1	0.08	-0.23	1	-0.92	-0.83	1
Post-Crisis									
	LMR	**CDS**					**LMR**	**CDS**	**Ratio**
RMO	-0.39	-0.16					0.52	0	0.58
CDS	0.73	1			**NA**		0.7	1	0.6
Ratio							0.95	0.6	1

[59] The definition of Ratio is explained in Chapter 4.3.

In the post-crisis period, the variable Ratio was dropped because the study does not look at persistence of QE's effect on credit risk and liquidity premia. The correlations between both credit risks, respectively and RMO were negative and quite small. For short-term credit risk, the figure did increase compared with its pre-crisis level but not significant. It suggested a weak negative tendency between credit risks and liquidity premia. The correlation between CDS and LMR stayed at their crisis level closely. Overall, these post-crisis correlations seemed to tell that QE reduced and reversed the connection between credit risks and liquidity premia.

In the EMU, the correlations were quite consistent across the three periods but they revealed different information compared with the UK market. Firstly, during the pre-crisis period, the correlation between both credit risks and liquidity premia were very low, respectively and the correlation between short-term credit risk EMR and liquidity premia was negative as they were in the UK sample. But, CDS had a negative correlation with EMR although it was small. As expected, correlations between Ratio, and RMO and CDS, respectively, were negative indicating that conventional liquidity operations worked satisfactorily in the pre-crisis period. Secondly, during the pre-QE-crisis period, the correlations indicate that conventional open market operations worked satisfactorily in the crisis. The correlations between Ratio and both credit risks and liquidity premia were negative and the values were bigger than pre-crisis period although the absolute value of correlations is not high, but they are more than twice for RMO versus Ratio and almost twice for CDS and Ratio compared with the earlier period. This implied that the crisis magnified the dependence of the interbank market on OMO. However, it was very interesting to notice that the correlation between the short-term credit risk premium and Ratio dropped to -0.01, virtually no correlation. Finally, during the crisis QE period, OMO included weekly LTROs with longer maturities as well as CBPP. Correlations between variables increased in the period apart from the relation between CDS and Ratio.

The correlation between short-term credit risk and liquidity premia changed to positive compared with the last two periods, which was comparable to the UK market. Despite the increased absolute amount and negative sign on correlations between Ratio and credit risks and liquidity premia, the statistics shows evidence that the operation of the ECS scheme had a significant impact on improving liquidity in the Euribor market.

In the US sample, the variable Ratio has a tight negative correlation between liquidity and credit risk premia variables, respectively. This initially confirms the effectiveness of the Fed's LSAP in reducing the borrowing costs in the money market by reducing liquidity and credit risk premia. However, the correlation statistics show a different picture compared with the UK and the EMU samples during pre-crisis and crisis pre-QE periods, respectively. Firstly, before the onset of the crisis, the liquidity and credit risk premia have a closely negative relationship, but the long-term credit risk premium CDS has a positive relation between the liquidity premium RMO in the UK and the EMU samples. Secondly, the correlations between liquidity and credit risk premia loosened significantly during the crisis period prior to the intervention of QE, but the relation became tighter in the UK sample and maintained (with little drop) in the EMU sample. During the post crisis period, the correlations remain positive, but the value between CDS and RMO becomes zero implying the short-term credit risk premium takes the major role in the liquidity premium.

To summarize, the correlations between variables in the UK generally showed supportive evidence of the effectiveness of QE in reducing credit risks and liquidity premia as well as boosting the correlation between them. Moreover, the correlation between short-term credit risk and liquidity premia increased after the crisis possibly reflecting banks' revaluation of their risk assessment models. In the EMU, the impact of OMO on both credit risk and liquidity premia increased slightly with weekly unconventional longer-term LTROs, but the correlations between credit risks and liquidity premia were persistently high. The low correlation between EMR and Ratio in the three periods indicates that there was only a weak tendency for Ratio to reduce EMR. For both samples, the correlation between long-term credit risk and liquidity premia was magnified by the crisis and the effect seemed to be quite persistent. In the US sample, the correlation between Ratio and liquidity and credit risk premia primarily confirms the impact of LSAP on reducing the borrowing costs.

Therefore, the correlation statistics provide the ground for empirical estimations to focus on

- The causality between credit risks and liquidity premia
- The ability of QE to influence these variables
- Whether QE had an impact on changing the relationships between variables, and if so, the magnitude of its effect.

The following sub-section represents unit root tests for evidence of selection of econometric models.

5.1.3 Unit Root Test Result

This study adopts the augmented Dickey-Fuller test (see Chapter 4.6.1) to examine the stationarity of variables in order to avoid spurious regressions. As saw in the Figure 5.4, spreads tended to wander up and down with no discernable pattern across the whole sample period. However, the spreads wandered with an obvious upward trend during the pre-QE-crisis period and downward trend during the QE period.

These features are likely to suggest that these spreads are random walk variables; especially they showed the features of random walk with drift during crisis period (positive drift during pre-QE-crisis period and negative drift during QE period). According to ADF testing procedure suggested by Hill *et al* (2008, p336), the selection of testing equation is based on visual inspection of plots in Figure 5.4a and Figure 5.4b. Table 5.6 shows the results of the ADF tests in different sub-periods and Table 5.7 summarizes the results.

Turning first to discuss the results for the UK, we see that the results are nearly the same for variables in different sub-periods for the three samples, except for the variable Ratio and RMO. In the UK, Ratio was expected to have a unit root due to the progressive expansion in size of QE. However, in the EMU, the QE measure was stationary across the sub-period. Noticeably, the immense easing of monetary policy in the UK during the crisis period had a larger effect on the liquidity component because RMO became stationary for the post-crisis period whereas the short-term credit risk premium remained volatile. In the US sample, RMO was stationary during crisis prior to LSAP and shows unit root during the period of LSAP. This result is not unexpected as the massive liquidity provision may have come as a stochastic shock on the spreads.

Based on the unit root test results, this section investigates the pairwise relationships between credit risks and liquidity premia as well as impact on these relations from liquidity provisions by the BoE, the ECB and the Fed during the crisis and how BoE's and the Fed's QEs may have changed the relationship.

Table 5.6 ADF Unit Root Test Statistics

	Pre-Crisis	Crisis: Pre-QE	Crisis: QE	Post-Crisis
		UK		
RMO	-3.87 [0.00]	-2.25 [0.46]	-2.30 [0.43]	-3.50 [0.01]
LMR	-3.10 [0.03]	-2.95 [0.15]	-0.82 [0.96]	-2.07 [0.26]
CDS	-1.45 [0.56]	-3.56 [0.04]	-1.71 [0.75]	-2.78 [0.07]
Ratio	NA	NA	-2.49 [0.33]	NA
Results are based on automatic selection AIC with maxlag = 100[60]				
		EMU		
RMO	-8.17 [0.00]	-1.53 [0.52]	-2.67 [0.08]	NA
EMR	-3.55 [0.01]	-2.49 [0.33]	-2.69 [0.24]	
CDS	-0.76 [0.83]	-1.88 [0.66]	-3.19 [0.09]	
Ratio	-4.29 [0.00]	-7.31 [0.00]	-5.43 [0.00]	
Results are based on automatic selection SIC with maxlag=21				
		US		
RMO	-1.50 [0.12]	-5.40 [0.00]	-1.32 [0.62]	-1.18 [0.22]
LMR	-0.07 [0.66]	-2.42 [0.14]	-2.00 [0.29]	-0.41 [0.53]
CDS	0.49 [0.82]	-1.58 [0.49]	-2.26 [0.18]	-0.19 [0.62]
Ratio	-10.37 [0.00]	-0.92 [0.78]	-1.99 [0.29]	-0.73 [0.40]
Results are based on automatic selection AIC with maxlag = 16.				
The selection for LMR during Crisis QE is based on AIC with maxlag = 40.				

[60] The different lag length is because that variables in the UK sample tend to suffer serial correlation so the lag length is increased.

Table 5.7 Summary of ADF Unit Root Test Result

	Pre-Crisis	Crisis Pre-QE	Crisis QE	Post-Crisis
		UK		
RMO	Stationary	Unit Root	Unit Root	Stationary
LMR	Stationary	Unit Root	Unit Root	Unit Root
CDS	Unit Root	Unit Root[61]	Unit Root	Unit Root
Ratio	NA	NA	Unit Root	NA
		EMU		
RMO	Stationary	Unit Root	Unit Root	NA
EMR	Stationary	Unit Root	Unit Root	
CDS	Unit Root	Unit Root	Unit Root	
Ratio	Stationary	Stationary	Stationary	
		US		
RMO	Unit Root	Stationary	Unit Root	Unit Root
LMR	Unit Root	Unit Root	Unit Root	Unit Root
CDS	Unit Root	Unit Root	Unit Root	Unit Root
Ratio	Stationary	Unit Root	Unit Root	Unit Root

5.2 Estimation Results[62]

According to the analysis of basic statistics and unit root results, a different approach is applied to the two samples. For the UK sample, a Banerjee *et al* (1998) single equation ECM is employed firstly (see Equation 33 in Section 4.5.2) because variables during crisis period are all I (1) variables. To cope with potential endogeneity in the spread regressions, a VECM (see Equation 36 in Section 4.5.2) is estimated and Engle and Granger (1987) procedure is used to obtain cointegrating vectors. For the EMU sample, the same procedure is used as for the UK sample during crisis pre-QE period. In the QE period, we first run Johansen cointegration test to find cointegrating relation between variables then

61 The ADF statistics reject the null hypothesis of unit root at 4%, which is just around the boundary 5%. However, from the plot of CDS for the crisis pre-QE period, it showed evident feature of non-stationarity. Therefore, we conclude CDS has unit root during the period.

62 We report Durbin-Watson test results for serial correlation in the work, but the LM test has also been carried out and the results are consistent with DW test. We report DW test statistics because it is simple and easy for readers to interpret. The DW statistic is also used as a general misspecification test and is widely applied in studies using daily data. Given the no. of observations and large degree of freedom, serial correlation of residuals is not a big problem for our study.

estimate the VECM including QE variable Ratio. When the cointegration tests suggests that there is only one cointegrating vector, we estimate an ECM ARDL model which can be used to interpret the long-run coefficients and make inferences about causality. This more lengthy procedure is used because the variable Ratio is stationary. ARDL ECM is also carried out. The reason is that Ratio is an I (0) variable during the period and the critical t-values may not allow for adding additional I (0) variables in the Banerjee test for cointegration. During the crisis pre-QE period in the US sample, we have the same issue as in the EMU sample during the QE period. Here, RMO is I(0) whereas other variables are I(1) variables so we adopt the same approach as in the EMU sample.

Moreover, recall the theoretical framework in Section 4.2. The credit and liquidity components are extracted from risk premium. In the research, the interest is on risk premium in money market. The credit risk measure that should be focused is really the short-term credit risk measure, LMR in the UK and the US and EMR in the EMU. Indeed, from the Figure 5.4, the plots showed the pattern that CDS spread moved away from LMR/EMR and RMO since the beginning of the crisis. Moreover, since the credit default swap is widely used to measure credit risk, it may be worth looking at its possible impact on the relationship as a long run factor. Therefore, the study reports both the relationship between liquidity and short-term credit risk premia and long-term credit risk premium.

In the remainder of this section, we first report results for the ECM during pre-QE-crisis period followed by crisis-QE period, for the UK, the EMU and the US. Then, the result for the VECM is presented.

5.2.1 Result of Single Equation Error Correction Models

Liquidity and Credit Risks prior to QE during the crisis period

This sub-section investigates the relationship between credit and liquidity premia during the pre-QE-crisis period for the UK, the EMU and the US. Equation 1-4 in Table 5.8a depicts the behavior of the spreads in the UK and the rest of the equations are for the EMU. Only the values of the error correction term are reported. Panel A contains equations concerning only short-term credit risk and Panel B includes both short- and long-term credit risks. Table 5.8b represents how liquidity and credit risk premia influence each other in the US sample.

The UK Sample

In the UK, equation 1 shows the error correction term on liquidity premium RMO. The coefficient, -0.109, is significant at 5% level indicating RMO error corrects and there is a long-run relationship between liquidity (RMO) and short-term credit premia (LMR). Ignoring the short-run dynamic lags, equation 1 in Table 5.8a can be written as

$$0 = -0.109\,RMO + 0.014\,LMR$$
$$(0.006) \qquad (0.006)$$ [63]

and can be re-arranged to obtain the long-run relation

$$\ldots 37)\ RMO = \frac{0.014}{0.109}\,LMR = 0.1284\,LMR$$ [64]

It suggests that an increase in short-term credit risk causes a widening of the liquidity premium in the long run.

[63] Standard errors are reported in the (). It applies in the following thesis.

[64] The long-run coefficients are obtained by re-arranging the estimated regression. The re-arragned long-run coefficients are not estimatable because it will change the specification of the error correction model.

In equation 2 in Table 5.8a, the position of liquidity premia and short-term credit risk is switched. The error correction coefficient, -0.015, is insignificant at 5% level so LMR does not error correct suggesting that no long-run relationship can be derived from equation 2. That is, the result does not provide evidence of a link from widening of the liquidity risk premium to credit risk.

With the inclusion of a long-term credit risk premium measure CDS, equation 3 and equation 4 support the results of equation 1 and equation 2. But, in equation 3, the influence of short-term credit risk LMR on liquidity premium RMO is shared by the long-term credit risk premium (CDS) observing a reduced long-run coefficient on LMR. Following the same steps as in equation 1, the long-run relationship for equation 3 can be derived as

$$RMO = \underset{(0.007)\ (0.039)}{0.011/0.152}\ LMR + \underset{(0.010)\ (0.039)}{0.021/0.152}\ CDS$$

$$\ldots 38)\ RMO = 0.0724\,LMR + 0.1382\,CDS$$

The coefficient on CDS is greater than on LMR. This may suggest that banks tend to focus on long-term default probability more when they make their lending decision in interbank market.

Table 5.8a Liquidity and Credit Risk before the Intervention

	Panel A		Panel B	
		UK		
	Eqn 1	Eqn 2	Eqn 3	Eqn 4
Variables	**ΔRMO**	**ΔLMR**	**ΔRMO**	**ΔLMR**
RMO_{t-1}	-0.109*	0.037	-0.152*	-0.028
	[-3.30]	[0.98]	[-3.88]	[-0.63]
LMR_{t-1}	0.014	-0.015	0.011	-0.017
	[2.18]	[-2.01]	[1.60]	[-2.24]
CDS_{t-1}			0.021	0.026
			[2.02]	[2.32]
Adj-R^2	0.25	0.06	0.25	0.08
Durbin-Watson	2.15	2.00	2.14	2.00
No. of Observation 387				
		EMU		
	Eqn 5	Eqn 6	Eqn 7	Eqn 8
Variables	**ΔRMO**	**ΔEMR**	**ΔRMO**	**ΔEMR**
RMO_{t-1}	-0.206**	-0.028	-0.215**	-0.045
	[-3.88]	[-0.59]	[-3.95]	[-0.90]
EMR_{t-1}	-0.005	-0.018	-0.003	-0.014
	[-0.55]	[-2.36]	[-0.31]	[-1.72]
CDS_{t-1}			0.006	0.005
			[1.34]	[1.42]
Adj-R^2	0.31	0.22	0.32	0.22
Durbin-Watson	2.07	2.03	2.08	2.05
No. of observation 284				

All equations include an intercept and short-run dynamics up to lag two. Only the coefficients of the error correction terms with *t*-values in squared brackets are reported. The superscript * and ** indicates significance of single-equation ECM test at 5% and 1% level, respectively, according to Banerjee *et al.* (1998, Table 1).

Overall, the UK's result suggests that in the interbank market, the credit risks (contained in the risk premium) drove up the other component, liquidity premium during the crisis pre-QE period. This supports the findings of Taylor and Williams (2009) that the main driver of the widened spread between LIBOR and OIS was the large credit risk premium required by the banks to lend.

The EMU Sample

Turning to the EMU sample, the liquidity premia RMO error corrects shown by equations 5 and 7 in the Table 5.8awhereas short-term credit risk premium EMR does not. The long-run relationship derived from equation 5 is

$$\ldots 39)\ RMO = \ -0.005/0.206\,EMR = -\,0.0243\,EMR$$
$$(0.009)\ (0.053)$$

The long-run relationship with the long-term credit risk premium CDS from equation 7 is

$$RMO = \ -0.003/0.215\,EMR + \ 0.006/0.215\,CDS$$
$$(0.010)\ (0.054) \qquad (0.004)\ (0.054)$$
$$\ldots 40)\ RMO = \ -0.0140\,EMR + 0.0279\,CDS$$

The long-run coefficient on EMR is negative in both Equations 39) and 40). This is hardly explained by the theory. However, the *t*-values on the coefficients of EMRs respectively are very small possibly suggesting little relationship between the spreads. This is consistent with the correlation between the two variables as discussed above. CDS representing long-term default risk formed positive relationship between liquidity premium in the long run. The higher probability for banks to default on their debt causes a widening of the liquidity premium in the long run.

The US Sample

In the light of the unit root results, an ARDL model that only contains the stationary variables and the single equation ECM are both applied to the US sample for the crisis period before the US QE. The disadvantage of ARDL is its lack of long run information on the relationship between the liquidity premium variable, RMO, and credit risk premia, LMR and CDS. Although the single equation ECM suggests that variables LMR and CDS are not cointegrated, the Johansen cointegration test shows there is at least one cointegrating relation between the variables. Therefore, we tested ARDL ECM as well. If LMR and CDS are cointegrated, we can include the I(0) variable RMO in the ARDL ECM model to obtain a long-run relationships and causalities between the three variables. Both ARDL and ECM results are represented in Table 5.8b.

The ARDL equations 9 to 12 in Table 5.8b reveal the short run relationship between the liquidity and credit risk premia. Both short- and long-term credit risk premia have a significant positive impact on the liquidity premium on the first day of change (see equation 9 and 10). The liquidity premium RMO has a significant positive impact on the short-term credit risk premium LMR in the short run (see equation 12). The causality is dual for liquidity and short- and long-term credit risk premia, respectively in the short run. The result shows that banks with higher default risk in the long run or short run should find it difficult to refinance. This implies a bad liquidity position, so the risk premium they pay to get refinanced should consist of higher liquidity premium than banks with lower credit risks. In turn, if a bank finds difficult to refinance e.g. it may take it longer time to find a willing lender or it may need to pay higher interest rate to obtain funding, the illiquidity could trigger a default on payment and this increases the probability of default.

Since there is no cointegration relation between LMR and CDS, we cannot obtain a long run relationship between variables during the crisis pre-QE period.

Table 5.8b Liquidity and Credit Risk before the Intervention – US

	Panel A		Panel B	
	ARDL			
	Eqn 9	Eqn 10	Eqn 11	Eqn 12
Variables	**RMO**	**RMO**	**ΔCDS**	**ΔLMR**
RMO_{t-1}	1.089***	0.640***	0.121***	0.012***
	[9.39]	[5.29]	[3.32]	[9.83]
RMO_{t-2}	-0.123	0.157	-0.034	-0.002
	[-1.05]	[1.33]	[-0.95]	[-1.40]
ΔLMR_{t-1}	20.682**			0.247**
	[2.00]			[2.11]
ΔLMR_{t-2}	-3.465			-0.021
	[-1.11]			[-0.48]
ΔCDS_{t-1}		0.284**	0.132	
		[2.35]	[1.69]	
ΔCDS_{t-2}		-0.259	-0.126**	
		[-1.14]	[-2.20]	
Adj-R^2	0.92	0.56	0.06	0.83
Durbin-Watson	2.02	1.97	2.00	2.04

All equations are ARDL (2, 2).

	ECM		ARDL ECM	
	Eqn 13	Eqn 14	Eqn 15	Eqn 16
Variables	**ΔLMR**	**ΔCDS**	**ΔLMR**	**ΔCDS**
LMR_{t-1}	-0.053	-0.813	-0.042	-0.709
	[-1.52]	[-0.73]	[-1.37]	[-0.63]
CDS_{t-1}	0.001	-0.014	0.001	-0.017
	[2.56]	[-0.96]	[1.71]	[-1.14]
RMO_{t-1}			0.005**	0.038
			[2.66]	[0.57]
RMO_{t-2}			-0.003	-0.008
			[-1.35]	[-0.12]
Adj-R^2	0.10	0.09	0.16	0.09
Durbin-Watson	1.99	2.02	2.04	2.01

No. of observations 337

All equations include an intercept and short-run dynamics up to lag two. HAC adjusted t-statistics are reported in square bracket. For ECM-ARDL, only the coefficients of the error correction terms with *t*-values in squared brackets are reported. The superscript *, ** and *** indicate significance of single-equation ECM test at 10%, 5% and 1% level respectively.

Liquidity and credit risks during QE

Looking at the QE period[65], our aims are 1) to see how the relationships between the spreads changed during QE operations; 2) to see whether the QE measure, Ratio, narrowed any of the spreads as suggested by the correlation statistics; 3) to see whether Ratio changed the relationship between credit risks and liquidity premia.

Moreover, we include another two variables in this sub-section, Ratio and Trend. Ratio variable is used as the proxy for the QE operations. As noted in Table 5.2, the Ratio variable for the UK and the US samples, respectively, is defined as the accumulated amount of purchase of QE with respect to the total bank assets. And, the Ratio variable for the EMU sample, ~~it~~ is calculated as the amount of liquidity that had been provided under Open Market Operation (OMO) and Covered Bond Purchase Programme (CBPP) with respect to total banks assets. The way that we construct the Ratio allows us to say by how much percentage liquidity to credit risk change in response to a one percent change in the Ratio. In the UK and the US, the purchases of assets through QE have been kept on central banks' balance sheets, respectively, so that when accumulate the amount of QE we create a trend. Therefore, we include the variable Trend in the UK and US samples, respectively. In the EMU sample, the ECB run LTROs that are longer-term refinancing operations, so it doesn't have the accumulated effect because the liquidity provided under LTROs is recycled when the repurchase agreements mature and is repaid. Therefore, we exclude variable Trend from the EMU sample.

The UK Sample

In the UK sample, the estimation followed the same procedure as in the crisis pre-QE-crisis. Due to the different methodology in the two samples in this period,

[65] Precisely, this period is post-Lehman Brother period in the EMU because ECB stepped into the market more determined than in the previous period. QE is a phase to denote intervention period in the two samples in general.

the results were reported in separate tables and begin with the UK sample. Equations 17 to 20 in Table 5.9 represent the relationship between credit risk and liquidity premia during QE period in the UK. By contrast to the pre-QE period, the coefficients of error correction terms on LMR in equation 18 and equation 20 show significance at 10% and 5% level of confidence. This indicates the reversed causality from credit risks to liquidity premia in the period. The long-run relationship derived from equation 18 in Table 5.9 is

$$\ldots 41)\ LMR = \underset{(0.019)}{0.047}/\underset{(0.004)}{0.013}\, RMO = 3.6154\, RMO$$

The increased value of coefficient on RMO in Equation 41) compared with the coefficient on LMR in Equation 37) reflects the augmented dependency between the two spreads in addition to the reversed causality. The long-run relationship derived from equation 20 in Table 5.9 does not change the causality but the reduced coefficient on RMO tells that the impact of RMO on LMR is taken up by the long-term credit risk measure, CDS.

Equations 21 to 28 in Table 5.10 estimate the effect of QE on narrowing and/or changing the credit and liquidity components in the interbank market. The coefficient on Ratio in equation 21 indicates that the interventions reduce the liquidity spread by 8.4 basis points[66] for Gilt purchase equivalent to one percentage point of banks' asset value. The insignificance of coefficients in equation 22 suggests that the operation of QE did not have any direct effect on short-term credit risk premium. That is, if QE reduced the spread of LIBOR and OIS, it was done through reducing liquidity premia. Moreover, the causality between liquidity premia and credit risks as in equation 18 and 20 in Table 5.9 indicates the reduction of liquidity premia would pass to credit risk premia with

[66] The figure is calculated as $\frac{0.958}{0.114} = 8.4$.

a time lag of a day.

Table 5.9 Liquidity and Credit Risk Premia during the Period of QE – UK

	Panel A		Panel B	
	Eqn 17	Eqn 18	Eqn 19	Eqn 20
Variables	**ΔRMO**	**ΔLMR**	**ΔRMO**	**ΔLMR**
RMO_{t-1}	-0.039	0.047	-0.034	0.050
	[-1.52]	[2.50]	[-1.33]	[2.59]
LMR_{t-1}	0.002	-0.013**	0.002	-0.015*
	[0.36]	[-3.46]	[-0.29]	[-3.47]
CDS_{t-1}			0.003	0.002
			[1.13]	[0.82]
Adj-R^2	0.11	0.38	0.12	0.37
Durbin-Watson	2.22	2.01	2.02	2.02
No. of Observation 332				

All equations include an intercept and short-run dynamics up to lag two. The coefficients of the error correction terms are reported with *t*-values in square brackets. The superscript * shows significance of Banerjee *et al* (1998, Table 1) at 5% and ** shows significance at 10%.

Moving to equation 23 and 24 in Table 5.10, the interesting finding is that the asset purchase programme of the BoE does not respond to a change of liquidity component but to the credit risk component (because the coefficient on error correction term is not significant in equation 23 but it is significant at 1% level in equation 24). Together with the finding above, it might imply that the fear of BoE seems to be the increased credit risk that was induced by the market illiquidity, which in turn resulted from the uncertainty of asset valuation. But, the direct action that BoE could take was to provide liquidity as the announced target of QE, so the interesting chain of effect was formed.

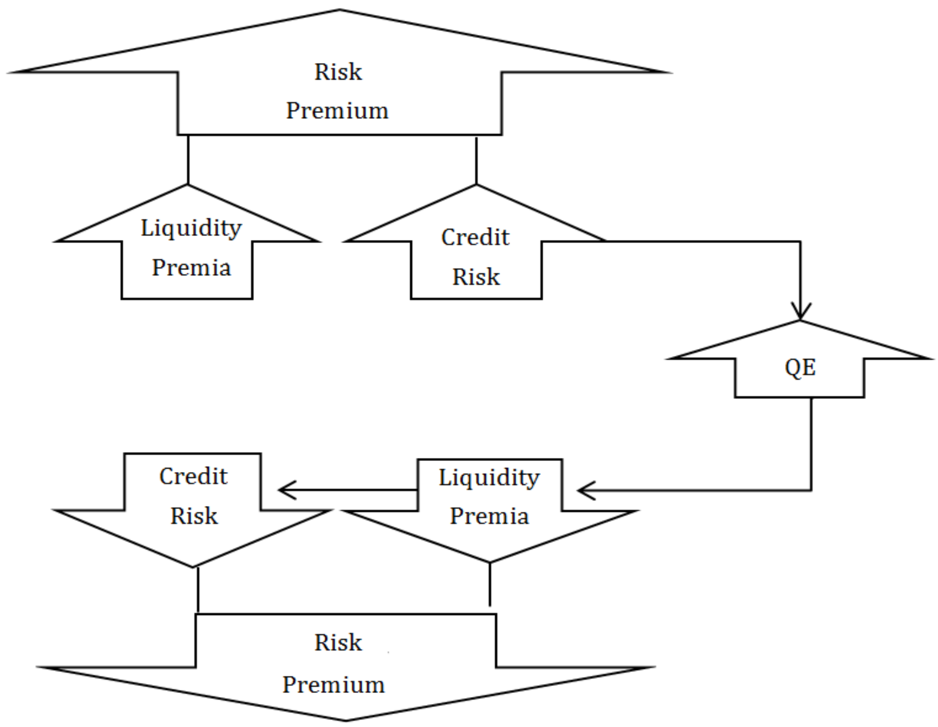
Table 5.10 How the QE Lowers Liquidity and Credit Risk Premia – UK

	Panel A				Panel B			
Variables	Eqn 21 **ΔRMO**	Eqn 22 **ΔLMR**	Eqn 23 **ΔRatio**	Eqn 24 **ΔRatio**	Eqn 25 **ΔRMO**	Eqn 26 **ΔLMR**	Eqn 27 **ΔRatio**	Eqn 28 **ΔRatio**
RMO_{t-1}	-0.114**		-0.0001		-0.107*		-0.0001	
	[-3.88]		[-0.27]		[-3.73]		[-0.34]	
LMR_{t-1}		-0.009		-0.0006		-0.009		-0.0006
		[-0.91]		[-5.01]		[-0.93]		[-4.73]
$Ratio_{t-1}$	-0.958	-0.324	-0.0010	-.0250***	-0.981	-0.389	-0.0019	-0.0228*
	[-3.10]	[-0.70]	[0.28]	[-4.39]	[-1.97]	[-0.76]	[-0.34]	[-3.64]
Trend	0.002	0.003	-.00009	-.00003	0.003	0.004	-.00007	-.00004
	[1.22]	[1.61]	[-4.06]	[-1.10]	[0.95]	[1.39]	[-2.01]	[-1.16]
CDS_{t-1}					-0.001	-0.001	-.00003	.00002
					[-0.28]	[-0.26]	[-0.51]	[0.40]
Adj-R^2	0.06	0.16	0.23	0.25	0.06	0.16	0.23	0.27
D-W	2.02	2.02	2.01	2.00	2.02	2.03	2.01	2.01
No. of Observation 332								

All equations include an intercept and short-run dynamics up to lag two. Only the coefficients of the error correction terms with *t*-values in squared brackets are reported. The superscript *, ** and *** indicate significance of single-equation ECM test at 10%, 5% and 1% level respectively.

Furthermore, the significance of the relevant coefficients of the error correction terms drops to the 10% level when estimations include CDS as in Panel B in Table 5.10. The estimated coefficients and associated *t*-statistics of CDS are small although inclusion of CDS as a regressor does not alter much the other coefficients. Thus the drop in significance level is more likely due to addition of an irrelevant variable, rather than vital information conveyed by CDS. This is an important issue, since CDS is frequently used in the literature as a measure of credit risk in the decomposition of the LIBOR-OIS spread. Essentially, it is the narrowing of the liquidity spread that reduces the credit spread in the long run and CDS does not play any significant role in the process. Also, here, it is the central bank's intervention rather than CDS that triggers the fall in the liquidity spread. Furthermore, equation 22 indicates that LMR and CDS are driven by different stochastic trends and cannot be exchanged against each other in the determination of the risk premia. To sum up, decomposing the LIBOR-OIS spread into its credit risk component and approximating the latter with CDS may be inappropriate, particularly during the period with central bank intervention.

Figure 5.11 The Likely Chain of Causality between Variables during QE



So far we discussed the estimation results from UK sample. The next sub-section shows the estimation results from the EMU sample. Since the intervention measure in the EMU sample is an I(0) variable, the Banerjee single equation ECM model cannot be applied when we estimate how the ECB's intervention changed the relationship between liquidity and credit components. Therefore, firstly, the Johansen cointegrating test is used to find the possible cointegrating relation between I(1) variable. Secondly, we run an ARDL ECM with HAC-adjusted error inclusive intervention measure. Alternatively, Ratio is included as a variable outside the cointegration space when estimating the VECM that is constructed by

EMR and RMO and testing for cointegration because the Johansen cointegration test suggests that there is one cointegrating relation existing between the spreads. Moreover, An ARDL ECM is applied when testing the relationship between credit and liquidity premia.

Table 5.12 Critical Values of the t-ratio Single-equation ECM Test

	Size			
T	0.01	0.05	0.10	0.25
25	- 4.12	- 3.35	- 2.95	- 2.36
50	- 3.94	- 3.28	- 2.93	- 2.38
100	- 3.92	- 3.27	- 2.94	- 2.40
500	- 3.82	- 3.23	- 2.90	- 2.40
∞	- 3.78	- 3.19	- 2.89	- 2.41

With constant and one independent variable

Source: adapted from Banerjee et al (1998), p 276

The EMU Sample

The unit root tests in the EMU sample suggest that Ratio is stationary i.e. I(0) variable whereas others are I(1) variables. Therefore, firstly, the estimation considered finding a cointegrating vector between credit risks and liquidity premia using the Johansen approach. Secondly, we ran an ECM-ARDL estimation including the Ratio variable if a cointegrating vector found in the first procedure.

The relationship between EMR and RMO during the QE period is shown in Table 5.13. Unlike the pre-QE-crisis period, the relationship between credit risks and liquidity premia became positive and the causality transits from credit risk to liquidity premia. As suggested by equation 29 in Table 5.13, the long-run coefficient on EMR is 0.006. The interesting finding is from equation 31 when we include CDS into the regression. The error correction term is still significant at 5% level supporting the conclusion from equation 29. Meanwhile, the coefficient on CDS is also significant at 1% level and the value is greater than the coefficient on EMR. The long-run equation is obtained as

$$\ldots 42)\ RMO = 0.004/0.253\ EMR + 0.024/0.253\ CDS$$

$$(0.003)\ (0.055) \qquad (0.007)\ (0.055)$$

Table 5.13 Liquidity an Credit Risk during the Period of QE – EMU Sample

	Panel A		**Panel B**	
	Eqn 29	Eqn 30	Eqn 31	Eqn 32
Variables	**ΔRMO**	**ΔEMR**	**ΔRMO**	**ΔEMR**
RMO_{t-1}	-0.149*	0.097	-0.253**	0.128
	[-3.44]	[2.71]	[-4.56]	[2.85]
EMR_{t-1}	0.006	-0.006	0.004	-0.006
	[1.91]	[-2.33]	[1.33]	[-2.38]
CDS_{t-1}			0.024*	-0.004
			[3.37]	[-0.79]
Adj-R^2	0.33	0.54	0.35	0.57
Durbin-Watson	2.08	2.09	2.04	2.09
No. of observations 428				

All equations include an intercept and short-run dynamics up to lag two. The coefficients of the error correction terms are reported with *t*-values in square brackets. The superscript * shows significance of Banerjee *et al* (1998, Table 1) at 5% and ** shows significance at 1%.

This result shows that increases on both credit risks can drive up liquidity premia but long-term credit risk CDS has significant and larger influence. The main driver of the rise in the EMU interbank rate was the large long-term credit risk.

Table 5.14 How the Intervention of ECB Lowers Liquidity and Credit Risks

	Panel A		Panel B	
	Eqn 33	Eqn 34	Eqn 35	Eqn 36
Variables	**ΔRMO**	**ΔEMR**	**ΔRMO**	**ΔEMR**
RMO_{t-1}	-0.253***	0.033	-0.337**	0.075
	[-3.97]	[0.71]	[-3.61]	[1.54]
EMR_{t-1}	0.012	-0.003	0.010	-0.003
	[2.75]	[-0.59]	[2.41]	[-1.02]
$Ratio_{t-1}$	-0.175**	-0.105	-0.165**	-0.095
	[-3.42]	[-1.78]	[-3.42]	[-2.04]
$Ratio_{t-2}$	-0.082	-0.036	-0.075	-0.034
	[1.70]	[-0.96]	[-1.57]	[-0.72]
CDS_{t-1}			0.021	-0.005
			[2.15]	[-0.96]
Adj-R^2	0.36	0.54	0.37	0.58
D-W	2.07	2.10	2.04	2.09
No. of observations 428				

All equations include an intercept and short-run dynamics up to lag two. The coefficients of the error correction terms are reported with HAC adjusted *t*-values in square brackets. The superscripts *, ** and *** indicate significance of single-equation ECM test at 10%, 5% and 1% level respectively.

There is no obvious deterministic trend in the EMU sample, so we did not present the results that contain trend property. In equation 33, the ECB intervention measure, Ratio, significantly reduces liquidity premia by 69 basis points[67] with one-day lag for the total easing amount of OMO and CBPP to one percent of banks' asset value. On the second day, the effect weakens and becomes insignificant. In equation 35, a similar response is revealed but the amount of response is much smaller because of the inclusion of CDS as noticed a few times in the UK sample. The short-term credit risk premium does not error

[67] The sample of EMU is in percentage because it would be too small for RMO spreads to adapt basis point. The figure of response is calculated as $\frac{-0.175}{0.253} = 0.69$ in unit of percentage which is equivalent to 69 basis points.

correct and the Ratio does not reduce the short-term credit risk premium significantly.

Therefore, the results for the EMU so far suggest that the ECB's OMO and CBPP operations reduced the liquidity premium drastically and significantly, but there is no established long-run causality from liquidity to the credit component. This may well explain the stubborn EMR spread particularly (the spread of CDS was also elevated but it represents the long-run default risk so it is expected to reflect policies with short-term focus to a lesser degree) since the onset of crisis in the EMU. The policy of the ECB mainly focuses on liquidity aspects so the effect on credit risk should be quite limited if it cannot be passed from the liquidity component. The risk of default may be from two causes, the liquidity issue and other bank-specific factors[68]. If the increased EMR and CDS spreads have been mainly led by illiquidity, we should observe a positive causality from liquidity to credit component, but we do not, and the measures of credit risk should fall back to their pre-crisis level as RMO did, but they do not. This likely implies that the increased credit risk in the EMU may not be mainly driven by the liquidity condition; instead, capital adequacy or other factors that related to banks' financial healthiness may be considered and be worth investigating. Mortimer-Lee (2012) suspects that the ECB might intend to help banks cover up a more chronic shortage of capital with liquidity and make an easier bank capital-adjustment process.

Moreover, if the spread between Repo and OIS is reduced, leaving Euribor rate unchanged, this will widen the spread between Euribor and Repo. As we saw in Figure 5.4b, EMR shifted downwards during the intervention period although it remained elevated compared with RMO. This possibly implies that the ECB's

[68] Such as capital adequacy and maturity mismatch.

intervention ultimately reduced Euribor more quickly than it reduced Repo rate and the reduction was largely contributed by the decrease of liquidity premia.

Table 5.15. ECB's Response to Change of Credit and Liquidity Risk

Variables	Eqn 37 **Ratio**	Eqn 38 **Ratio**	Eqn 39 **Ratio**
DRMO	-0.054		
	[-0.88]		
$DRMO_{t-1}$	0.038		
	[1.00]		
$DRMO_{t-2}$	0.036		
	[0.77]		
DEMR		0.075	
		[2.15]	
$DEMR_{t-1}$		0.004	
		[0.12]	
$DEMR_{t-2}$		-0.009	
		[-0.17]	
$Ratio_{t-1}$	0.392	0.402	0.395
	[5.64]	[5.66]	[5.54]
$Ratio_{t-2}$	0.262	0.265	0.253
	[7.61]	[7.46]	[6.95]
$Ratio_{t-3}$	0.139	0.152	0.142
	[2.38]	[3.07]	[2.47]
DCDS			0.007
			[0.48]
$DCDS_{t-1}$			0.020
			[1.32]
$DCDS_{t-2}$			-0.010
			[-0.78]
Adj-R^2	0.49	0.49	0.49
Durbin-Watson	2.02	2.03	2.03
No. of observations 428			

All equations are ARDL (3, 2) model. HAC adjusted *t*-values in square brackets. Coefficients on Ratio start to be insignificant since lag length 4.

Since the variable Ratio is stationary, to find out how ECB's monetary policy responded to change of credit risk and liquidity component, we use the Autoregressive Distributed Lag model (ARDL). The disadvantage is that there is no long-run relationship available for our case. The results are reported in Table 5.15. There is weak evidence (see equation 38 in Table 5.15) that the ECB reacted to changes in the short-term credit risk premium. Ratio is mostly an autoregressive process. The amount of OMO and CBPP in relation to total banks' assets influences ECB's response for up to 3 days.

Figure 5.16 Summary of Result during the QE Period – EMU

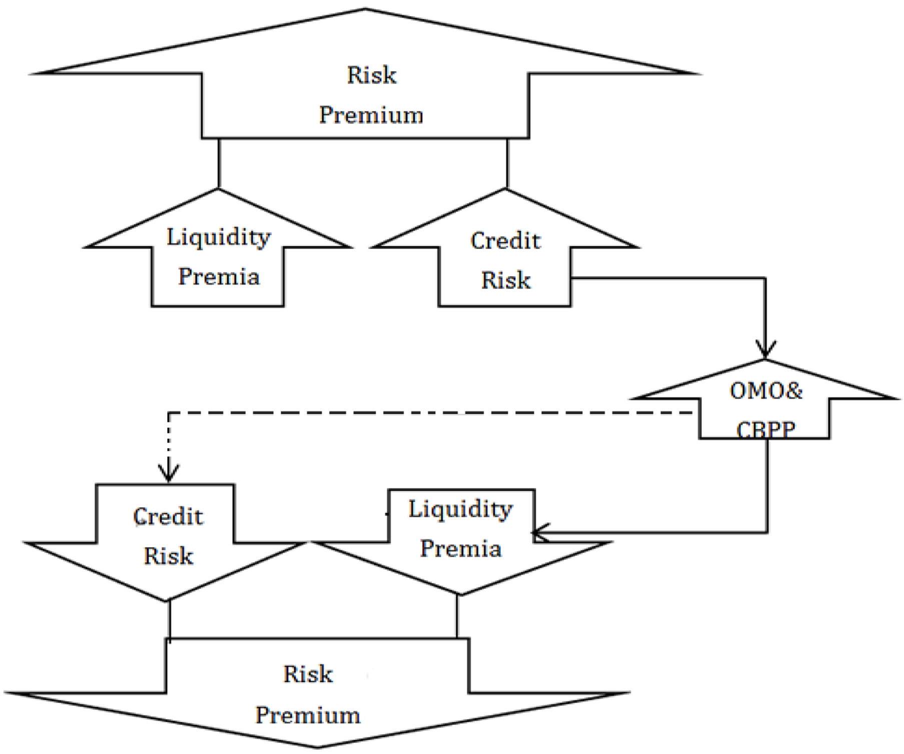


Figure 5.16 summarizes the finding of the EMU sample during the QE period. The increased risk premium resulted from a rise in credit risk and liquidity premia. The increased credit risk caused he ECB's response – applying unconventional monetary operation. Those operations directly reduced liquidity premia leaving credit risk spreads elevated. There is a possible weak link between liquidity

component and credit risk because of the character of the instruments used in the measures, so the spread of EMR showed a downward shift during the QE period.

The US Sample

Since all variables are I(1) variables, we used the Banerjee single equation ECM to test for cointegration and long-run causality. The relationships between the liquidity premium RMO and the credit risk premia LMR and CDS, respectively are shown in Table 5.17.

During the QE period, both RMO and CDS error correct in the long run. One cointegration relationship is captured – the liquidity premium RMO is cointegrated with the long-term credit risk premium CDS and the causality is dual (see equation 42 and 44 in Table 5.17). The short-term credit risk premium LMR does not error correct and there is no causality between LMR and the other variables, which is a remarkable difference compared with the crisis pre-QE period. This confirms that both credit risk and liquidity premia have contributed to the increase of the risk premium in the money market because of the dual causality, but the long-term credit risk premium has had significant impact compared with the short-term credit risk premium. The long run relationship can be derived from equation 42 as

$$0 = -0.259RMO + 0.40CDS$$

$$\ldots 43)\ RMO = 0.40/0.259\,CDS = 1.544\,CDS$$

$$(0.132)\ (0.079)$$

Equation 43 tells us that CDS has a significant positive impact on RMO in the long run. One basis point increase of (a bank) CDS premium is likely to push up the liquidity premium for borrowing for the bank by 1.5 basis points.

The long-run relationship from equation 44 can be written as

$$0 = 0.323RMO - 0.073CDS$$

$$\ldots 44)\ CDS = \ 0.323/0.073\, RMO = \ 4.425RMO$$

$$(0.100)\ (0.22)$$

Table 5.17 Liquidity and Credit Risk Premia during the Period of QE – US

	Panel A				**Panel B**		
	Eqn 40	Eqn 41	Eqn 42	Eqn 43	Eqn 44	Eqn 45	Eqn 46
Variables	**ΔRMO**	**ΔLMR**	**ΔRMO**	**ΔRMO**	**ΔCDS**	**ΔCDS**	**ΔCDS**
RMO_{t-1}	0.036	0.001	-0.259**	-0.023	0.323**		0.278
	[0.87]	[2.19]	[-3.27]	[-0.59]	[3.24]		[2.29]
LMR_{t-1}	-1.064	-0.017		-0.493		3.059*	1.529
	[-1.75]	[-2.10]		[-0.63]		[2.98]	[1.28]
CDS_{t-1}			0.040*	0.004	-0.073**	-0.062	-0.085**
			[3.04]	[0.53]	[-3.37]	[-2.76]	[-3.55]
Adj-R^2	0.73	0.76	0.12	0.71	0.08	0.06	0.09
D-W	2.09	1.95	1.98	1.87	2.00	2.00	2.03
No. of Observation 350							

All equations include an intercept and short-run dynamics up to lag two. Only the coefficients of the error correction terms with HAC adjusted *t*-values in squared brackets are reported. The superscript *, ** and *** indicate significance of single-equation ECM test at 10%, 5% and 1% level respectively.

Equation 44 reveals that the impact from RMO to CDS in the long run is bigger (i.e. a 4.3 basis point increase on CDS with every basis point increase on RMO) than the influence from CDS to RMO as shown in the Equation 43). The dual causality between CDS and RMO magnifies the impact on the risk premium (LIBOR – OIS). One basis point increase on CDS pushes up RMO by 1.5 basis points and the 1.5 basis point increase on RMO in turn increases CDS by another 4.43 basis points.

Moreover, with the inclusion of LMR in equation 43, RMO does not error correct and none of the coefficients are significant. In equation 46, although CDS still error corrects, the coefficients on RMO and LMR are insignificant. This likely tells that the short-term credit risk does not play an important role in the US money market regarding the increased risk premium in the crisis.

Table 5.18 shows the ECM result with the variable 'Ratio'. Panel A and Panel B represent how the inclusion of the intervention variable Ratio changes the relationship between liquidity and credit risks premia. Panel C shows how the variable Ratio responds to the changes of RMO, LMR and CDS.

Equations in Panel A and Panel B again show that the short-term credit risk premium LMR does not error correct in the long run and it does not cointegrate with other variables. The liquidity premium RMO error corrects and has a long run relationship with the Ratio variable. The long-run relation can be derived from equation 47 as

$$0 = -0.348\,RMO - 1.346\,Ratio$$

$$\ldots 45)\; RMO = -1.346/0.348\,Ratio = -3.868\,Ratio$$

$$(0.441)\;(0.068)$$

The Ratio has reduced the liquidity premium RMO significantly in the long run showing the effectiveness of the Fed's intervention to reduce borrowing costs. In equation 50, RMO still significantly error corrects, but the effect of Ratio and CDS become insignificant.

Table 5.18 How QE Changes Liquidity and Credit Risk Premia – US

	Panel A				Panel B		
	Eqn 47	Eqn 48	Eqn 49	Eqn 50	Eqn 51	Eqn 52	Eqn 53
Variables	**ΔRMO**	**ΔLMR**	**ΔRMO**	**ΔRMO**	**ΔCDS**	**ΔCDS**	**ΔCDS**
RMO_{t-1}	-0.348***		-0.050	-0.370***			0.235
	[-5.15]		[-1.69]	[-5.19]			[2.07]
LMR_{t-1}		-0.042	-1.465			0.640	
		[-1.32]	[-1.12]			[0.27]	
$Ratio_{t-1}$	-1.346*	-0.012	-0.651	-0.840	-2.742**	-2.563	-2.235
	[-3.05]	[-1.02]	[-1.31]	[-2.14]	[-3.28]	[-2.27]	[-2.68]
Trend	0.002	-0.000	-0.000	-0.004	0.008	0.009	0.011
	[-0.387]	[-0.97]	[-0.04]	[-1.02]	[1.33]	[1.41]	[1.70]
CDS_{t-1}				0.019	-0.092**	-0.091**	-0.104**
				[1.42]	[-3.31]	[-3.28]	[-3.65]
Adj-R^2	0.15	0.08	0.71	0.16	0.07	0.06	0.08
D-W	1.99	2.05	1.87	2.00	2.00	2.00	2.00
	Panel C				**Panel D**		
	Eqn 54	Eqn 55	Eqn 56	Eqn 57	Eqn 58	Eqn 59	Eqn 60
Variables	**ΔRatio**	**ΔRatio**	**ΔRatio**	**ΔRatio**	**ΔRMO**	**ΔLMR**	**ΔCDS**
RMO_{t-1}	-0.0000			-0.000	-0.048	0.001	0.266
	[-1.05]			[-1.05]	[-1.33]	[2.23]	[2.26]
LMR_{t-1}		-0.003		-0.003	-1.527	-0.013	0.751
		[-2.14]		[-2.04]	[-1.16]	[-1.48]	[0.38]
$Ratio_{t-1}$	-0.0004	-0.001	-0.0002	-0.001	-0.717	0.002	-2.005
	[-0.72]	[-1.42]	[-0.29]	[-1.20]	[-1.51]	[1.66]	[-2.00]
Trend	0.0000	-0.000	-0.000	-0.000	0.0001	-0.000	0.012
	[-0.25]	[-1.02]	[-0.18]	[-1.17]	[0.11]	[-0.22]	[1.69]
CDS_{t-1}			0.0000	0.000	-0.002	-0.000	-0.107**
			[0.03]	[0.28]	[-0.20]	[-0.04]	[-3.70]
Adj-R^2	0.88	0.88	0.88	0.88	0.71	0.76	0.08
D-W	2.00	2.00	2.01	2.01	1.87	1.94	2.02

No. of Observations 350

All equations include an intercept and short-run dynamics up to lag two. Only the coefficients of the error correction terms with *t*-values in squared brackets are reported. The superscript *, ** and *** indicate significance of single-equation ECM test at 10%, 5% and 1% level respectively.

In equation 51, the result shows the significant error correction of CDS and the long-run relationship between CDS and Ratio. The long-run relation equation is derived as

$$\ldots 46)\ CDS = -2.742/0.092\, Ratio = -29.804\, Ratio$$
$$(0.836)\ (0.028)$$

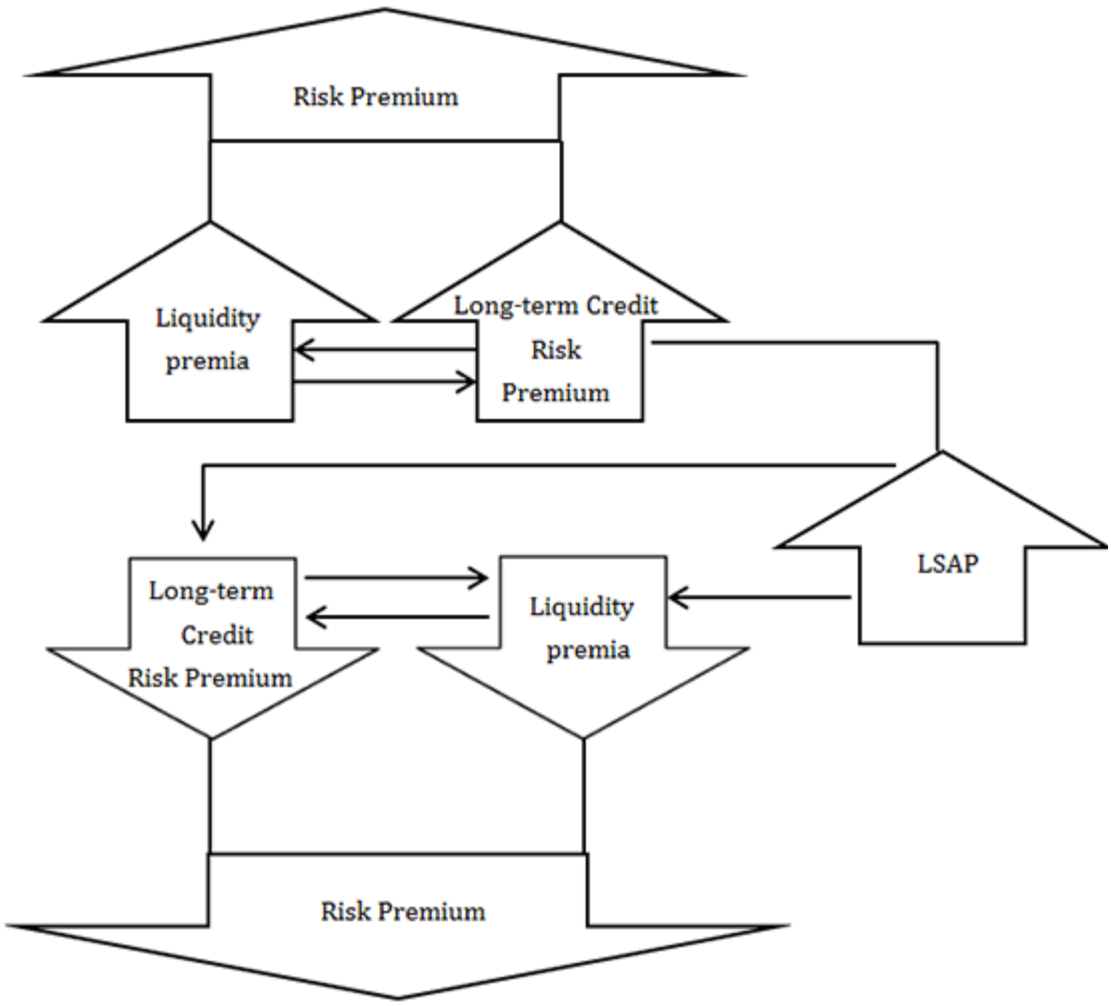
Compared with Equation 45, the effect of Ratio on reducing CDS is much bigger than reducing RMO. Together with Equation 44 they may imply that CDS, the long-term credit risk premium, is the main driver that widened the risk premium in the US money market. Due to the causality from liquidity premium to CDS, the Fed's LSAP has reduced the long-term credit risk premium dramatically and significantly.

Moving to Panel C in Table 5.18, the variable Ratio does not error correct and does not respond to changes in other variables. Therefore, the diagram in Figure 5.19 summarizes the result in the US sample during the period of QE.

To summarize the US sample, prior to the intervention of QE, RMO is stationary and LMR and CDS are nonstationary. In the short-run dynamic relation, both long-term credit risk and liquidity risk premia have contributed to the increased risk premium in the US money market and they have dual causality. Since the onset of LSAP, both liquidity and long-term credit risk premia have decreased. The operation of LSAP has significantly reduced the long-term credit risk premium, but there is no causality from credit or liquidity risk premia to Ratio i.e. the change of credit and liquidity risk premia do not cause changes in the Ratio variable. The dual causality still holds between long-term credit and liquidity risk premia. Moreover, there is no significant evidence confirming the relationship between short-term credit risk and liquidity premia and Ratio does not significantly reduce the short-term credit risk premium. This is different from our findings for the EMU.

In the next subsection, the VECM results are reported. The VECM is used to address the potential problems that might be produced by endogeneity. The discussion is organized in relation to the market sample to provide a comprehensive summary of what the estimations have found so far

Figure 5.19 Summary of Results during the QE Period – US



5.2.2 VECM Results

The single equation ECM analysis in the previous section ignored the issue of endogeneity and assumed that the critical values provided by Banerjee *et al.* (1998) would hold despite presence of heteroscedasticity in financial time series. This section therefore estimates the VECM described by Equation 36 in Chapter 4 using OLS and reports the *t*-statistics that are consistent with the presence of heteroscedasticity and autocorrelation. Lag of differences up to 2 is used for the system as a whole; additional lags are added to individual variables until their residuals pass the Ljung-Box test for serial correlation. The required cointegrating vectors (E_{t-1}) are obtained using Engle and Granger (1987) procedure.

The UK Sample

Our discussion starts with the pre-QE-crisis period. Table 5.20 reports the estimation results for the VECM of liquidity and credit risks. *E1* is the residual obtained by regressing RMO on a constant and LMR. In addition to the HAC *t*-statistics, White's heteroscedasticity consistent *t*-statistics are also reported.

The HAC *t*-statistics find no error correction for either component of the LIBOR spread. However, Johansen's trace and max-eigenvalue tests indicate the presence of a cointegrating vector and hence there must be error correction at work. White's *t*-statistic suggests significant error correction for RMO. As Ljung-Box test indicate absence of serial correlation in the residuals, we take this as evidence for the claim that credit risk is the long run forcing variable and RMO error corrects in response to any disequilibrium in the system.

Moving to the QE period, with inclusion of Ratio, there are three long-run relationships found by ECM analysis:

$$\ldots 47)\ RMO_t = a_0 + a_1 Ratio_t + a_2 t + E1_t$$
$$\ldots 48)\ LMR_t = b_0 + b_1 RMO_t + E2_t$$
$$\ldots 49)\ Ratio_t = c_0 + c_1 LMR_t + c_2 t + E3_t$$

where Equations 47 and 49 were obtained when including Ratio, and Equation 48 was got without Ratio. The residuals Ei are obtained as mentioned in the endnote of Table 5.20. So, in terms of VECM, the following error correction term can be formed:

$$\ldots 50)\quad \alpha\beta' \begin{bmatrix} RMO_{t-1} \\ LMR_{t-1} \\ Ratio_{t-1} \end{bmatrix} = \begin{bmatrix} -d_1 & 0 & 0 \\ 0 & -d_2 & 0 \\ 0 & 0 & -d_3 \end{bmatrix} \begin{bmatrix} 1 & 0 & -a_1 \\ -b_1 & 1 & 0 \\ 0 & -c_1 & 1 \end{bmatrix} \begin{bmatrix} RMO_{t-1} \\ LMR_{t-1} \\ Ratio_{t-1} \end{bmatrix}.$$

Table 5.20 The relationship between liquidity and credit risk before QE

	Eqn 61	Eqn 62
	ΔRMO	ΔLMR
$E1_{t-1}$	-0.062	0.025
	(-2.15*)	(0.72)
	[-1.47]	[0.61]
Adj-R^2	0.33	0.05
Durbin-Watson	2.03	2.00
Ljung-Box test:		
Q(10)	7.75	6.83
p-value	0.65	0.74

White's heteroscedasticity consistent and HAC t-statistics are reported in round and square brackets respectively. The residual E1 is obtained from the static OLS regression: RMO = –1.903 + 0.124LMR + E1. The lag length of the VECM is 2, with additional lag up to 3 for ΔRMO in Eqn 65.

In general α may not be diagonal; it is simply a description of the error corrections established by the single equation ECM analyses. It is not difficult to see that in Equation 50 there are two cointegrating vectors, which is confirmed by Johansen's trace and max-eigenvalue tests. By virtue of the fact that any row of β' can be obtained from linear combination of the other two rows, we have $a_1 b_1 c_1$ = 1. Based on the coefficients obtained from the single equation ECM analyses (eqn 18 in Table 5.9 and Eqn 21 and 24 in Table 5.10), we have $a_1 b_1 c_1$= 0.73[69]. For the VECM as described in Equation 36 in Chapter 4, *E1* and *E3* are used because the correlation between them is low, at -0.08.[70] By virtue of Equation 50), the error correction term in Equation 37 takes the form:

$$\ldots 51) \qquad AE_{t-1} = \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \\ \alpha_{31} & \alpha_{32} \end{bmatrix} \begin{bmatrix} E1_{t-1} \\ E3_{t-1} \end{bmatrix} = \begin{bmatrix} -d_1 & 0 \\ \alpha_{21} & 0 \\ 0 & -d_3 \end{bmatrix} \begin{bmatrix} E1_{t-1} \\ E3_{t-1} \end{bmatrix}.$$

A large and positive $E1_{t-1}$ implies a high RMO value at time *t-1*, which in turn implies LMR would tend to error correct upwards in the next time period. This implies a positive α_{21}. The estimated VECMs are reported in Table 5.21. The results broadly confirm the above analysis culminated in Equation 51, and thus confirm the single equation ECM results.

To summarize both ECM and VECM findings in the UK, the relationship between liquidity and credit spreads depends crucially on the intervention of the central bank. Before the massive liquidity provision, credit risk was the main driver of the interbank spread. Angelini *et al.* (2010), who examined interbank spreads in the pre-intervention period and also found that credit risk drives the LIBOR spread, support our results. They attribute the role of credit risk as the main

[69] $a_1 = \frac{0.047}{0.013} = 3.62;\ b_1 = \frac{-0.958}{0.114} = -8.40;\ c_1 = \frac{-0.0006}{0.025} = -0.024$

[70] The other two correlations are -0.83 (between *E1* and *E2*) and -0.43 (between *E2* and *E3*).

driver of the interbank spread to the rise in risk aversion rather than the quantity of risk. Angelini *et al.* therefore support the claim made by Taylor and Williams (2008, 2009) that liquidity injections will be ineffective in reducing the interbank spread.

Table 5.21 The Effect of QE on Liquidity and Credit Risk Premia - UK

	Eqn 63	Eqn 64	Eqn 65
	ΔRMO	**ΔLMR**	**ΔRatio**
$E1_{t-1}$	-0.094	0.080	0.0002
	(-2.58)	(2.17)	(0.50)
$E3_{t-1}$	-0.763	-0.042	-0.016
	(-1.16)	(-0.14)	(-3.29)
Trend	0.000	0.002	-0.0000
	(0.19)	(1.99)	(-2.99)
Adj-R^2	0.08	0.39	0.58
D-W	2.03	2.03	1.99
Ljung-Box test:			
Q(10)	14.2	8.84	4.69
p-value	0.16	0.55	0.91

HAC t-statistics are reported brackets. The residuals E1 and E3 are obtained respectively from the static OLS regression: RMO = 0.166 – 8.635Ratio + 0.0215Trend + E1 and Ratio = –2.096 – 0.0189LMR + 0.00343Trend + E3. The lag length of the VECM is 2, with additional lags up to 6 and 11 for ΔLMR and ΔRatio in Eqn 68 respectively.

Since the intervention of the BoE, however, all spreads have been falling. Joyce et *al.* (2010) find that QE lowered gilt yields and suggest that its impact should also be felt across a range of assets. Contrary to the claim made by Angelini *et al.* and Taylor and Williams, we find this effect at the short end of the yield curve: central bank's asset purchases (*Ratio*) reduces the liquidity spread (RMO), which in turn lowers the credit spread (LMR).

The EMU Sample

In the EMU sample, we found that credit risks cause changes in liquidity component in all sub-period. Table 5.22 reports results obtained using VECM.

The Johansen cointegrating test suggests that there is one cointegrating relation exiting between pairs of variables. Moreover, the previous ECM result clearly shows that the long-run credit risk measure CDS explains liquidity variable RMO better than the short-run credit risk proxy, so equation 68 in Table 5.22 is also carried out. Both White's and HAC statistics find error correction for liquidity component (see equation 66 and equation 68), but EMR does not error correct indicating the causality is from EMR to RMO i.e. EMR explains RMO. Moreover, CDS does not error correct (tested using VECM, but result is not reported since it is just a prudent estimation) so RMO does not cause CDS in the long run either. The Ljung-Box test shows no serial correlation in the residuals. Therefore, both EMR and CDS force the increase of risk premium spread in the long run and RMO adjusts to deviation from equilibrium in the system.

Table 5.22 The Relationship between Liquidity and Credit Risks Prior to QE

	Eqn 66	Eqn 67	Eqn 68
	ΔRMO	ΔEMR	ΔRMO
$E4_{t-1}$	-0.083	0.073	
	(-2.05*)	(1.62)	
	[-1.94*]	[1.62]	
$E5_{t-1}$			-0.093
			(-2.27*)
			[-2.04*]
Adj-R^2	0.37	0.20	0.37
Durbin-Watson	2.06	1.98	2.06
Ljung-Box test:			
Q(10)	11.21	8.59	11.02
p-value	0.34	0.57	0.36

White's heteroscedasticity consistent and HAC t-statistics are reported in round and square brackets respectively. The residual E4 is obtained from the cointegrating vector regression: RMO = 0.015 – 0.019 EMR + E4. E5 is obtained from the static OLS: RMO = -0.010 + 0.019 CDS + E5. The lag length of the VECM is 2, with additional lag up to 5 for ΔRMO and ΔEMR. Superscript * indicates 5% significance level.

During the intervention period, apart from what we investigate in pre-intervention period, the interest is also in how the ECB's intervention would alter the relationship between credit and liquidity risks. The intervention measure Ratio is an I(0) variable as we have mentioned before, so based on the Johansen cointegrating results, Ratio is entered as a variable outside the cointegration space in the VECM.

Table 5.23 The Effect of ECB's Intervention on Liquidity and Credit Risk Premia

	Eqn 69	Eqn 70	Eqn 71	Eqn 72
	ΔRMO	ΔEMR	ΔRMO	ΔCDS
$E6_{t-1}$	-0.253	0.006		
	[-5.22]	[0.16]		
$E7_{t-1}$			-0.190	-0.144
			[-3.22]	[-0.90]
$Ratio_{t-1}$	-0.195	-0.127	-0.123	-0.208
	[-3.39]	[-2.65]	[-2.08]	[-1.29]
$Ratio_{t-2}$	-0.089	-0.046	0.009	-0.057
	[-1.51]	[-0.94]	[0.02]	[-0.33]
Adj-R^2	0.35	0.35	0.38	0.38
LM Test:				
$\chi^2(10)$	7.39	7.39	8.05	8.05
p-value	0.12	0.12	0.09	0.09

[] reports *t*-statistics. The long run relationship from VECM: E6 = RMO – 0.047 EMR + 0.005 and E7 = RMO – 0.084 CDS + 0.065. Residuals in all the equations, respectively, suffer heteroscedasticity.

The results in Table 5.23 suffer from heteroscedasticity, but they form the similar results as suggested by ARDL-ECM, which allowed HAC adjustment. In addition to the previous findings, equation 70 reveals that Ratio reduces EMR in the short run.

To summarize, credit risk, especially the long-run credit risk played a significant role in widening the risk premium spread through an increase of liquidity premia. The ECB's additional and unconventional liquidity provision under OMO together with CBPP (although the amount was relevant small) successfully reduced liquidity premia. The evidence is found that those provisions reduced short-term credit risk but only at slow and small amount because there is established causality from liquidity component to credit risk.

The US Sample

As noted previously, the liquidity risk premium variable RMO is an I(0) variable during the crisis period prior to QE in the US sample. This makes it difficult to obtain a long run relationship between liquidity and credit risk premia. Neither the Banerjee ECM nor ARDL ECM could find a cointegrating relation between the variables. However, the Johansen cointegration test suggests there is at least one cointegrating relation between LMR and CDS. Therefore, we run a VECM on LMR and CDS, and include RMO as an exogenous variable. The result is represented in Table 5.24.

Prior to the operation of LSAP, we find that there is no cointegration relation existing between LMR and CDS so we cannot obtain the long run relationship between variables in the single equation ECM test. In the VECM regression, equation 77 in Table 5.24 shows that LMR error corrects and is cointegrated with CDS with inclusion of RMO as an exogenous variable in the long run. The equation 78 shows that the causality runs from CDS to LMR. The long-run relationship derived from equation 77 can be written as

$$\ldots 52)\ LMR = 0.005\ CDS + 0.047\ RMO$$ [71]

[71] $0.005 = \frac{-0.043 \times -0.005}{0.043}$; $0.047 = \frac{0.005-0.003}{0.043}$

Table 5.24 Liquidity and Credit Risk Premia Prior to QE

	Eqn 77 ΔLMR	Eqn 78 ΔCDS
$E8_{t-1}$	-0.043**	-1.27
	[-2.48]	[-1.96]
RMO_{t-1}	0.005	0.063
	[3.57]	[1.14]
RMO_{t-2}	-0.003	-0.020
	[-1.85]	[-0.35]
Adj-R^2	0.13	0.06
LM Test:		
$\chi^2(4)$	6.73	6.73
***p*-value**	0.15	0.15

[] reports *t*-statistics. The long run relationship from VECM: E8 = LMR – 0.005 CDS – 0.768. Residuals in all the equations suffer heteroscedasticity.

Equation 52 tells us that both long-term credit risk and liquidity premia have a positive impact on the short-term credit risk premia, but the liquidity premium has bigger effect.

During the period of QE, The single equation ECM found two cointegrating relations, RMO and Ratio, and CDS and Ratio and the Johansen cointegration test also suggest the same. Moreover, the short-term credit risk premium LMR does not appear to have a relation with the liquidity premium RMO and long-term credit risk premium CDS. The Fed's LSAP proxy Ratio does not respond to changes in credit and liquidity risk premia. Since the VECM captures the cointegration between LMR and CDS for the period prior to the crisis, we therefore test three VECMs at this point, RMO and Ratio, CDS and Ratio and LMR and Ratio. The result is represented in Table 5.25.

Table 5.25 The Effect of QE on Liquidity and Credit Risk Premia – US

	Eqn 79 ΔRMO	Eqn 80 ΔRatio	Eqn 81 ΔCDS	Eqn 82 ΔRatio	Eqn 83 ΔLMR	Eqn 84 ΔRatio
$E9_{t-1}$	-0.347***	-0.000				
	[-7.68]	[-0.98]				
$E10_{t-1}$			-0.087**	-0.000		
			[-4.42]	[-0.10]		
$E11_{t-1}$					-0.040**	-0.002
					[-3.78]	[-1.48]
Adj-R^2	0.15	0.15	0.08	0.08	0.09	0.09
LM Test:						
$\chi^2(4)$	6.11	6.11	1.88	1.88	5.25	5.25
***p*-value**	[0.19]	[0.19]	0.76	0.76	0.26	0.26

[] reports *t*-statistics. The long run relationship from VECM: E9 = RMO + 4.353 Ratio – 17.281, E10 = CDS + 21.99 Ratio – 213.80 and E11 = LMR + 0.368 Ratio – 2.341. No heteroskedasticity on residuals from eqn 81 and eqn 82.

The VECM result in Table 5.25 confirms the previous findings. In addition, equation 83 finds that LMR error corrects and is cointegrated with Ratio in the long run. The residuals obtained suffer from heteroscedasticity, so the t-statistics may be over optimistic. The OLS VECM is also tested in order to be prudent and unfortunately, the t-statistic on the error term drops to -1.24 with HAC adjusted for heteroscedasiticy. Therefore, it is unlikely to establish a relationship between LMR and Ratio. Also, there is still no causality captured from credit and liquidity premia to Ratio i.e. changes on credit risks and liquidity premia are unlikely to cause changes in Ratio.

To conclude, prior to the operation of LSAP, both credit risks and liquidity premia have contributed to the increased risk premium because of the established causality between long-term credit risk and liquidity premia and short-term credit risk premium. Since the operation of LSAP, the causality between short-term credit risk and liquidity premia has gone. Also, there is little evidence for the relationship between short-term credit risk and other variables. It seems likely that the short-term credit risk premium becomes less important since the operation of LSAP. It is possible because given liquidity is readily available, banks with sound capital adequacy and asset structure are less likely to default in the short run and capital adequacy and asset composition are long-term measurements for banks' soundness. Moreover, the results show that Ratio has significantly reduced liquidity and long-term credit risk premia. This finding confirms that LSAP fulfills its intermediate purpose to reduce borrowing costs.

5.3 Comparison

This chapter investigates the relationship between liquidity and credit components in the risk premium spread and how the central banks' interventions alter the relationship in the UK, the EMU and the US, respectively. A similar econometrics approach is applied in each case with variations reflecting the features of variables in each sample. The results obtained are very comparable. Firstly, credit risk is found to be the main driver of the interbank spread before those liquidity provisions. The causality between liquidity and credit components proves to be from credit risk spread to liquidity premia in the crisis period except the causality was reversed during QE period without operations of QE in the UK. In the US, there is dual causality between long-term credit risk and liquidity premia. Moreover, long-term credit risk, CDS, showed significant influence on risk premia in the EMU and the US samples whereas CDS is likely to be an irrelevant variable in the UK.

Secondly, the interventions successfully reduced risk premia in the three samples. In the UK, the reduction of the credit risk premium depends on the causality from risk premia during the crisis QE period. In the EMU, one equation captured evidence that liquidity provision directly reduced short-term credit risk but only by a small amount. This finding is contrary to the claim made by Angelini *et al* and Taylor and Williams. In the US, the operation of LSAP has significantly reduced both liquidity and long-term credit risk premia. There is still no evidence for the effect of LSAP on short-term credit risk premium.

Finally, the BoE and the ECB responded to change in credit risks directly, especially short-term credit risk, but the response e.g. increased amount of liquidity provision only directly reduce liquidity premia not credit risk. Without an established causality between liquidity premia and credit risk premium, this leaves credit risk premia (both short and long-term) remaining elevated during the period in the EMU sample. In the US sample, the change of risk premia measures do not have an impact on the amount of LSAP purchase, which is as expected because the amount of monthly purchase has been set at the beginning of the programme.

Chapter 6 Summary and Conclusion

The sudden and persistent widening of LIBOR (EURIBOR) – OIS spreads at the beginning of the recent financial crisis broke the traditional interest-rate transmission mechanism of monetary policy, so central banks (the BoE, the ECB and the Fed) appeared to lose their power to influence market interest rates and, ultimately, their targets for inflation and GDP. Under the circumstances, the central banks resorted to unconventional monetary policy tools such as liquidity provisions and quantitative easing in the UK and the US, and longer-term refinancing operations and small-scale operations in the covered bond purchase programmes in the EMU since late 2007. We have pointed out that the ECB has limited ability to operate in the secondary market to purchase government bond primarily because it is a monetary union and the purchase of government bonds may induce moral hazard among certain member governments, so its main focus has been the restoration of the malfunctioning money market in the EMU by offering fixed-rate full allotment liquidity at longer-term e.g. twelve-month refinancing operations. In the UK and the US, after a series of liquidity provision to banking system, the BoE and the Fed started quantitative easing in early 2009 and late 2008, respectively. One of the advantages of quantitative easing compared with the traditional interest-rate regime is the different transmission mechanism. The operation of QE aims to bypass the money market, passing instead through portfolio rebalancing, liquidity and signal channels to intermediately influence asset prices and change total wealth and borrowing costs.

In the previous chapters, given the context, we have discussed three objectives of the research 1) the factors that drove up the money market risk premium spread; 2) the effectiveness of central banks' (the BoE, the ECB and the Fed) large-scale liquidity provisions in reducing the spread; 3) the changing relationship between liquidity and credit risk premia during the operation of the unconventional policies. As mentioned before, the intermediate target of quantitative easing is to change (more precisely, to reduce) the borrowing cost. The money market interest rates provide benchmarks to other lending rates in financial markets, so a well-founded study of how risk premia have been changed by the operations of quantitative easing offers the basis for assessing the effectiveness of these new policy instruments.

In the study, we have looked at the behaviour of risk premia in the UK, the EMU and the USA by decomposing it into credit and liquidity risk premia. Compared with literatures that have estimated the effect of central banks' interventions on interest rate spreads, our study has used a variable which we called 'Ratio' – the accumulated QE amount divided by total bank assets (accumulated open market operations, which include LTROs, and covered bond purchase over total bank asset, for the EMU) instead of a dummy variable which has been the approach of earlier studies. This measurement can provide information on the extent to which the risk premia has been reduced by a one-unit increase in the monetary base.

In the estimation, the first research question – the factors that drove up the risk premia spreads in the UK, the EMU and the US, has been studied by looking at the sub period of the crisis, pre-QE.. We can conclude that both liquidity and credit risk premia have contributed to the widening risk premia in each of the three money markets because of the causality between liquidity and credit risk premia, but credit risk premia played a more important role in the UK and the EMU due to the single causality. In the UK, the causality runs from short- and long-term credit risk premium to liquidity premium i.e. one basis point increase of short-term (long-term) credit risk premium has increased the liquidity premium by 0.13 basis points (0.14 basis points) and there is no reverse causality. In the EMU, it is slightly different in that the long-term credit risk premium, CDS, has played a more important role in increasing the liquidity premium. The causality runs from the long-term credit risk premium to liquidity premium. One basis point increase in the long-term credit risk premium increased the liquidity premium by 0.03 basis points. As same as the UK sample, the liquidity premium has not passed the increase to the credit risk premia. In the US, the situation is different from the UK and the EMU because the liquidity premium variable is I(0) and the two credit risk premia are not cointegrated, so we cannot obtain the long-run relationship. In the short run dynamic ARDL model, the causality between liquidity and credit risk premia is dual. Both short- and long-term credit risk premia have significantly increased liquidity premium, but the short-term credit risk premium has shown a bigger effect i.e. 20.68 basis points against 0.28 basis points. In the meantime, one basis point increase in liquidity premium has increased the short- and long-term credit risk premia by 0.01 and 0.12 basis points, respectively.

The second and the third research questions have been studied in the period of operation of QE (LTROs). Firstly, the results have confirmed that the operations of QE significantly reduced both liquidity and credit risk premia in the UK and the US. That is, the QE has fulfilled its objective of reducing the cost of borrowing in the UK and the US, respectively. In the EMU, although the operations have responded to the change of short-term credit risk premium, the LTROs significantly reduced the liquidity premium and it has not directly reduced the credit risk premia due to the lack of causality from liquidity premium to credit risk premia i.e. the causality remained as it was before the operation of LTROs. The missing causality from liquidity premia to credit risk may also imply that the increased credit risk in the EMU may not relate to liquidity aspect. This might provide some evidence for the suspicions of Mortimer-Lee (2012) regarding the intention of LTROs because low capital adequacy can lead to default under severe market condition. Secondly, in the UK, the causality between liquidity and credit risk premia has been reversed. The causality now runs from a liquidity premium to short-term credit risk premium. The variable Ratio has responded to the change of short-term credit risk premium. And, it has reduced the liquidity premium directly. Relying on the reversed causality, the variable Ratio has reduced the short-term credit risk premium indirectly. The long-term credit risk premium, CDS has no significant role since the onset of QE. Finally, in the US, the causality remains dual, but the long-term credit risk premium, CDS, has taken over the role of short-term credit risk premium to have bigger effect on the risk premium spread. The difference from the UK and the EMU is that the variable Ratio has neither responded to the liquidity nor the credit risk premia.

Despite the interesting findings in the study, there are some limitations that constrain the results. Firstly, we use three-month LIBOR (EURIBOR) to calculate the short-term credit risk and liquidity premia. LIBOR (EURIBOR) is not a transaction-based rate. The participant banks have the incentive to under/over-report their willing lending rate in the survey that is used to calculate LIBOR rate. This is known as LIBOR misreporting. We discuss the issue in Appendix 3. Secondly, banks operating in the interbank market are big multinational banks. They can get access of funds from the UK, the EMU or the US, in our case. Therefore, this creates the issue of international spillover effects. By solely looking at each market, we ignore the possible effect of operations that have been run by other central banks. If the effect is big, our result may be influenced. Finally, the Enhanced Credit Support run by the ECB contains a set of tools, as we have pointed out in Chapter 2, and the LTROs and CBPP are part of the set. For example, the fixed-rate allotment procedure ran together with LTROs is not separately measured and considered in our study. The effect is merged into the Ratio variable.

Overall, our results show evidence to support the conclusion that both liquidity and credit risk premia were the drivers of the widening LIBOR – OIS spreads in the UK, the EMU and the US. QE significantly reduced liquidity and credit risk premia in the UK and the US, so we can conclude that QE successfully reduced the cost of borrowing. In the EMU, the operation of LTROs and CBPP (although the amount is very small compared with LTROs) is proved to reduce liquidity premium and so to reduce the risk premium. The evidence is less convincing that the LTROs and CBPP have restored the functioning of money markets successfully, but it shows the positive result of the unconventional measures to narrow the spread between term interbank and overnight interest rates.

Given the nature of the study e.g. unfolding effect from the quantitative easing operations, there is large scale for the study to be extended while the time goes. Firstly, it is possible to consider the spill-over effect. As shown in the Appendix 1, some LIBOR banks who bid in Sterling panel also bid in USD panel, which means they may have access to both quantitative easing benefit from the UK and the US. Therefore, it would be interesting and worth to research further the impact that is created by the BoE and the Fed, respectively, as well as the possible impact of inter-reaction between the BoE and the Fed. For example, banks who received liquidity from the Fed in the US market might proportionally use the fund in their global operations, so their lending decision in the LIBOR sterling panel may be affected due to the increased liquidity position and the due change of LIBOR rate may influence the BoE's decision to conduct their future quantitative easing operations. Secondly, researches can particularly focus on the transmission channels to examine the effectiveness of quantitative easing to reach its final target. For example, to investigate the dynamics in the portfolio rebalancing channel, studies can show how effectively the liquidity that has been provided by the purchase of long-term government bonds has been transferred into credit in other financial markets.

Appendices

Appendix 1 Banks Bidding in LIBOR (£ and $) and in Euribor

LIBOR Sterling Panel	LIBOR USD Panel
Abbey National plc	Bank of America
Bank of Tokyo-Mitsubishi UFJ	Bank of Tokyo-Mitsubishi UFJ
Barclays Bank plc	Barclays Bank plc
BNP Paribas	BNP Paribas
Citibank NA	Citibank NA
Credit Agricole CIB	Credit Agricole CIB
Deutsche Bank AG	Credit Suisse
HSBC	Deutsche Bank AG
JP Morgan Chase	HSBC
Lloyds Banking Group	JP Morgan Chase
Mizuho Corporate Bank	Lloyds Banking Group
Rabobank	Rabobank
Royal Bank of Canada	Royal Bank of Canada
The RBS Group	Société Générale
Société Générale	SMBC
UBS AG	Norinchukin Bank
	The RBS Group
	UBS AG

Euribor Euro Panel

Country	Bank
Belgium	Belfius, KBC
Finland	Nordea, Pohjola
France	Banque Postale, BNP Paribas, HSBC France, Natixis, Credit Agricole s.a., Credit Industriel et Commercial CIC, Société Générale
Germany	Deutsche Bank, Commerzbank, DZ Bank
Greece	National Bank of Greece
Ireland	Bank of Ireland
Italy	Intesa Sanpaolo, Monte dei Paschi di Siena, UniCredit, UBI Banca
Luxembourg	Banque et Caisse d'Epargne de I'Etat
Netherlands	ING Bank
Portugal	Caixa Geral De Depositos
Spain	Banco Bilbao Vizcaya Argentaria, Banco Santander Central Hispano, CECABANK, Caixabank S.A.
Other EU banks	Barclays Capital, Den Danske Bank
International banks	London Branch of JP Morgan Chase Bank N.A., Bank of Tokyo Mitsubishi

Appendix 2 Banerjee Single-Equation ECM Critical Value

With constant	Size			
T	0.01	0.05	0.10	0.25
25	-4.12	-3.35	-2.95	-2.36
50	-3.94	-3.28	-2.93	-2.38
100	-3.92	-3.27	-2.94	-2.40
500	-3.82	-3.23	-2.90	-2.40
> 500	-3.78	-3.19	-2.89	-2.41

Appendix 3: The Issue of LIBOR Misreporting

One of our measures for credit risks, the spread between LIBOR and Repo, might be criticized because of the misreporting problem associated with LIBOR rate. LIBOR is London Interbank Offered Rate so LIBOR rates are not transaction based data. They are calculated currently by Thomson Reuters from the responses of participant banks to the survey that enquires the interest rate and size if they would like to borrow at 11 am every trading day (Monticini and Thornton, 2013). LIBOR currently reports for ten currencies with fifteen maturities.

In fact, active discussions on how well LIBOR captured funding costs during the crisis began with the publication of the *Wall Street Journal* article on May 29, 2008. Banks participated in LIBOR bidding appeared to underreport LIBOR rate as a signal of financial soundness and make profits (Monticini and Thornton, 2013). The Federal Reserve Bank of New York (FRBNY) Markets and Research and Statistics Groups (2008) in their proposal of enhancing the credibility of LIBOR point out the problem of incentive of misreporting and introduce the approach of random sampling from an extended panel to reduce the public exposure of biding statistics from participant banks so to eliminate the incentive of misreporting for the purpose of signaling. The Bank of England (*Press Release*, 20/07/2012) also stressed that the possibility of accidental or deliberate misreporting is likely associated with any system based on self-reporting.

Research on this issue concentrated on comparing LIBOR survey responses with other borrowing rates, notably bank bids at the Federal Reserve Term Auction Facility and term borrowing from Fedwire payments. Kuo *et al* (2012) found that LIBOR survey responses broadly track TAF and Fedwire data between 2007 and 2009, but also that LIBOR lay below them at certain times. They discuss a range of factors that may account for the discrepancy and they conclude that while misreporting by LIBOR panel banks would cause LIBOR to deviate from other funding rates, their result does not indicate that LIBOR misreporting occurred.

Importantly, Taylor and Williams (2008) used alternative measures to the LIBOR spread (CDs, term fed funds and Eurodollar rates) and their main findings on the LIBOR spread were unchanged. In an earlier paper, Abrantes-Metz *et al* (2011) find that the statistical second-digit distribution of LIBOR fixing deviates from the distribution implied by Benford's law, while Abrantes-Metz *et al* (2012) did not find systematic evidence of LIBOR misreporting based on a comparison of LIBOR quotes matched to CDS spreads. Schwarz (2010) finds no evidence of misreporting on euro LIBOR in the early crisis based on e-MID data and Gyntelberg and Woolridge (2008) note that dollar LIBOR differed from Eurodollar rates during January 2008, but they do not conclude that LIBOR was misreported. Therefore, given these evidences, our study continues employing LIBOR and Repo as the measure for credit risk.

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