QUANTITATIVE EASING (QE) AND INVESTING IN FINANCIAL ASSET MARKETS

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THESIS SUMMARY

This study is an empirical investigation into the effects of the Quantitative easing (QE) operations implemented in the aftermath of the financial crisis of 2008 by the BoE and the Fed on the broader financial markets in the UK and US. It avoids a major pitfall of earlier studies that just focused on the impact of QE on government bond yields. Considering the channels of the QE policy, it assess the effects of QE operations on bond yields and equity market returns in the US and UK using an event study before using a GARCH specification augmented with QE intensity and period variables to model the returns and volatility dynamics for the US and UK equity markets primarily, as well as others that did not implement the QE policy at the time. It also examines the effects of QE on the covariance between the inter-financial (i.e. the UK and US equity markets) and intra-financial (i.e. the equity and bond markets in the UK and US) using the DVECH model. An investigation of the long-run relationship of the US, the UK, France and Germany equity markets, following the QE operations using the multivariate cointegration and VECM techniques is made. We report significant effects on equity and bond market yields following the QE announcements and the actual bond purchases. Though there is evidence of increased (positive) co-variance between the UK and US equity markets following the actual QE purchases, this appeared to have been induced by the BoE and not the Fed QE operations. Conversely, the intra-financial markets analyses of the effect of QE on the covariance between the equity and bond markets in the UK and US respectively revealed significant (negative) covariance between the bond and equity markets following the QE operations. No evidence is found of an increasing convergence amongst the US and the UK equity markets, following the QE actions. As the toolkit of monetary policy in the aftermath of the recent financial crisis has been expanded to now include a hitherto unconventional tool in the mode of QE, the findings of this study provide the monetary authorities with an understanding of the broader financial market especially the equity market reaction function to the QE policy and thereby fills this gap in the literature. This thesis adds to several existing literatures on equity market volatility, equity-bond market covariation and equity market cointegration from a QE perspective. As well as adding to a growing body of literature that has examined the broader effects of QE.

Keywords: QE, LSAPs, Unconventional Monetary Policy, Equity Markets, Bond Markets, Variance, Covariance, GARCH, DVECH, Unit-roots, Cointegration, VECM.

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Glossary of Terms

APF	Asset Purchase Facility
BoE	Bank of England
BOJ	Bank of Japan
CABs	Current Account Balances
CBPP	Covered Bond Purchases Program
CE	Credit Easing
CPI	Consumer Price Inflation
DMO	Debt Management Office
ECB	European Central Bank
ECM	Error Correction Model
FED	Federal Reserve Bank
FOMC	Fed Open Market Committee
FRBNY	Fed Reserve Bank of New-York
FRFA	Fixed Rate Full Allotment
GDP	Gross Domestic Product
GSEs	Government Sponsored Enterprises
IRFs	Impulse Response Functions
JGBs	Japanese Government Bonds
LSAPs	Large Scale Asset Purchases
LTRO	Long Term Refinancing Operations
MBS	Mortgage Backed Securities
MEP	Maturity Extension Program
MPC	Monetary Policy Committee
MRO	Main Refinancing Operation
OIS	Overnight Interest Swap
OMO	Open Market Operation
OMTs	Outright Monetary Transactions

QE	Quantitative Easing
QEP	Quantitative Easing Program
SMP	Security Market Program
TIPS	Treasury Inflation Protected Securities
TVP	Time Varying Parameter
VARs	Vector Auto-regressions
VECM	Vector Error Correction Model
ZIRP	Zero Interest Rate Policy
ZLB	Zero Lower Bound

CHAPTER 1: INTRODUCTION

1.1 Background

In responding to the financial crisis of 2008-2009, central banks such as the US Federal Reserve (Fed) and the Bank of England (BoE) reduced significantly the short-term nominal interest or the policy rates close to their zero lower bound. However, as the crisis intensified, with deteriorating economic situations in these economies and with short-term interest rates already close to zero[1], further interest rate cuts became harder, thereby limiting the effectiveness of conventional monetary policy.

In meeting the challenges posed by reaching the effective zero lower bound on the short-term nominal interest rate, the aforementioned central banks including others like the European Central Bank (ECB) resorted to unconventional or less-conventional monetary policy measures in order to provide further stimulus in the aftermath of the significant deterioration of economic conditions and mounting deflationary risks following the financial crisis. Prominent among the unconventional monetary policy measures is the policy of large-scale asset purchases (LSAPs) or quantitative easing (QE) as conducted by the Fed and BoE commencing from late 2008 and early 2009.

QE operations are those that unusually increase the monetary base through large scale asset purchases. These operations especially[2] as implemented by the Fed and the BoE involved the withdrawal of large quantities of longer term Treasury and gilt-edged securities from the private and non-bank sector through purchases in the secondary market, thereby altering their relative supplies available to the public. The broad objective of these QE operations was to bring about a reduction in long-term interest rates, thereby reducing the cost of capital to businesses and

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[1] Although zero is a reasonable approximation on the lower bound for interest rates, the costs of storing and protecting large amounts of currency would imply that short-term rates can become slightly negative in some instances.

[2] While the Fed and BoE injected reserves into the US and UK economies by buying bonds, the ECB generously lent money to banks to inject reserves into their 'bank-centric' economies. (Fawley and Neely, 2013).

households, so as to increase aggregate demand and real economic activity. The principal distinguishing feature of QE from the conventional open market operations (OMO) is that with QE, the central bank seeks directly to influence asset prices such as longer-term bond yields rather than a short-term rate, and such influencing of long-term yields can have an effect on other imperfect substitutes to long-term bonds such as equities, through a portfolio rebalance mechanism which may further boost the economy as will be explained below.

The rapidly expanding body of literature on QE reviewed in the second chapter of this thesis, has explored a number of issues connected to the use of QE ranging from theoretical and empirical studies of how effective the large scale asset purchases has been in lowering long-term yields and helping the wider or real economy recover from the financial crisis. This literature has broadly concluded that QE led to reductions in yields and long-term interest rates which have had positive economic effect by raising the level of real GDP and CPI inflation, and thereby prevented the global or world economy from drifting into another great depression as experienced in the 1930s.

Despite this increasing body of research on the efficacy or effectiveness of the QE policy, however justified, given the unprecedented nature of the QE operations in the US and the UK, there has been little attempt or relatively less attention in the academic literature to this point, devoted to the possible effects on the broader aspects of the financial markets of the QE policy. This dearth in scholarly literature on these potential effects of the QE is in contrast to the acknowledgement by policymakers as the QE operations continued of its potential risks or unintended consequences. For example, on August 2010, former chairman of the Fed, Ben Bernanke alluded to potential risks of the Fed's balance sheet expansion which pointed to the 'difficulty of calibrating and communicating policy responses,' and 'reduced public confidence in the Fed's ability to execute a smooth exit from its accommodative policies… leading to an undesired increase in inflation expectations,' (Bernanke, 2010). In public discussion the possibility of inflation spiralling out of control due to the unprecedented increase in the money supply associated with a policy of QE has also been raised. Apart from the risk of inflation, another point that has been made is that if the government were to issue debt just to meet the demands of QE, then this will entail a risk to central bank balance sheets and the level of government debt which might become unmanageable.

As germane or relevant as the aforementioned risks to the wider economy, are also effects to the broader financial market. One aspect of QE albeit having not being given much consideration if any at all, is the effect on the other aspects of the financial markets, other than the bond markets, such as the equity markets that might result from the portfolio balance transmission mechanism of QE. Some of the existing analysis or literature of the impact of QE has identified the portfolio balance mechanism as a veritable channel through which the QE policy has been effective.

The thrust of the portfolio balance transmission mechanism is that with the central bank bond purchases, the money holdings of the sellers are increased and unless money is a perfect substitute for the assets sold, the sellers would rebalance their portfolios by buying other imperfectly substitutable assets. This shifts the excess money balances to the sellers of those assets who may, in turn, attempt to rebalance their portfolios also by buying further assets and as this goes on, the prices of assets rise until the point where investors, in aggregate, are willing to hold the overall supplies of asset and money. Higher asset prices mean lower yields and lower cost of capital for firms and households, which act to stimulate aggregate spending or demand.

However, as QE portfolio balance effects due to the negative supply shocks to the bond markets cause investors to switch from bonds to other imperfect substitutes like equities, increased variance in the equity markets, changing covariance structures between different financial assets/markets returns may result from investors seeking an attractive return away from the bond markets to other aspect of the financial market such as the stock markets for example. Whether or not large scale government bond purchases or QE provide unambiguously positive net benefits to the broader financial markets such as markets for stocks, and other imperfect substitutes to Treasury bonds like corporate bonds is ultimately an empirical matter, which has received little to no attention at all in the QE literature.

This study fills this gap in the literature by investigating the effect of the QE or LSAPs by the BoE and the Fed on majorly the UK, the US and on other financial markets. Using data on the Fed and BoE's QE operations, equity and bond market returns and equity price indices, the study test the effect of the QE operations on several measures of financial market stability including equity market volatility, equity and bond markets covariance, and equity market cointegration against the background of the unconventional monetary policy of QE or LSAPs.

1.2: CONVENTIONAL AND UNCONVENTIONAL MONETARY POLICY

Quantitative monetary targets were the fulcrum of monetary policy in the early 1980s. In the late 1980s however, most central banks jettisoned this approach, due to its perceived failure. This failure was largely due to the perceived instability of velocity and the money demand function in many countries since the 1980s (Werner 2012). Since then central banks have emphasised interest rate policies in their official statements and the conventional way for monetary authorities to conduct monetary policy has focused on interest rate decisions by setting the policy rate. Monetary authorities starting with the BOJ on 19th March 2001 and more recently the Fed and BoE resorted again to quantitative monetary targets- QE or large scale asset purchases- once the hitherto conventional or traditional instrument of monetary policy (the short-term nominal interest rate) was encumbered due hitting the effective zero[3] bound. The zero bound can be a significant impediment for the monetary authority in combating deflation or hitting any higher inflation target, as further interest-rate cuts becomes harder as policy rates approximates zero. The lower bound could be removed by allowing interest rates to go negative. Such a negative interest rate (NIR) would apply not only to the reserves at the central bank, but also to bank deposits and other savings accounts. In the circumstance of a NIR, money becomes the so called 'hot potato' which the banking populace should want to get rid of. Although, NIR do not alter the balance sheet of the central bank, they can have adverse effects on savers, if the banks for instance decide to recover the cost of the rate by levying charges on their customers.

The introduction of quantitative easing or asset purchases as the policy tool or action in the event of the effective zero bound being reached, thus shifted the hitherto focus of monetary policy from 'price' (i.e. rate) setting to quantitative monetary targets. However, with the primarily objective of the central bank still maintaining price stability amongst other objectives which may include maintaining full employment, economic growth, and at the highest level financial stability. The QE or LSAPs provides an additional tool to help the central bank meet its objectives.

1.2.1 Conventional monetary policy (interest rate)

The financial crisis and its aftermath of what is now known as the great recession posed a number of genuine challenges for the conduct of monetary policy by central banks. Pre-crisis, the aim of monetary policy was to achieve low and stable inflation, the policy framework was inflation targeting, and the principal tool was the policy rate which the central bank provided funds to commercial banks. As proposed, among others, by Woodford (2003), within this

[3] The BoE considered a negative bank rate in February 2013, but decided against it. The rationale behind imposing negative interest rates is to discourage people or organisations from certain investments. For instance the imposition of negative interest rates by the ECB was to discourage banks from depositing money with it, and instead lend to Eurozone businesses.

framework, optimal monetary policy essentially boils down to setting a short-term nominal interest rate using a wide variety of macroeconomic signals but in a manner akin to Taylor rule[4], whereby interest rates responded more than proportionately to changes in inflation and also responded to the gap between actual and full employment. However, it has been argued and pointed out by others like Benhabib et.al. (2001) that the inability of the much touted policy rule to prevent the economy from entering a deflationary spiral is a critical shortcoming of the Taylor rule as a guide to policy. In a separate vein, Arestis et.al. (2016) estimated the monetary policy preferences of the EMU and of the UK, showing that policy preferences changed across different regimes including where monetary policy violates the Taylor principle by accommodating inflationary pressures.

Starting August 2007, the US FOMC eased monetary policy aggressively in the aftermath of the worst financial crisis experienced since the Great Depression, lowering the federal funds rate target from $5^{1/4}$% in September 2007 to 0 to ¼% in December 2008. In the UK, very similar size cuts in the Bank rate was undertaken by the UK's MPC with cuts of 3 percentage points in the Bank Rate during 2008 Q4 and a further $1^{1/2}$ percentage points in early 2009. In early March 2009, Bank Rate was reduced to ½%,[5] deemed to be a lower bound.

Other Central banks in the ECB, Canada, China and Switzerland also undertook interest cuts. Despite the substantial cuts in the nominal interest rates, the cost of credit to both households and businesses rose sharply and substantial credit spreads i.e. wedges between short-term nominal interest rates and the rates facing firms and households emerged.

The failure of the cost of finance to households and businesses to fall despite the sharp easing of monetary policy brought to the fore once again the question about what can be done to boost the

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[4]A Taylor rule is a rule for setting of the short-term interest rates in order to achieve a target rate of inflation. The required short-term interest rate depends on the rate of inflation for the previous period, the extent to which the past inflation rate deviated from the target rate of inflation, the extent of the deviation of output from its natural rate and the equilibrium real rate of interest.
[5] The Bank rate was further reduced by the BoE to ¼ % after the Brexit referendum in June 2016.

economy when interest rates have fallen to a level below which they cannot be driven by further monetary expansion, and of course whether monetary policy (conventional) can be effective at all under such circumstance (Krugman, 2008). This view about the ineffectiveness of monetary policy during a financial crisis dates back to Keynes (1936). However, a few like Mishkin (2008) argued that the view that monetary policy is ineffective during a financial crisis is simply wrong, but rather it may be necessary to pursue more aggressive monetary policy easing during a crisis than normal.

The question of how policy should be conducted when the zero bound is reached or when the likelihood of reaching it can no longer be ignored – raised a number of fundamental issues for the conduct of monetary policy. In fact it has been argued that awareness of the possibility of hitting the zero bound calls for fundamental changes in the way that policy is conducted even when the bound has not yet been reached (Krugman, 1998; Eggertsson and Woodword, 2003). With the zero lower bound being reached in the US and UK, the usual official rate could not be changed in terms of the appropriate adjustment of an operating target for overnight interest rates. The result was that conventional monetary policy had become inadequate in attaining monetary policy objective.

1.2.2 Unconventional monetary policy (QE)

The extent, to which the zero bound represents a genuine constraint on attainable equilibrium trajectories for real activity and inflation, is what gives unconventional monetary policy or QE traction. The objective of the various LSAP programmes also referred to as QE is to spur aggregate economic activity once the possibility of further interest rate cut had been exhausted. QE involve the open-market purchases of various kinds of assets especially longer-term assets by the central banks which cause an expansion of the monetary base and broad money thus increasing the quantity of money supply. To illustrate the mechanisms of how LSAP works a simple balance sheet of all parties involved is depicted.

Figure 1: Central bank

Assets	Liabilities
+ Gilts	+ Reserves

Figure 2 : Commercial bank

Assets	Liabilities
+ Reserves	+ Deposits

Figure 3: Non-bank private sector

Assets	Liabilities
-Gilts	
+Deposits	

Given that the central bank succeeds in its aim of by-passing the banking sector and purchases assets solely from the non-bank private sector like the insurance companies and pension funds as intended[6], as it is believed that these institutions were more likely to use the proceeds of the sales to invest in other imperfect substitutes.

By buying assets from the non-bank private sector, the central bank pays for the asset purchased by crediting the accounts of the sellers of the assets with their commercial banks through the electronic creation of excess reserves for commercial banks. Thus, the central bank expands its own balance sheet, with the holdings of gilts marched by reserves (Fig. 1). The banking sector's balance sheet also expands as the increased holdings of deposits by the non-bank private sector are matched against the newly created central bank reserves (Fig.2) The non-bank private sector holdings of gilts falls, however, in paying for the gilts or bonds purchased, the central bank credits the accounts of the sellers of the asset. QE hence increases their holdings of bank deposits, and by implication broad money (Fig.3). It is this set of actions to balance sheets engendered by the central bank asset purchases that produces a portfolio rebalancing and so begins the monetary transmission process of QE to asset prices and aggregate spending in the wider economy.

Seen this way, the QE is remarkably similar to the central bank open-market operations (OMO). The distinguish features being the circumstances under which the LSAPs are taking place and their scale (Bean, 2009; Sinclair and Ellis (2012). In fact, the policy of purchasing short-term treasury bills and expanding the monetary base is exactly what happens when the monetary authority conducts an OMO. The main difference is that QE involves a direct injection of a

[6] The BoE and Fed asset purchases were aimed at non-banks by being directed at long-term assets mainly Treasuries or gilts with maturities initially ranging between 10 and 25 years typically held by financial institutions like pension funds and insurance companies.

specified quantity of broad money, rather than influencing its price through variations in the price of base money and the purchase of longer-term bonds instead of short-term treasury bills.

However, both the use of direct (quantity of money supply) and indirect (interest rate) controls of monetary policy have their advantages and disadvantages. Direct controls are relatively easily to implement and the direct fiscal cost are relatively low. Their appeal derives from circumstances where the monetary authorities wish to channel liquidity or credit to meet specific objectives such as witnessed in the aftermath of the financial crisis. To the extent that they are effective, direct controls may lead to financial repression and disintermediation. If they lead to disintermediation, the share of financial holdings over which the monetary authorities can apply monetary control decreases, as funds may flow into informal financial markets. By contrast, indirect controls encourage intermediation through the formal financial sector. They also permit the monetary authorities room for more flexibility in policy implementation. Small, frequent changes in instrument settings, enables the monetary authorities respond quickly to correcting policy errors or shocks. The main disadvantage of the interest rate control of monetary policy is their ineffectiveness or encumbrance at the ZLB.

1.3: Motivation for the Research

The benefits of QE are in general well understood by practitioners and academics. Through QE monetary authorities hope to stimulate depressed economies LSAPs, thereby lowering their yields, thus diminishing the cost of capital for firms and households and through this, it is expected that consumption and investment spending would also increase.

However, not much has been said about other likely effects of the QE policy. This much was acknowledged at the conference on QE and unconventional monetary policy organised in the winter of 2011 by the BoE: "…The second area of concern, and one not covered in the conference, is what might be the costs of unconventional monetary policy… The use of unconventional monetary policy may have a number of unintended consequences. This include, for example, financial market distortions, exit problems, and the potential loss of central bank independence and credibility…These are all contentious issues… For now, while the problems of recovery dominate, these issues receive less attention, but as future events unfold the debate is likely to shift into these areas." (BoE Quarterly Bulletin 2012Q1:54).

It suffices from the above, to say that this study is apposite or timely, not only because the QE operations have now been tapered or wound up, but also because a comprehensive analysis of the potential impact of the LSAPs is necessary, given the possibility of the tool being retained by monetary authorities to achieve their objectives, before interest rates rise to levels normally seen during an economic boom or recovery. This study is also motivated by the need to empirically establish the financial markets, particularly, the equity market reaction function to the QE actions and operations. Hence it evaluates the first of three potential consequences or effects of the QE policy identified above i.e. financial market distortions.

1.4: Research Objectives

This study is an empirical investigation of the effects of QE on the financial markets. Specifically it focuses on the QE operations implemented in the the US and UK and the effects of these on the equity and bond markets in the US and the UK and on other equity markets in countries that did not implement such QE measure at the time, e.g. France and Germany; or at all e.g. Australia. The main objectives are:

1. To examine the effect of QE on the equity market returns and volatility in the UK, US and other equity markets outside the UK and US.
2. To investigate the impact of the actual bond purchases or QE by the BoE and Fed on the covariance between the US and UK equity markets on the one hand, and the covariance between the stock and bond markets within the US and within the UK on the other.
3. Ascertain the implication (if any) of QE for the long-term relationship between the equity markets of the US, UK and the Euro-area.

To achieve the above research objectives, several empirical analyses using econometric techniques and models including univariate GARCH models, multivariate DVECH models, vector auto-regression (VAR) estimation, multivariate cointegration and error correction models (ECMs), unit root tests, and causality tests are utilised.

1.5: Overview of the Chapters

Chapter two provides an exhaustive review of the empirical literature on QE. It starts with a look at the transmission channels or mechanisms of QE especially the portfolio balance channel which underpins this study. This chapter also provides a catalogue of the QE actions by the Bank of England and the US Federal Reserve Bank. Then follows a comprehensive review of the existing literature of empirical studies of the US QE operations, the UK QE operations and the macroeconomic impacts of the QE operations, which helps situate or position the current study in the gap found in this literature. Further review of empirical studies based on the segmentation versus the expectation views of QE was also carried out in this chapter.

Chapter three begins the empirical chapters of this thesis by looking at the effect of QE on the equity markets. The chapter developed some hypotheses and discussed the empirical and the data used for the analyses in it. This chapter also presents some descriptive statistics of the equity return dataset as well as the cross-sectional distribution of the different phases of the QE operations in both the UK and the US before the empirical results of the analysis carried out.

Chapter extends the analyses to a multivariate setting incorporating the bond markets in the UK and US thus providing the empirical results to the second research objective on the effect of QE on the covariance structure between and within the UK and US financial markets.

Chapter five reports the empirical results for the third study on the implications of QE for long-run equity market relationship or cointegration focusing on the equity markets in the US,UK, France and Germany.

Chapter six concludes this thesis by providing a summary of the main findings, articulating the central contributions of this research to knowledge and other relevant stakeholders such as financial market investors and the monetary authorities before discussing the limitation of the thesis and suggesting an area for further research.

Chapter 2. LITERATURE REVIEW

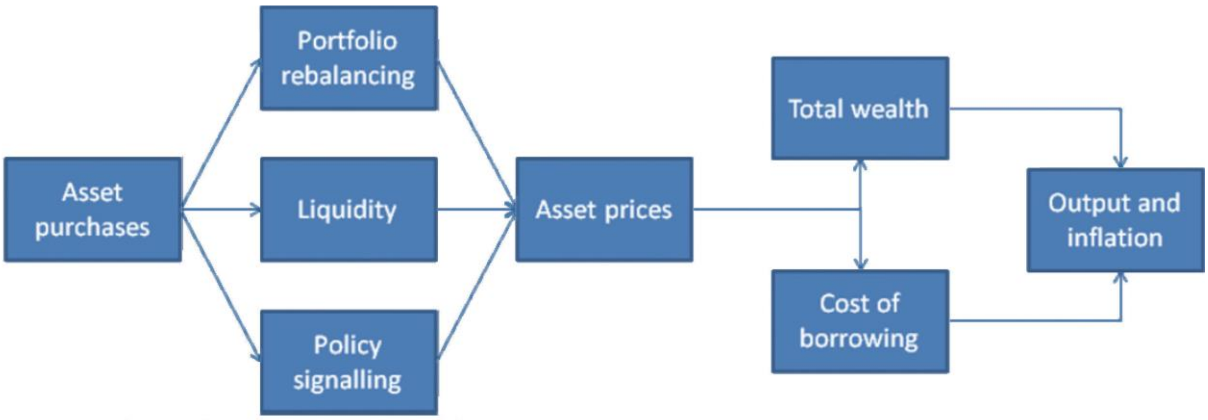
2.1 Introduction

This review chapter is structured as follows: Section 2.1 discusses the transmission channels linking QE from the financial markets to the macro economy. In particular, this section explains how LSAPs may reduce yields (first leg of the transmission), and how this then pass through to the real economy via reduced cost of capital and increased spending (second leg of the transmission); within this section also is a brief look at the theories of the term structure of interest supporting the transmission channels. Section 2.2 catalogues QE experiences and operations, starting with the earlier Japanese (BOJ) experience of the early 2000s and including the recent BoE, the Fed and the ECB QE operations. A comprehensive review of the empirical literature on the effects of the QE programmes on the yields in the bond markets in the U.S. and U.K. follows in section 2.3 while the empirical evidence on the macroeconomic effects of QE are reviewed in 2.4. Section 2.5 looks at further evidence on the segmentation vs expectation perspectives to quantitative easing efficacy, while section 2.6 concludes.

2.2: Transmission Channels of QE

As stated previously, the aim of QE is to inject money into the economy in order to stimulate nominal spending. As highlighted through the various balance sheet transactions in the preceding chapter, when the monetary authority buys these assets creating new base money or reserves for commercial banks, it simultaneously also boost the amount of deposits (broad money) held by the non-bank private sector which include households and firms. This additional money working through a number of channels (see Figure 4 for a schematic representation of the QE transmission channels) should then all things being equal, affect the level of spending and income in the economy. The channels through which the effect of QE gets transmitted are the preoccupation of this section. Three channels: portfolio rebalance, policy signalling and liquidity are discussed.

Figure 4 : Stylised transmission mechanism for QE



Source: Adapted from BoE

2.2.1 Portfolio balance Channel

The nature of the portfolio balance mechanism was first articulated by Tobin (1958), in a work on portfolio allocation, where he stated that a range of assets, in addition to money are likely to be imperfect substitutes for one another. Viewed this way, an expansion of one asset's supply affects both the yield on that asset and alternative assets (Tobin 1958, 1961, 1963). The insight offered by this argument is that by varying the relative quantities of financial claims with different maturity, monetary authorities could be able to influence the pattern of yields on different assets due to their imperfect substitutability. At the time, Tobin had long pushed the view that different securities should be treated differently, but macroeconomic modelling tended not to follow up the implications of imperfect substitution between assets, with notable exceptions including Brunner and Meltzer (1973) and Friedman (1976). This probably reflected the convenience of the perfect-substitute baseline, where all nonmonetary assets and debts are taken to be perfect substitutes at a common interest rate (Andre's et.al. 2004)

Monetary policy discussions in recent years especially following the Japanese banking crisis of the late 1990s to early 2000s have given the issue a prominence absent at the time the view was first canvassed. The possibility that short and long-term securities are imperfect substitutes subsequently became an issue in monetary policy discussion. For instance, in a speech on November 21, 2002, FOMC member Ben Bernanke considered the channels for monetary expansion available to the Fed beyond lowering the policy rate when he observed:

'One relatively straightforward extension of current procedures would be to try to stimulate spending by lowering rates further out along the Treasury term structure-that is, rates on government bonds at longer maturities."

This would appear an agreement with Tobin (1969) central theme that the influence of central bank actions on aggregate demand cannot be summarised by a single yield, the short term interest rate, but are reflected in a variety of asset yields. That assertion, in principle rests on a model where different securities are imperfect substitutes for one another.

A notable recent work[7] on the theoretical underpinnings of the portfolio rebalance channel is Vayanos and Villa (2009) which model the term structure of interest rates as resulting from the interaction between investors clienteles with preferences for specific maturities (preferred habitat) and risk-averse arbitrageurs. Because arbitrageurs are risk averse, shocks to clienteles' demand for bonds affect the term structure and constitute an additional determinant of bond prices to current and expected future short rates. The position that longer term yields depend in part on the relative quantities outstanding of longer term assets in the hands of the private sector was the subject of a substantial literature in the 1950s and the 1960s (Culbertson, 1957; Modigliani and Sutch, 1966).

The expectations hypothesis of the term structure (Lutz, 1941) however assumes that current and expected yields of short-term bonds determine the yields of long-term bonds, while the supplies of the bonds do not affect yields. This theory is based on the view that when the expected return of one asset is higher than that of another asset, investors will trade those assets to make a profit. In other words, short-term and long-term bonds are perfect substitutes for one another. With perfect substitution, the relative supplies of the assets do not matter because they do not affect the current short rate or future expectations of short rate and a reduction in the supply of the bonds does not affect the yield on the bond.

[7] Earlier work by Andres et.al. (2004) confirm that some of the observed deviations of long-term rates from the expectations theory of the term structure can be traced to movements in the relative stocks of financial assets, just as claimed by Tobin (1969). Thus providing support for the existence of unconventional or quantitative channels of monetary policy.

Once a role for imperfect substitutability is accepted, the efficacy of portfolio rebalancing then hinges on the degree of substitutability between assets. Hence, it is likely to be greater the less substitutable money is for bonds and the more substitutable (relative to money) risky assets are for bonds. Central bank asset purchases through this channel then push up the prices of the assets bought as well as the prices of other assets that are imperfect substitutes. Higher asset prices mean lower yields and lower cost of capital for firms and households, which act to stimulate investment and consumption spending. Cheaper and easier access to capital not only helps to maintain output but also improves the prospect for full employment.

The portfolio rebalance channel is commonly broken down into a local supply or scarcity effect and a duration effect. The local supply effect is anchored on segmentation in the bonds market and captures the impact of a shift in the quantities of specific maturities of government debt held by private agents. For example, for investors like pension funds, selling gilts to the central bank moves them away from their preferred habitat or segment in the maturity structure. Such a scarcity effect may be spread over time and it could be manifested in bond rates for a particular maturity.

The duration effect captures how LSAP may also affect asset prices by altering the aggregate amount of the interest rate risk in bond markets. The prices of fixed income assets, such as government bonds, are affected by future movements in the interest rates, the extent of which is termed duration. Investors would demand a term premium to compensate them for exposure to this kind of risk. With central bank purchases of long-duration assets, it reduces the aggregate amount of duration risk that is left in the market that needs to be borne by the private investor. As a result, the compensation required by investors to hold all remaining bonds carrying duration risk falls, putting downward pressure on longer-term interest rates.

2.2.2 Policy Signal Channel

Another channel through which asset purchases may influence longer-term interest rates is through the information revealed about the likely trajectory of future monetary policy. The signalling or expectation effect as it also called captures the changes in the expected path of future short-term rates that arise from perceived new information that central bank asset purchases might convey to economic agents about the state of the economy and the monetary authority's reaction function or policy objectives such as inflation targeting.

Proponents of the policy signalling or the expectations channel such as Krugman (1998) posit that with nominal interest rates at the zero bound, the only way to reduce real rates further is to generate an increase in inflation expectations. In order to create expectations of higher inflation, the central bank must be deemed credible by agents to the commitment of allowing a looser monetary policy than would normally be the case. A looser monetary policy will lead to inflation being above target in the future and so the optimal policy response to the zero lower bound involves a commitment to overshoot the inflation target in the future in order to avoid an even greater undershoot today. This in turn would enhance current spending enabling the economy to avoid entering into a 'black hole' (depression).

Expectations help to achieve this goal if the central bank or monetary authority signals that it intends policy rates to remain lower for an extended or longer period, based on its assessment of the economic outlook. In such situation, investors or agents may alter their expectations of the future path of the policy rate and by such a signalling channel, announcements of LSAPs would lower the expectations component of long-term yields.

2.2.3 Liquidity Channel

Added to the portfolio rebalance and signalling channels is a third channel, the liquidity channel. This channel may operate at times of financial market stress and relates to the beneficial market effects that LSAPs by the central bank may have in times of significant financial market strains by providing market liquidity. In early phase of the financial crisis, central banks focused on providing liquidity through various liquidity support measures. There may also be effects on the prices and hence yields of longer-term assets if the presence of the central bank as a consistent and significant buyer in the markets improves market functioning and liquidity.

By standing as a ready buyer for longer-term assets, LSAPs by the central bank should allay fears in the minds of investor, allowing them to take larger positions in these securities or make markets in them more functional, since they are assured of being able to sell the assets without incurring a discount on their prices to the central bank. Such improved trading opportunities engendered by the presence of the central bank could reduce the liquidity risk premiums embedded in asset prices, thereby lowering their yields. This liquidity channel would appear to have been important in the early stages of the LSAPs programme and when financial markets are impaired or dysfunctional, though the effect may be small in gilt markets, which are normally highly liquid, a view supported by the BoE:

'The *MPC's asset purchase programme was directed towards large-scale purchases of conventional gilts. The impact was expected to be seen in gilt markets, but also across a broader range of asset prices and in real activity and inflation. The MPC did not explicitly use these purchases to signal future intentions, emphasising its commitment to meeting the inflation target through the usual channels of monetary policy communications – including the MPC minutes and the quarterly Inflation Report. Nor were its actions focused on improving the functioning of gilt markets where liquidity premium, even in stressed times, were considered to be small'. (Joyce et.al. 2010:8).*

In conclusion, it is important to emphasize that the three channels discussed in this section are not necessarily mutually exclusive, and may in fact work simultaneously. This is especially true for the portfolio rebalance and policy signalling channels (Bauer and Rudebusch 2013).

2.3: The QE Operations: A Review

The phrase QE was coined and first applied to the Japanese liquidity trap. A liquidity trap can be described as a situation in which conventional monetary policy have become ineffective, due to the nominal rate of interest being near or at zero and injecting monetary base into the economy will have no effect, if private agents see base money and bonds as perfect substitutes. It is on this fundamental distinction i.e. the imperfect substitutability between financial assets that the portfolio balancing mechanism of QE rests.

Following the bust of an asset price bubble in the early 1990s, the Japanese economy witnessed prolonged stagnation and general prices measured by the consumer price index (CPI) steadily reduced in growth rate. With the bleak economic outlook, and hovering deflationary spiral, as a result of the bust of the global IT (dotcom) bubble, the BOJ on the 19th of March 2001, adopted a new monetary easing framework-the Quantitative Easing Program (QEP), with a view to stemming the continuous decline in the general price level and also engendering sustainable economic growth.

In its announcement of 19 March 2001- universally cited by commentators as the first time a policy called QE was implemented by a central bank-The BOJ announced a high target of bank reserves held with central bank, which would be achieved by purchasing more government bonds (BOJ, 2001b). The QEP under the zero interest rate policy (ZIRP) - a policy hitherto unprecedented worldwide- implemented by the BOJ from 2001 to 2006 centred on three main pillars:

(i) To change the main operating target for money market operations from the uncollateralised overnight call rate to the outstanding current account balances (CABs) held by financial institutions at the BOJ, and provide ample liquidity to realise a CAB target substantially in excess of the required reserves.

(ii) To make the commitment that the ample liquidity provision would continue to stay in place until the core consumer price index (excluding perishables) registers stably at zero percent or an increase year on year.

(iii) To increase the amount of outright purchases of long-term Japanese government bonds (JGBs), up to a ceiling of the outstanding balance of banknotes issued, should the BOJ consider such an increase to be necessary for providing liquidity smoothly.

With the transition to the QEP in March 2001, the CAB target became five trillion yen, a level higher than the required reserve level of four trillion yen. The target was subsequently raised in response to the deteriorating economic conditions to 30-35 trillion yen in January 2004, and remained at this level until the BOJ exited the QEP. In order to meet the targeted CABs, the BOJ steadily increased its purchases of long-term JGBs from an initial 400 billion yen per month to 1,200 billion per month starting from October 2002. As of the end of 2005, the BOJ had expanded the monetary base to about 117 trillion yen (Ugai, 2007). Also from July 2003 to March 2006, as a limited time measure, the BOJ purchased asset-backed securities intended to support the development of the asset-backed securities market.

The core CPI growth turned positive from November 2005, and the rate for January 2006 announced in early March was ½%. On March 9, 2006, the BOJ stated that the year-on-year growth in the core CPI is expected to remain positive, and judged that the conditions laid out in the commitment under the QEP had been fulfilled. Consequently, the BOJ exited the QEP and decided to change the operating target of money market operations back to the uncollateralized overnight call rate, and to encourage the rate to remain at effectively zero percent[8].

[8] See Ugai (2007) for a survey of the empirical evidence of the BOJ QEP.

As part of the response to the intensification of the financial crisis, towards the end of 2008, the Fed and the BoE also deemed it necessary to ease monetary conditions further through a programme of asset purchases financed by the issuance of central bank reserves. This programme has been referred to as LSAPs or credit easing[9] (Fed) and QE (BoE) in reference to prior BOJ policy. The remainder of this section catalogues the QE operations of the BoE, the Fed as part of their policy responses to the financial crisis.

2.3.1 U.S. LSAP Operations

In response to the great recession, the FOMC started cutting the federal funds rate on the 18th of September 2007, from an initial 5.25 per cent target. While it cut rates rapidly by historical standards, the Fed did not signal any great sense of urgency. It was not until April 30, 2008, that the target funds rate got down to 2 percent, where the FOMC decided to keep it while awaiting further developments. The Fed neither expanded its balance sheet nor did it increase bank reserves during this period (Blinder, 2010). The FOMC began cutting interest rates again six months later at its October 10th 2008 meeting following the collapse of Lehman Brothers. Not only did the FOMC push the funds rate to its floor (zero), it also started expanding its balance sheet, bank reserves and lending operations (Blinder, 2010).

In the period after the collapse of Lehman Brothers in September 2008, the Fed's non-standard measures aimed at repairing the functioning of financial markets, can be divided into three categories: (i) lending to financial institutions, (ii) providing liquidity to key credit markets, and (iii) large-scale asset purchase program (LSAP). Latterly, the second round of quantitative easing by the Fed, which started in the second half of 2010, focused mainly on purchases of US Treasury

[9] Former Fed's Chairman Bernanke tried to call the Fed's new policies credit easing, probably to differentiate them from the actions taken by the BOJ earlier in the decade, but the label did not stick. He defined credit easing to encompass all Fed operations to extend credit or purchase securities.

securities, with the primary goal of stimulating the US economy by lowering yields, and pushing up asset prices in riskier market segments thereby inducing positive wealth effects.

Unlike the third category of measures implemented by the Fed in its first round of support, the other two categories were intended to provide liquidity to key credit markets, and to reduce funding pressures. Under these measures, the Fed established the Asset-Backed Commercial Paper, Money Market Mutual Fund Liquidity Facility, the Commercial Paper Funding Facility, and the Money Market Investor Funding Facility. The aim of these facilities was to avoid fire-sales of assets by providing liquidity backstop to financial institutions. These categories of the Fed measures can be associated with the central bank's lender of last resort role (Bernanke, 2009). These policies therefore have a different impact on the economy than the Fed's third policy tool, the LSAP. The overall LSAP composed of asset purchases of government sponsored enterprises (GSE) debts, mortgaged back securities (MBS) and, in a later stage of US Treasury bonds. While the MBS purchase was done with the intention of lowering mortgage interest rates and stabilizing the housing markets, the ultimate goal of the Treasury purchases was to stimulate economic activity by lowering long term rates to support investment spending, and boosting asset prices to stimulate demand.

The decision by the Federal Reserve to purchase large volumes of asset came in November 2008, when the Fed announced purchases of housing agency debt and agency mortgage-back securities (MBS) of $600 billion. Then in March 2009, the FOMC decided to increase the purchases of agency-related securities and to also purchase longer-dated Treasury securities of up to $1.75 trillion (Gagnon.et.al. 2010). The FOMC later on in 2009 committed to purchase the full $1.25trillion of agency MBS explaining that the phase of purchases later termed QE1 would be round up in March 2010.

While market liquidity had normalised by the end of 2010 (Kandrac, 2015), the slow pace of economic recovery made the FOMC to announce an additional LSAP program termed QE2- consisting solely of US Treasury bond purchases. In September of 2011 (three months after the QE2 ended), the FOMC announced additional balance sheet actions to help stimulate the US economy. The FOMC first decided to extend the average maturity of its Treasury securities holding a policy it called the maturity extension program (MEP) or also referred to as 'operation twist'. After this the FOMC then decided to reinvest principal repayments from its holdings of agency MBS and agency debt into agency MBS, a policy aimed at supporting conditions in the mortgage markets, but also would help to achieve the aim of supporting a stronger economic recovery.

In September 2012, the FOMC decided to purchase an additional $40 billion of agency MBS monthly and to continue with these monthly purchases if the outlook for the labour market did not improve substantially. Three months later, the FOMC announced additional outright purchases of Treasury securities at a monthly pace of $45 billion per month to continue after the MEP. These additional treasury purchases later became known as QE3 which continued until October 2014 when the QE operations were wound up in the US. The implementation of the Fed's LSAPs was carried out by the Federal Reserve Bank of New York (FRBNY) under delegated authority from the FOMC. To the extent possible, the operations by the FRBNY were scheduled to avoid conflicting with other operations or market, and events, such as Treasury debt auctions, agency offerings significant planned economic news releases[10]. In general, the composition of purchases was skewed in favour of longer-maturity securities. A summary of the Fed's QE actions is shown in Table 1

[10] Summaries for agency & Treasury purchases are available at http://www.newyorkfed.org/markets/pomo/display/index.cfm. Summaries for agency purchases are available at http://www.newyorkfed.org/markets/pomo/display/index.cfm?opertype=agny.

Table 1: List of Federal Reserve's LSAPs (QE) actions.

Date	Description of the event
QE1	
25/11/2008	Initial LSAP announcement. The Fed announces purchases of $100 billion in GSE debt and up to$500 billion in MBS Creation of the Term Asset-Backed Security Loan Facility (TALF)
01/12/2008	Chairman Bernanke says that Fed could purchase substantial long-term Treasuries
16/12/2008	The FOMC mentions possible purchases of longer-term Treasury securities. Also the Fed funds rate reduced to the range 0-0.25
28/01/2009	FOMC says that it is ready to expand agency debt and MBS purchases, as well as to purchase long-term Treasuries.
18/03/2009	FOMC says it will purchase an additional $750 billion in agency MBS, increase its purchases of agency debt by up to $100 billion, and buy up to $300 billion in long-term Treasuries.
12/08/2009	The FOMC states that the Fed will slow the pace of the LSAP by purchasing the full amount by the end of October instead of mid-September
23/09/2009	The Fed will slow the purchases of agency MBS and agency debt, finishing the purchases by the end of 2010Q1. Treasury purchases will still run till October 2009.
04/11/2009	The amount of agency debt will be halted at $175 billion, instead of $200 billion.
QE2	
10/08/2010	The FOMC states that it will reinvest principal payments from agency debt and agency mortgaged-backed securities in longer-term Treasury securities. Holdings of Treasury securities will be rolled over as they mature.
27/08/2010	Chairman Bernanke mentions potential policy options for further easing and suggests that the FOMC is likely to buy longer-term securities.
21/09/2010	FOMC states that the Federal Reserve will continue to roll over its holdings of Treasury securities as they mature.
15/10/2010	Chairman Bernanke states that the Fed is prepared to provide additional accommodation if needed to support the economic recovery.
03/11/2010	States its intention to purchase $600 billion more in longer-term Treasury securities by the end of second quarter of 2011, at a pace of about $75 billion per month.
22/06/2011	QE2 ends with Treasury purchases to be wrapped at the end of month, as scheduled; principal payments will continue to be reinvested.
Operation Twist	
21/9/2011	Maturity Extension Program i.e. operation twist announced: The Fed will purchase $400 billion of Treasuries with remaining maturities of 6 to 30 years and sell an equal amount with remaining maturities of 3 years or less
20/06/2012	Operation Twist extended as the Fed will continue to purchase long-term securities and sell short-term securities through the end of 2012. Purchases/sales will continue at the current pace, about $45 billion monthly.
QE3	
22/8/2012	FOMC states that additional monetary accommodation likely fairly soon
13/9/2012	QE3 announced: The Fed will purchase $40 billion of MBS per month as long as the outlook for the labour market does not improve substantially in the context of price stability.
12/12/2012	QE3 expanded: The Fed will continue to purchase $45 billion of long-term Treasuries per month but will no longer sterilize purchases through the sale of short-term Treasuries.
15/10/2014	Announcing the decision on QE, made at its October policy meeting, Fed Chair Janet Yellen, said the final tranche of bonds under its QE programme would be bought this month-ending the QEP.

2.3.2 U.K. QE Operation

In March 2009, the BoE MPC announced the start of its asset purchase programme at the same time as it reduced Bank Rate to 0.5%. Prior to this, the Asset Purchase Facility Fund was set up on the 29th of January 2009 as a subsidiary of the Bank of England, under a remit from the Chancellor of the Exchequer, with the initial objective of improving the liquidity of the corporate credit market by being used as a vehicle for purchases of high-quality private sector assets. The fund is fully indemnified by the treasury from any losses arising out of or in connection with the Asset Purchase Facility (APF), The APF was mandated to purchase up to £50 billion of private sector assets comprising corporate bonds and commercial paper –financed by the issuance of Treasury bills and Debt Management Office (DMO) cash management operations with the first purchase of commercial paper on the 13th of February 2009.

The APF's remit was further expanded ahead of the Monetary Policy Committee (MPC), meeting on March 5th 2009, to be used to purchase a range of eligible assets. In order to meet the Committee's asset purchases objectives, the BoE announced it would buy private and public assets, but that it was likely that the majority of overall purchases would be of gilts. The purchases of gilts were initially restricted to conventional gilts with a residual maturity between 5 and 25 years. Further extensions of the programme were subsequently announced at the 7th May, 6th August and 5th November 2009 MPC meetings which resulted in the increases of £125 billion, £175 billion and £200 billion respectively for the (QE 1) operation. At the August MPC meeting the maturity range of gilts purchases was extended to three years and over. By February 2010, when the MPC announced that it would pause its programme of purchases, the Bank had made £200 billion of asset purchases, of which £198 billion were gilts spread across a wide range of maturities.

However, as the financial crisis worsened, with increasing concerns over the competitiveness and macroeconomic imbalances of some economies within the Euro-area, the medium-term outlook for the UK deteriorated and the risk of undershooting the 2% medium term CPI inflation target in the medium term heightened. Given these scenarios, between October 2011 and May 2012 the BoE purchased an additional £125 billion of gilts (QE2). After a brief halt in purchases, in July 2012 the MPC announced a further £50 billion of gilt purchases to run till November 2012 (QE3). In the March 2013 remit for the MPC, the chancellor confirmed that the APF, will remain in place for the financial year 2013-2014. Cumulatively, the £375 billion of asset purchases represent about 25 per cent of annual GDP and measured in terms of face-value. Table present a summary of the BoE APF and QE related actions.

Table 2: The BoE APF and QE-related actions

Date	Description of the event
19/01/2009	The Chancellor of the Exchequer announces that the BoE will set up an asset purchase programme (initially to be financed using Treasury Bills and the DMO's cash management operations).
30/01/2009	APF Fund established.
5/02/2009	Bank rate reduced from 1.5 to 1 per cent.
11/02/2009	February *Inflation Report* and associated press conference gives strong indication that QE asset purchases are likely.
13/02/2009	First purchases of commercial paper begin.
QE1	
5/03/2009	Bank Rate reduced from 1 to 0.5 per cent. The MPC announces it will purchase £75 billion of assets over 3 months funded by the issue of central bank money. Conventional gilts likely to constitute the majority of purchases. Purchases split between two auction maturity sectors for gilts with remaining maturities of: (a) 5–10 years (b) 10–25 years
11/03/2009	First purchases of gilts begin.
25/03/2009	First purchases of corporate bonds begin.
7/05/2009	The MPC announces that QE asset purchases will be extended by £50 billion to £125 billion.
3/08/2009	Secured commercial paper facility launched.
6/08/2009	The MPC announces that QE asset purchases will be extended by £50 billion to £175 billion. The buying range is to be extended to all conventional gilts greater than 3 years. Purchases split between three auction maturity sectors: (a) 3–10 years (b) 10–25 years (c) Greater than 25 years. The Bank announces a gilt lending programme, which allows counterparties to borrow gilts from the APF's portfolio via the DMO in return for a fee and alternative gilts as collateral.
5/11/2009	The MPC announces that QE asset purchases will be extended by £25 billion to £200 billion.
22/11/2009	The Bank announces that it will act as a seller, as well as a buyer, of corporate bonds in the secondary market.
8/01/2010	First sales of corporate bonds
4/02/2010	The MPC announces that QE asset purchases will be maintained at £200 billion. The Chancellor authorizes the Bank to continue to transact in private-sector assets, with further purchases financed by issuance of Treasury Bills. The MPC's press statement says that the Committee will continue to monitor the appropriate scale of the asset purchase programme and that further purchases will be made should the outlook warrant them.
QE2	
6/11/2011	The MPC announces that QE asset purchases will be extended by £75 billion to £275 billion.
9/02/2012	The MPC announces that QE asset purchases will be extended by £50 billion to £325 billion. The three auction maturity ranges are changed to gilts with remaining maturities of: (a) 3–7 years (b) 7–15 years (c) Greater than 15 years
10/05/2012	The MPC announces that QE asset purchases will be maintained at £325 billion.
QE3	
5/07/2012	The MPC announces that the QE asset purchases will be extended by £50 billion to £375 billion.
4/08/2016	The MPC voted to reduce the Bank Rate from 0.5% to 0.25% following the Brexit referendum.

2.3.3 ECB Enhanced Credit Support Program

The ECB avoided the QE and CE (credit easing) labels, and has termed its approach which was anchored on ample liquidity provision to Eurozone banks-enhanced credit support (Trichet, 2009a). With deteriorating financial conditions in the aftermath of the financial crisis, the 3-month Euribor/overnight indexed swap (OIS) spread widened, hitting an all-time high of 198 basis points reflecting the huge rise in perceived counterparty risk (Fowey and Neely, 2013). The ECB responded to these widened spreads on the 15th of October 2008, stating that it would lend as much as banks wanted at a fixed-rate tender provided the banks had collateral-while it also expanded the list of eligible collateral. These fixed-rate tender, full-allotment (FRFA) operations reversed the ECB's conventional policy of offering a fixed allotment of funds at rates determined by the bidding process.

The ECB at the early stages of the crisis appeared relatively more sanguine about the economic outlook. Hence it had focused on liquidity support for struggling banks much more than on stimulating demand through rate cuts or QE. More importantly, the nonfinancial private sector in the Eurozone relies much more on the banking system for credit than on the securities markets, and the ECB's efforts have appropriately focused on ensuring the banks are strong and have adequate resources to lend. The ECB implemented the FRFA liquidity provision through its usual lending procedures.

The ECB's primary policy instrument in the normal times, is refinancing operations, direct lending to banks against eligible collateral at two maturities. The main refinancing operations (MROs) with a duration of two weeks and the longer-term refinancing operations (LTROs) with a duration of three months. Under the new policy, the ECB filled all MRO and LTRO loan requests at the ECB's primary policy rate, i.e. the main refinancing rate. From October 2008 to

May 2009, the ECB cut this rate from 4.25% to 1%. Even the generous supply of FRFA loans at low rates by the ECB did not allay fears over counterparty risk, and this continued to plague European interbank markets. On May 7, 2009, after reducing its main refinancing rate to 1%, the ECB introduced the 12-month LTROs and the covered bond purchase program[11] (CBPP). The ECB committed to purchase 60 billion euros in covered bonds. The president of the ECB at the time, Jean-Claude Trichet, insisted that the program was not QE and would not expand the ECB's balance sheet. Stating that he expected automatic sterilisation as the CBPP would commensurately decrease the demand for the elastically supplied LTROs.

However, in May 2010, following the escalating sovereign debt crisis within the Eurozone, the ECB announced the Securities Markets Programme (SMP), allowing the ECB purchase government debt in the secondary market. The ECB explained that the motives for the SMP program was to ensure depth and liquidity in the dysfunctional segments of the market, with the objective of the SMP to address the malfunctioning of securities markets.

Starting from March 2016, the ECB started an expanded asset purchase programme, under which private and public sector securities are purchased to address the risks of a too prolonged period of low inflation. This APP was preceded by the cutting of the interest rates i.e. the marginal lending facility to 0.25%; the main refinancing operations (fixed rate) to 0% and the deposit facility to -0.40%. Table 3 is a summary of important ECB's actions in response to the financial crisis and its aftermaths.

[11] In the event of a bond default, covered bond holders have recourse to the issuer of the bond, as well as the underlying collateral pool hence why they are called 'covered'.

Table 3: A Timeline of the ECB ECS Programme

Date	Program	Description of the event
28/3/2008	Long-term refinancing operations(LTRO)	LTRO expanded: 6-month LTROs are announced.
15/10/2008	Fixed-rate tender full allotment (FRFA)	Refinancing operations expanded: All operations will be conducted with fixed-rate tenders and full allotment; the list of assets eligible as collateral in credit operations with the bank is expanded to include lower-rated (with the exception of asset-backed securities) and non-euro-denominated assets.
7/5/2009	Covered bond purchase program(CBPP)/LTRO	CBPP announced/LTRO expanded: The ECB will purchase 60 billion euros in euro-denominated covered bonds; 12-month LTROs are announced. ECB lowers the main refinancing rate by 0.25% to 1% and the rate on the marginal lending facility by 0.50% to 1.75%.
10/5/2010	Securities markets program (SMP)	SMP announced: the ECB will conduct interventions in the euro area public and private debt securities markets; purchases will be sterilised.
30/6/2010	CBPP	CBPP finished: Purchases finish on schedule; bonds purchased will be held through maturity.
6/10/2011	CBPP2	CBPP2 announced: The ECB will purchase 40 billion euros in euro-denominated covered bonds.
8/12/2011	LTRO	LTRO expanded: 36-month LTROs are announced; eligible collateral is expanded.
2/8/2012	Outright monetary transactions (OMT)	The ECB President Mario Draghi indicates that the ECB will expand sovereign debt purchases.
6/9/2012	OMT	OMTs announced: Countries that apply to the European Stabilization Mechanism (ESM) for aid and abide by the ESM's terms and conditions will be eligible to have their debt purchased in unlimited amounts on the secondary markets by the ECB.
16/03/2016	Expanded asset purchase programme (APP)	The ECB embarked on an APP to address the risks of a too prolonged period of low inflation. The APP are intended to be carried out until the end of 2017 and in any case until the Governing Council sees a sustained adjustment in the part of inflation that is consistent with its aim of close to 2%.

2.4. Review of Empirical Studies of the Effects of QE Operations

This section reviews the empirical literature on the effects of QE operations mainly within the U.S. and the U.K. The empirical studies have mostly examined the immediate impact of the LSAPs on yields in the bond markets. While a few others have focused on the effect of QE on the macro-economy indicators of the GDP and CPI in the US, and the UK.

2.4.1 Review of Studies of the U.S. QE Operation

Gagnon et.al. (2011) using event studies[12] based on LSAPs announcement dates regressed the 10-year yield term premium on the supply of government bonds, unemployment gap, core consumer price index (CPI) inflation found that the Fed's first round LSAPs of $600 billion reduced term premium on the 10-year government bond by 30-82 basis points (bps). They conclude that the Fed's LSAPs led to economically meaningful and long lasting reductions in longer-term interest on a range of securities such as Treasuries, agency mortgage-backed securities, and even securities not included in the LSAPs, which they believed was due to lower risk premiums including term premiums, rather than expectations of future short term interest rates.

Investigating the local supply effect using the 2009 Federal Reserve's $300 billion purchase of nominal Treasury coupon securities, D'Amico and King (2010) estimated a significant local supply effect in the Treasury term structure: the yield on a given security fell in response to purchases of that security as well as securities of similar maturities. Their results indicate that the local-supply effects of the LSAP as a whole shifted the yield curve down by about 30bp. They also argued that on the days when a security was eligible to be brought, purchases of securities with similar maturities had almost as large effects on its yield as did purchases of the security

[12] Event study assumes that all changes in the variable of interest that occur within a short time period are due to the event under consideration. The event study literature largely follows Cook and Hahn (1989). Their work has been followed by a large number of papers applying a similar approach to various asset prices, including Bomfim (2003), Bomfim and Reinhart (2000), Cochrane and Piazzesi (2002), Kuttner (2001), Bernanke and Kuttner (2003), Roley and Sellon (1996, 1998), Thorbecke (1997),and Thornton (1998).

itself. This supports the view that Treasuries of similar maturities are close substitutes but that substitutability diminishes as maturities get farther apart which is consistent with the imperfect substitutability principle of the portfolio rebalance channel and the preferred habitat-theory of term structure.

Also providing additional empirical evidence in support of the preferred-habitat theory and portfolio rebalancing channel is Doh (2010), who tried to unravel the quick reversion of the 10-year Treasury yield to its pre-announcement level in only five weeks. His regression results suggest that the Fed's LSAPs reduced the 10-year Treasury yield via the reduction in term premium, as implied by the preferred-habitat theory. Other important contributions on the effects of the Fed's LSAPs in support of portfolio rebalancing and preferred habitat assumption include Hamilton and Wu (2011), Swanson (2011), and Neely (2012) who investigated the impact of the U.S. QE1 on foreign 10-year government bond rates. He submitted that the U.S. asset purchase announcements had significant impacts on the international long-term rates with falls of 78, 65, 54, 50, and 19bps in Australia, U.K., Canada, Germany and Japan, respectively while also reducing the spot value of the dollar.

However, a few others presented a different picture, emphasizing the importance of the signalling channel or the expectation hypothesis in the Fed LSAPs. For example, Krishnamurthy and Vissing-Jorgensen (2011), using an event study methodology to evaluate the effect of the Fed's LSAPs between 2008-2009 (QE1) and 2010-2011 (QE2) on interest rates found significant evidence for the signalling channel which drove down the yields (with larger effects on intermediate than long-term bond) for both the QE1 and QE2. This led them to question whether the Fed could have achieved the economic recovery without the Fed taking on additional balance sheet risk.

Providing evidence in support of both the signalling and portfolio rebalancing channels for the Fed's first LSAPs program (QE1), are Bauer and Rudebusch (2013) who used an estimated dynamic term structure model (DTSM) to decompose the fall in long term (the 5-year and 10-year) Treasury yields into changes in expected future policy rates, and changes in term premium components. They found that cumulatively, the 10-year yield decreased by 89bps, while the 5-year yield decreased even more strongly by 97bps. For the 5-year yield, the relative contributions of expectations and term premium components are 32 percent and 68 percent, respectively. For the 10-year yield, the contributions are 35 and 65 percent, respectively for the expectations and term premium components.

Other notable contributions on the impacts of the Fed LSAPs include Christensen and Rudebusch (2012) who also substantiate an important role from the signalling channel for the Fed's LSAPs, Wright (2011), and Glick and Leduc (2012), who estimated the total effect on the 10-year U.S. Treasury yield over all LSAPs announcements declined by approximately 100bp.

Lo Duca et.al. (2016) analysed the link between global corporate bond issuance and the US QE using a panel setting. They find that purchases and holdings of MBS and Treasuries by the Fed have a strong impact on gross corporate bond issuance across advanced and emerging economies. Specifically, asset holdings and purchases crowded out investors from markets where the Fed intervened and accelerated portfolio rebalancing across assets and countries leading to stronger corporate bond issuance across the globe. A counterfactual analysis shows that bond issuance in emerging markets since 2009 would have been halved without QE.

2.4.2 Review of Studies of the U.K. QE Operation

Early empirical study of the U.K. QE programme by Meier (2009) using event study, found that that the first round of BoE asset purchases (QE1) impacted gilt yields, reducing the 10-year yield on U.K government gilts by at least 35-60bps. Subsequent studies such as Joyce.et.al. (2011) investigating the effects of the BoE QE1 and QE2 operations using an event study based on a 2-day window length, also found that the first phase of LSAPs of £200 billion of gilts depressed yields by around 100bps. However, Meaning and Zhu (2011) also using the event study technique with a one-day window found a reduction of close to 50bps in gilt yields. One obvious difference in their study compared to the study by Joyce et.al. (2011), is the choice of window length used in the event study methodology. While Joyce et.al, using a two-day window suggested a depression in gilt yields of about a 100bps, Meaning and Zhu (2011) using a one-day window reported a 50bp reduction.

Evidence in support of a statistically significant portfolio rebalancing effects from the BoE QE operations is provided by Joyce.et.al. (2011). They estimated a counterfactual scenario, based on QE1 employing VAR a model incorporating monthly historical data from 1991-2007 anchored with returns on and portfolio comprising gilts, investment-grade corporate bonds, and money as the endogenous variables, and industrial production, inflation and the slope of the yield curve as exogenous variables, they mimic the effects of QE by assuming a shock that reduces the quantum of gilts in private-sector portfolios. Their results show that the assumed shock reduces yields on gilts by 85bps, even though; the impacts unwind quickly reducing to 32bps after a 6 month period. In terms of the effect on gilt yields and other asset prices, the effect was smaller.

Breedon et.al. (2012) measure the impact of the U.K.'s initial QE1 operation on bonds using a macro-finance model of the U.K. government liability curve with which they constructed a counterfactual estimate of the term structure over the QE period, in order to simulate the impact of QE on the yield curve directly. They found that QE indeed was effective in terms of lowering longer term bond yields with an impact of around 50bps at the ten year maturity concluding, that QE had a significant and economically important impact on the bond market.

Goodhart and Ashworth (2012), reported significant diminishing returns following the BoE QE2. Going by their analysis, gilt yields actually rose on average by around 9 bps over the seven events, the yield curve steepened by 13 bps. While the FTSE 100 declined by around 5 per cent. Their conclusion was that the impact of QE2 was at best very modest and significantly less than QE1 arguing further that if policy makers fail to improve the bank lending or liquidity channel, further rounds of QE could potentially have negative returns and may contribute to keeping the economy trapped in a low growth equilibrium.

Other notable contributions on the effects of the BoE QE operations include Glick and Leduc (2012), and Martin and Milas (2012) who did a brief event study of the BoE latter QE purchases of £50 billion, using the 20-, 10-, and 5-year (zero-coupon) U.K. government bond rates. They reported very marginal decline in bond yields following the latter QE purchases by the BoE.

In summary, the empirical studies of the effects of the Fed and BoE's QE operations on their bond market reveal that the LSAPs (mainly QE1) did have significant effects in reducing the 10 year yields (see Table 4), although with the precise estimates varying across studies and methodologies. One major critique aside the obvious focus on the bond market by some of the studies is that the choice of the window length used in event studies to track the reaction of asset yields and prices is crucial, as a 2-day window tend to find larger effects, while a 1-day window and econometric models based on high frequency data tend to find relatively smaller effects that die out or unwind rapidly. This would suggest a little caution in interpreting evidence on the effects of QE from the event studies, as they may have overestimated the effects because of the possibly exaggerated impact due to using a larger event window.

Table 4: Estimated effects of LSAP/QE on 10 year bond/gilt yield from the literature

Studies	**Total Impact (US)**	**Total Impact (UK)**
Meier (2009)		-35bp to -60bp
Doh (2010)	-39bp	
Hamilton & Wu (2011)	-13bp	
D' Amico and King (2010)	-30bp to -45bp	
Gagnon et.al. (2011)	-30bp to -82bp	
Neely (2011)	-107bp	
Wright (2011)	-25bps	
Joyce et.al. (2011)		85bp to -100bp
Meaning & Zhu (2011)		-50bp to -75bp
Krishnamurthy & Vissing-Jorgensen (2011)	-33bp	
Glick and Leduc (2011)	-50bp to -60bp	-50bp
Breedon et.al. (2012)		-50bp

2.4.3 Review of Empirical Studies on the Macro-economic Effects of QE

This section reviews the literature on the impact of QE on real activity i.e. the GDP (output) and the price level (inflation). Evidence comes from econometric modelling based on policy and no-policy counterfactual scenarios using data drawn largely from before 2008 implicitly assuming that key macroeconomic relationships in the data are unaffected by the unusual circumstances of the financial crisis.

Baumeister and Benati (2010) using a time-varying parameter structural VAR (TVP-VAR) model for the U.S. and the U.K. economies which allows the capturing of the macroeconomic structure in the context of the Great Recession of the 2007-2009[13] found that a compression in the long-term yield spread exerts a powerful positive effect on both output growth and inflation when interest rates are at the effective zero lower bound. In their counterfactual simulation[14] for the U.S. they showed that without the large-scale asset purchase program the U.S. economy would have been in deflation for two quarters with annualized inflation being as low -1% in 2009Q2, annualised real GDP growth would have shrunk by 10% in 2009Q1, and that the unemployment rate would have been consistently above its actual value throughout 2009 reaching 10.6% at the end of 2009. A similar picture also emerged for the U.K. in their counterfactual simulation with findings that inflation would have fallen to minus 4 percent and output growth would have dropped by 12 percent at annual rates in the absence of the BoE asset purchases. They concluded that the QE policy actions in the U.S. and the U.K. prevented economic catastrophe and averted significant risks of deflation and output collapses.

[13] In their analysis, they define a pure spread shock as a disturbance that leaves the short-term policy rate unchanged, which allows a characterisation of the responses of macroeconomic aggregates to a decline in long-term yield spreads induced by central banks' bond purchase programs under circumstances where the short rate cannot move, which is exactly the situation encountered at the zero lower bound.

[14] Their counterfactual simulation for the U.S. was conditional on the estimates from Gagnon et.al. (2011) estimated impact of the Fed's asset purchases on U.S. long-term yield spreads-specifically the average between their lower and upper estimates of the impact on the 10-year government bond yield spread, which is 60bps. In their counterfactual simulation for the U.K. they relied on the BoE Deputy Governor, Charlie Bean (2009) broad estimate of the impact of the BoE's gilt purchases on long term yield spreads of around ½ percentage point fall in the spreads on commercial paper.

Chung et.al. (2012) used a different approach based on the Federal Reserve Board's FRB/US large-scale macroeconomic model, to investigate the impact of the Fed's QE programme on the U.S. macro-economy. Their counterfactual simulations incorporating a simple model of the portfolio rebalance channel calibrated to mimic the first round of QE operation reduction of long-term interest rates by 50bps suggest that the expansion of the Fed's balance sheet by the QE1 and QE2 operations boosted the GDP by 3% or 300bps and that inflation climbed 1% higher than would have prevailed in the absence of asset purchases by the Federal Reserve, implying that the QE operation averted a deflationary spiral and kept unemployment from escalating in the U.S. The effect of the Fed's LSAPs, they argued is similar to a 300bps reduction in the policy or federal fund rate from 2009Q1 to 2012.

Chen et.al. (2012) in investigating the macroeconomic effects of the Fed's $600 billion LSAP2, in an estimated DSGE model, with quarterly data for the US from 1987:Q3 to 2009:Q3 for the seven series of real GDP per capita, hours worked, real wages, core personal consumption expenditures deflator, nominal effective Federal Funds rate, the 10-year Treasury constant maturity yield, and the ratio between long-term and short-term US Treasury debt; concluded that the effects of the Fed's LSAPs on macroeconomic variables, such as the GDP growth and inflation, were likely to be modest, although with a lasting impact on the level of GDP.

Bridges and Thomas (2012) estimated the impact of QE in the U.K. using a money demand and supply framework. They assumed that the U.K. QE1 operation of £200 billion increased the money supply (M4) by around £120 billion or 8 percent. They then analyse the impact of the increase in the M4 for the aggregate economy using an eight variable structural non-stationary I (1) VAR model estimated using quarterly data running from 1964Q1-2007Q3 on the level of real GDP, annualised CPI inflation, the real exchange rate, the broad money supply, the deposit rates, and short term interest rates. Their results showed a peak positive impact on the level of real GDP of around 150bps or 1.5 percent at the start of 2010 before declining and becoming negligible by mid-2011. The impact on inflation was a little larger than the GDP at a peak of around 2 percentage points which occurred in 2011 before declining thereafter.

Lyonnet and Werner (2012) also investigated the effectiveness of the QE policy as implemented by the BoE since March 2009. Using the general-to-specific econometric modelling methodology[15] capturing the final policy target of nominal GDP regressed on a number of explanatory variables including bank reserves and the maturity structure of central bank bond holdings found no empirical evidence that the QE had any apparent effect on the UK economy. They also highlighted that despite the BoE's policies, bank credit growth contracted by record amounts in late 2011 while the UK economy entered into a double-dip recession in the first half of 2012.

Lenza et.al. (2010) using a Bayesian VAR model of the euro area economy with monthly data from 1991M1-2009M8, capturing variables, covering various aspects of real activity, nominal variables and monetary aggregates, computed a policy scenario conditional on actual money market rates and a no-policy scenario conditional on a path for money market rates that would have prevailed in the absence of the ECB's policy intervention. One aspect of the authors' empirical findings that stand out is that the ECB's policy response appears to have had adverse effect on short-term loans to non-financial institutions. Suggesting that the unconventional monetary or QE policy interventions by central banks may not be without unintended outcomes.

[15] The general-to-specific methodology allows all competing monetary policy tools, intermediary instruments and differing interpretations of QE to be equally represented in the first general model. Afterwards, a sequential downward reduction to the parsimonious form is implemented by dropping the less significant variables, which amounts to a horse-race between the variables in the first general model which enables an assessment of the relative performance of the competing policy models.

In a counterfactual policy evaluation with an empirical application to the UK QE using an ARDL (1, 1) model, Pesaran and Smith (2014) reported that the QE had an immediate positive effect of growth, but that this effect tends to disappear quite quickly, certainly within a year. Applying their proposed policy ineffectiveness test statistic, their null hypothesis of policy ineffectiveness is not rejected i.e. QE did not have a significant effect on UK growth.

In summary, the consensus of the literature (excluding a few) on the effects of QE on the real economy is that QE does work- having a positive impact on the macro-economy. The results of the studies on the effects of the QE operations on real GDP or output and inflation have concluded that QE increased the level of GDP between the range of 1-3 percentage points with a similar size effect on the general price level or inflation, implying that QE has averted deflationary pressure in the wake of the last global financial turmoil.

A critique of these studies or empirical analyses of the macro-economic effects of QE, is the implicit assumption that the historically observed or underlying relationships in the data used to decipher counterfactual and non-counterfactual scenarios have not been affected by the recent financial crisis i.e. (the Lucas critique). There is reason to doubt that the underlying behavioural relationships have remained unaffected given the severe economic dislocations in the aftermath of the financial crisis especially the zero lower bound on policy rates.

2.5 SEGMENTATION VS EXPECTATION: SOME EMPIRICAL EVIDENCE

Early evidence in support of the price impacts of supply shifts have come from a few historical episodes such as the Federal Reserves' Operation Twist' (OT) of the early 1960s. Although the early finding at the time was that the OT attempt at twisting the yield curve i.e., influencing the long end of the yield curve by selling short term bills and simultaneously using the proceeds to buy the long term bonds in the open market, was mainly unsuccessful (Modigliani and Sutch, 1966). Kuttner (2006) attributed the inability of OT in flattening the yield curve as intended at the time, to the insufficient or small purchase of bond securities by the Fed.

More evidence in support of the price impacts of supply shifts came from Bernanke, Reinhart and Sack (2004), in the case of LSAPs of US long-term Treasury bonds by the Japanese government at the height of the Asian currency crisis and the Japanese financial crisis of the 1990s and 2000s. Their findings were that LSAPs of the US Treasury bonds during this period lowered the yields of the five-year and 10-year bonds by an average of 50 to 100 bps. Garbade and Rutherford (2007) also provide evidence in support of supply shifts, using the episode of the US Treasury buyback program of 2000-2001, where the US Treasury conducted 40 buybacks, with a total value of $63.5 billion. Their findings were that the Treasury buybacks narrowed the spread of the 20-year rate and the one-year by 0.75%.

In contrast, Woodford (2012) attributes most of the effect of asset purchases to some form of signalling. Similarly, Farmer (2012), with a core monetary model of inflation, augmented by a complete set of financial markets showed that LSAPs of MBS and long-term bonds by the Fed signalled the Fed's intent to achieve the inflation target and therefore condition financial market expectations, thus helping in preventing deflation at the zero lower bound. While Steeley (2013) argued that the QE by the BoE led to an increased yield curve dimensionality providing support for the expectations channel by suggesting that the BoE gilt purchase auctions may have in fact resulted in a change in inflation expectations.

2.6 Conclusion

One obvious aspect that has not been really investigated or covered in the literature on the effects of QE, specifically from the financial market perspective is the interactions in the broader financial markets and broader asset categories i.e. in the link from the LSAPs or bond purchases to the broader aspects of the financial market. This is where the current study fills the gap in the QE literature and the subsequent empirical chapters after this review chapter are devoted to the investigation of the effects of the QE operations on the broader financial markets beyond the effects on yields in the bond markets as focused on by earlier studies.

Chapter 3.The Effect of the Fed and BoE QE on the UK, US and other Equity Markets

3.1 Introduction

This chapter empirically examines the impact on equity markets of the QE operations implemented by the Bank of England (BoE) and the Federal Reserve (Fed) in the aftermath of the recent financial crisis. It focusses on the effect of these QE operations on the return and volatility of the equity markets an area overlooked by previous studies (see the QE literature review in chapter 2) on the effects of QE. Earlier studies on the QE operations have majorly focused on the impacts on yields in bond markets and the macroeconomic aggregates of GDP (output) and CPI (inflation) arising from the large scale bond purchases by the aforementioned monetary authorities.

Although the QE operations have largely involved bond purchases, the portfolio balance channel as espoused in Tobin (1958 and 1963), which is anchored on the doctrine of imperfect substitutability between different types of financial assets, holds that central bank asset purchases of the QE kind not only push up the prices of the assets bought while also lowering the yields on these assets, but also the prices of other assets that are imperfect substitutes to the ones bought. This provides the theoretical grounding and motivation for this study focussing on the effects of QE on the stock or equity markets.

The literature on the effects of macroeconomic policy news/announcements on returns in stock markets and volatility in stock markets has an extensive history. Officer (1973) investigated the effects of volatility in the business cycle variable of industrial production on the variability of the market factor defined as the returns to all stocks listed on the New York Stock Exchange (NYSE) for the three sub-periods from February 1919 to January 1929, from February 1929 to January 1944, and from February 1944 to June 1969. He found a strong relationship between the two variables concluding that economy wide factors are mainly responsible for the pattern of market-factor variability.

Campbell (1987) argued generally that the state of the term structure of interest rates predicts stock returns. He found that when realised excess returns on assets including bills, bonds and stocks, are regressed on information variables which measure the state of the term structure, the fitted values are far from constant. Instead, they vary for the period studied (1959-1978) with a standard deviation on an annualised basis of almost ¼% per month for bills, 6% for bonds and 17% for stocks. Over the same period, average bond returns were 1½% a year less than bill returns and 5% less than stock returns. He concluded that higher short term interest rates led to higher stock market volatility.

Schwert (1989) investigated a number of factors that could influence stock volatility. He analysed the relation of stock volatility with real and nominal macroeconomic volatility, economic activity, financial leverage, and stock trading activity using monthly data from 1857 to 1987. He noted that stock return variability was abnormally high during the 1929-1939 Great depression and although agreeing with Black (1976) with the findings that aggregate leverage is significantly correlated with volatility, he noted that this explained a relatively small part of the movements in stock volatility.

Antoniou and Holmes (1995), investigated the impact of trading in the FTSE-100 stock index futures on the volatility of the underlying spot market for the period November 1980 to October 1991 using the GARCH framework. Their results for the impact of trading in the FTSE-100 index futures suggested that futures trading had led to increased spot price volatility. In particular, the variance of price changes pre-futures was integrated, implying shocks had a permanent effect on price changes, whereas their post-future sample was found to be stationary.

Becker et.al. (1995) investigated the equity market linkage between the US and UK focusing on intraday price movements of stock index futures contracts for the FTSE100 and the S&P500 from July 1, 1986 to December 28, 1990. They reported a heightened UK return volatility at 11.30am and 1.30pm GMT, which tallied with regular macroeconomic releases in the UK and US respectively. In addition, it was found that FTSE prices respond to UK news while the US market ignores this information. Thus concluding that their finding was consistent with the view that documented equity market linkages are attributable to news emanating from the US. Such that international markets respond alike to US news while the US generally ignores foreign news, resulting in an international correlation pattern in which US prices lead foreign returns.

In an attempt to provide an answer as to why the US stock market is much more volatile at some times than others, Hamilton and Lin (1996) arrived at a similar conclusion as did Schwert (1989a, 1989b) that economic recessions are the single largest factor, accounting for over 60% of the variance of stock returns.[16]

Bekaert et.al. (2013) documented a strong co-movement between the VIX, the stock market option-based implied volatility, and monetary policy measured as the real interest rate, i.e. the Fed funds end-of-the-month target rate minus the CPI inflation rate. They decomposed the VIX into a proxy for risk aversion and expected stock market volatility. Characterising the dynamic links

[16] This is a very small selection from a vast literature that to review would encompass an entire chapter in itself. other studies that have examined the effects of monetary policy surprises and other macroeconomic news on stock market volatility include Rozeff (1974), Ederington & Lee (1993), Bomfim (2003), Graham, Nikkinen, & Sahlstrom (2003), Nikkinen & Sahlstrom (2001, 2004a, 2004b), Kearney & Lombra, (2004), Steeley (2004), Nikkinen et.al.(2006), Brenner et al (2009). There are also parallel literatures examining the effects of news on bond market returns and on volatility, for example, Jones et al (1998), Balduzzi et al., (2001), De Goeij and Marquering (2006), Brenner et al (2009), Nowak (2011) and Abad and Chulia (2013).

between stock market volatility, and monetary policy in a simple vector-autogressive (VAR) system using monthly data for the US from January 1990 to July 2007, They found that stock market volatility which they also referred to as uncertainty appear to be unaffected by monetary policy. However, periods of high uncertainty were followed by a looser monetary policy stance.

Kim and Nelson (2014) investigates the impact of business cycle-related market volatility on expected stock returns. Using data on excess stock returns on a market portfolio, constructed from the CRSP value-weighted portfolio, the 30-day US Treasury bill rate and the Conference Board Coincident Economic Index over the period January 1959 to June 2012 in a bivariate regime-shift model of stock returns and output growth they found that business cycle-related market volatility is priced in the stock market by higher expected return, whereas the unrelated component is not.

Tan and Kohli (2011) examine the volatility of the US stock market over the period 2008 to 2011, which encompasses the early phase of the US QE. They examine an AR (1) process and a modified constant elasticity of variance model, both applied to the VIX measure of implied volatility for the S&P500 index. They found a significant drop in the VIX implied volatility that then reverted to previous levels following the ending of the early phase of QE. Joyce et.al. (2011) also examine the behaviour of the option-implied volatility of the FTSE100 index using monthly data between January 2009 and June 2010, a period encompassing the UK QE1 phase. They found that the twelve-month implied volatility fell during 2009.

Koijen et.al (2016) use data on security-level portfolio holdings of institutional investors in the euro area to investigate the impact of the ongoing asset purchase programme of the ECB on sovereign bond yields. Their results suggest that the programme lowered bond yields and the purchases by the ECB are absorbed differently across institutions with banks and mutual funds most elastic than insurance companies and pension funds.

This study investigates the impact on the equity markets of the US and UK QE operations implemented in the aftermath of the great recession. It specifically adds to a small number of studies of the effects of QE, by including all the phases of QE in the UK and the US (including the MEP in the US), isolating their separate effects, using daily data, measuring the intensity of QE activity on specific purchase days and calibrating this directly into the data modelling process and also broadening the analysis to more than a single country. Which enables an assessment of whether the QE activity affects not only the equity market of the country within which the QE activity took place but ascertain if there were spill-overs effects on other equity markets. In summary, this chapter examines the impact of the unconventional monetary policy actions or QE operations on the return, volatility, cross correlation and trade volume in the equity markets of the UK and the US.

Following this introductory section, the next section presents the data and summary statistics. Section 3.3 develops a number of hypotheses vis-à-vis the transmission channels of QE. The empirical methodology implemented in this chapter to test the effects of QE on the equity market returns, volatility and trade volume is discussed in section 3.4. The result from the event study of the effects of the US and UK QE operations on bond and equity market yields is presented in section 3.5. The empirical results from the estimated GARCH models showing the impact of the QE operations on the US and UK equity markets are presented in section 3.6. The results of the QE liquidity channel test are presented in section 3.7. Section 3.8 looks at the impact of the US and UK QE operations on other equity markets, while section 3.9 concludes this chapter.

3.2 Data and Summary Statistics

To examine the effect of QE on the equity markets, the study employ daily data on equity indices (as a measure of returns), the ratio of the relative to total amount of the market value of bond purchases by the BoE and the Fed (as a measure of QE intensity), the QE intensity measure captures the actual size of QE activity on each particular day of the QE purchases, to determine whether this has an effect beyond a general effect of the markets being within a period of QE. In addition, indicator variables capturing the different phases of the QE operations and other market events, which may have had an impact on the financial markets, such as the collapse of Lehman Brothers in 2008, and the Northern Rock incidents in the UK also feature in the data modelling process.

Daily closing observations adjusted for dividends of the FTSE100 and S&P500, and subsequently the CAC40, the DAX30 and the ASX price indices were taken from DataStream. These price indices (*p*) are converted to returns (*r*) by the standard method of calculating the log-difference, r_t= log (p_t/p_{t-1}). These observations start from 2004:01 and run to 2014:10. Although the QE (bond/gilt) operations commenced in March 2009, the choice of the relatively longer sample starting period from 2004, is to enable a basis for comparison for pre and during QE episodes especially for the US and UK equity markets.

QE purchases data were obtained from the BoE and Fed websites respectively for the UK and the US and were calculated such that the market value of bonds purchased on any given day t since the start of QE in March 2009, was divided over the total value of bond purchases in the entire QE period ending October 2014 . The indicator variable(s) is assigned the value of 1s during its period and 0s elsewhere. For example the indicator variable capturing the Lehman Brothers collapse takes the value of 1 from September 15th 2008 and zero before this date.

Similarly designed indicator variables were used to capture the effects of the various QE phases or periods in the US and UK.

Before going further, the study at this juncture show descriptive statistics and the cross section distribution of the QE operations in the UK and the US and the descriptive statistics of the equity returns used in the study. Summary statistics of the QE operations and the daily equity returns information for the UK and the US are presented in Tables 5 and 6 respectively.

Table 5: Summary statistics of the UK and US QE operations.

UK (Billions of £s)			
	Frequency	**Mean**	**S.D.**
QEI	92	1936.404	696.9535
QEII	78	1374.283	104.9464
QEIII	74	944.9270	237.1380
US (Billions of $s)			
QEI	60	5000.000	2306.007
QEII	176	4945.727	2720.339
MEP	160	3174.700	1601.354
QEIII	421	2331.808	1384.799

Table 5 shows the mean (average) in billions of £ and $ respectively for the QE operations for the UK and US. The upper panel shows the statistics for the UK QE operations in phases of QE1, QE2 and QE3, while the lower panel shows the statistics for the US QE operations as executed in phases of QE1, QE2, and the maturity extension program (MEP) and QE3. For the UK QE1, the mean value is £1,936,404,000 totalling £178,149,168,000 (i.e. mean value multiplied by the frequency); for the UK QE2, the mean value is £1,374,283,000 totalling £107,194,074,000; while for the UK QE3, the mean value is £944,927,000 totalling £69,924,598,000. Summing across these phases of the QE operations for the UK, amounted to a value of £355, 267,840,000.

Similarly for the US QE1, the mean value is $5,000,000,000 totalling $300,000,000,000; for the US QE2, the mean value is $4,945,727,000 totalling $870,447,952,000; whereas the mean value for the MEP is $3,174,700,000 totalling $507,952,000,000; while the mean value for the US QE3 is $2,331,808,000 totalling $981,691,168,000. Summing across the various operations for the US gives a market value of $2, 660,091,120,000. Figures 5 and 6 show the cross-sectional distribution of asset purchase during the individual phases of the QE operations as a proportion of the total value of the QE operations or bond purchases, for the UK and the US respectively.

Table 6: Summary statistics of the daily equity returns Jan 2004-Oct 2014.

	USA	UK
Mean%	0.020	0.013
Standard Deviation%	1.230	1.166
Skewness	-0.313	-0.154
Kurtosis	15.092	12.370
Jarque-Bera (p-value)	15042 (0.000)***	10477 (0.000)***
Num. of Observation	2713	2803

*** indicates statistical significance at 0.01 level.

Table 7: Daily equity market correlations for the US and UK

Period	02/01/2004-10/03/2009	11/03/2009 - 9/10/2014	02/01/2004-9/10/2014
N	1306	1406	2713
ρ	0.541	0.671	0.593
Prob.(F-stat)	0	0	0

Note: N is number of observations, ρ is the correlation coefficient, Prob. (F-stat) is the P-value of the F-statistic of the corresponding two-variable regression.

Figure 5: Cross-Section Distribution of QE Purchase Activity: UK

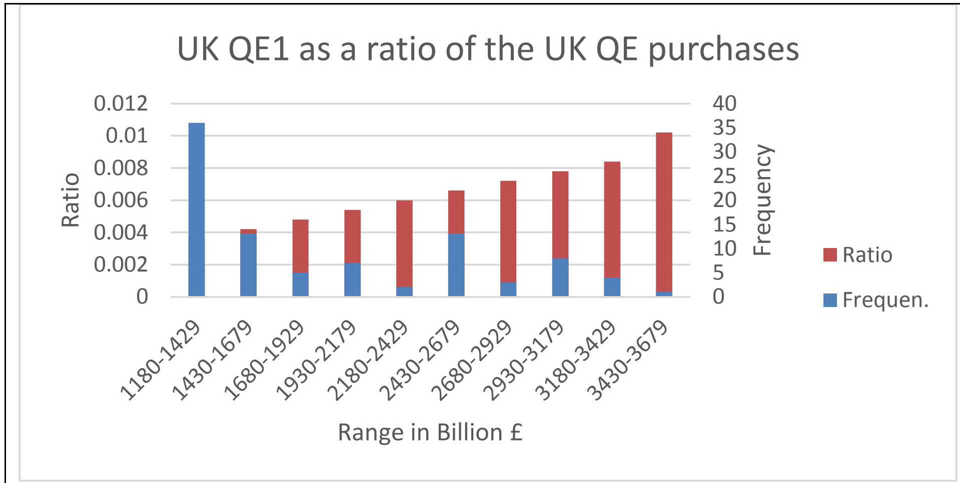


Figure 5a

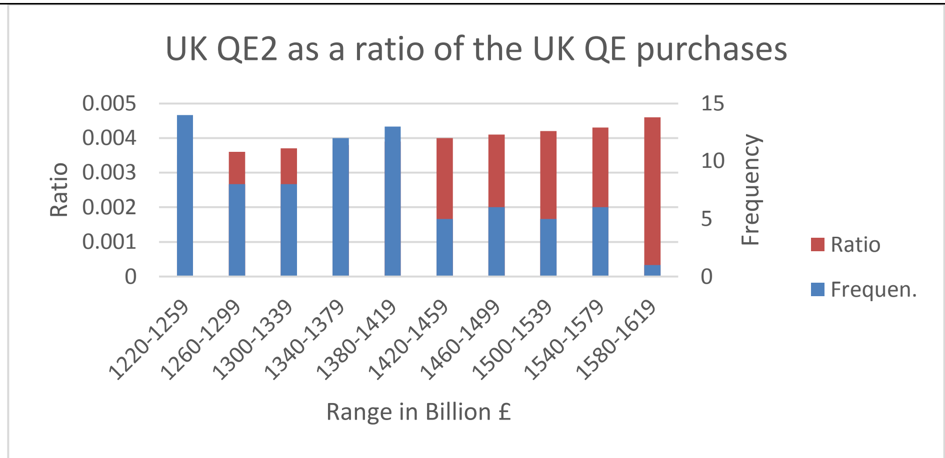


Figure 5b

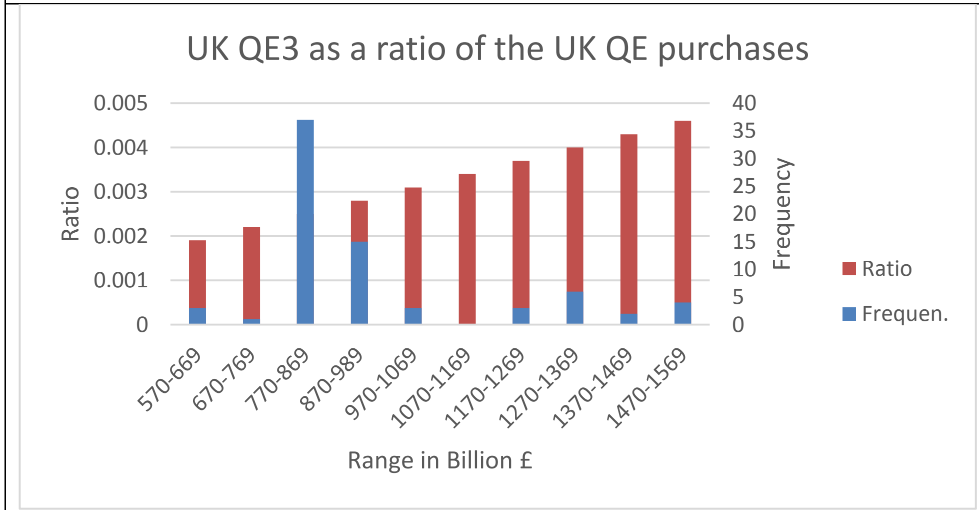


Figure 5c

Figure 6: Cross-Section Distribution of QE Purchase Activity: US

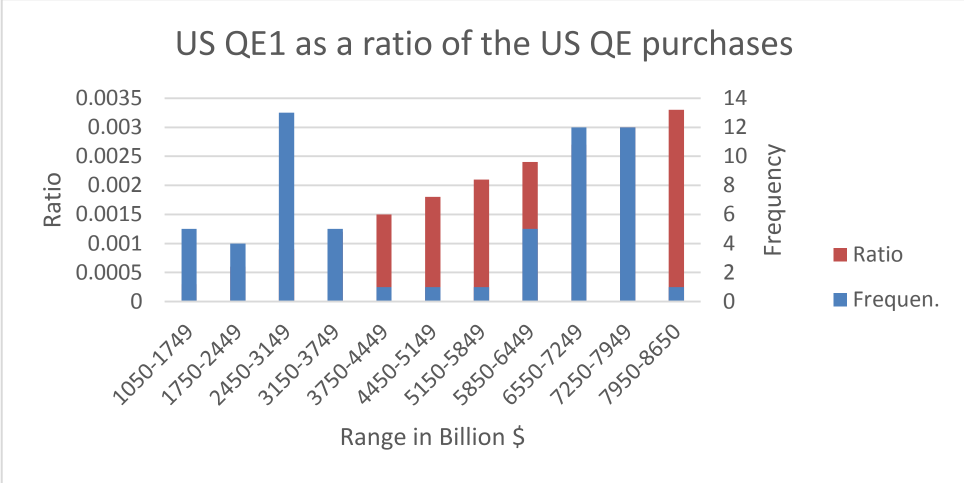


Figure 6a

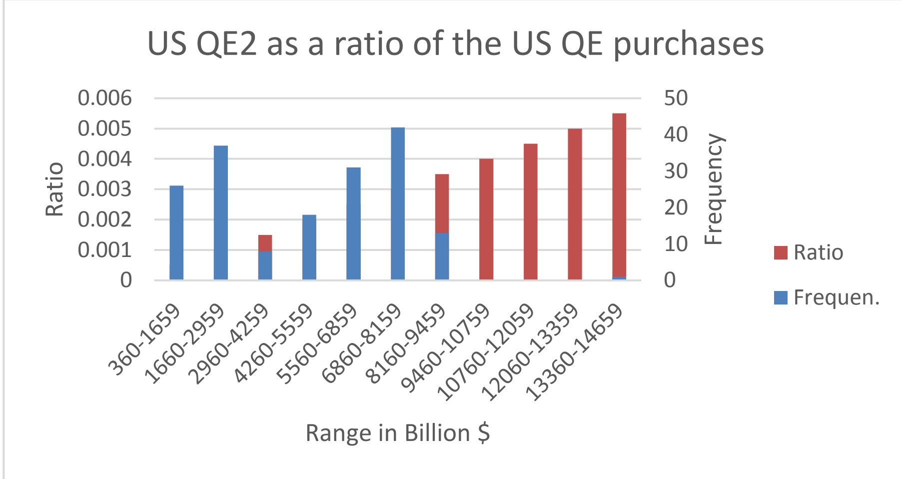


Figure 6b

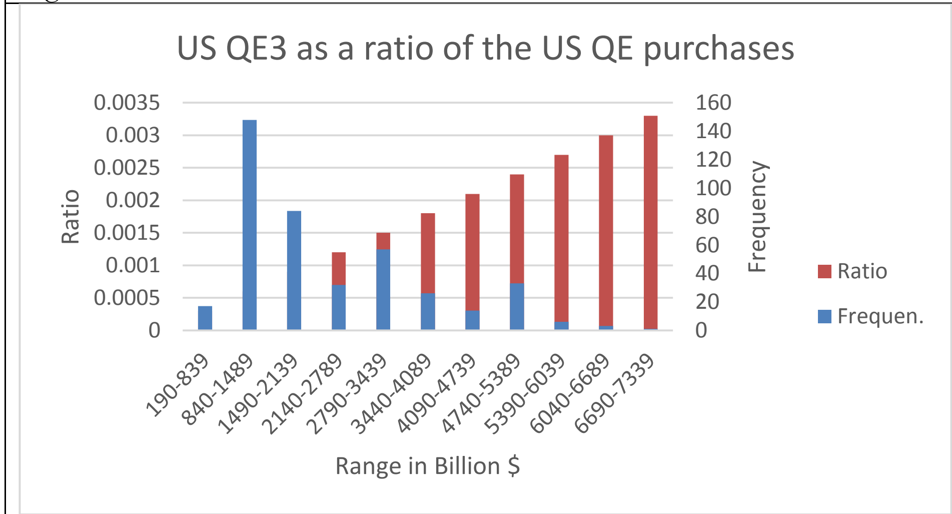


Figure 6c

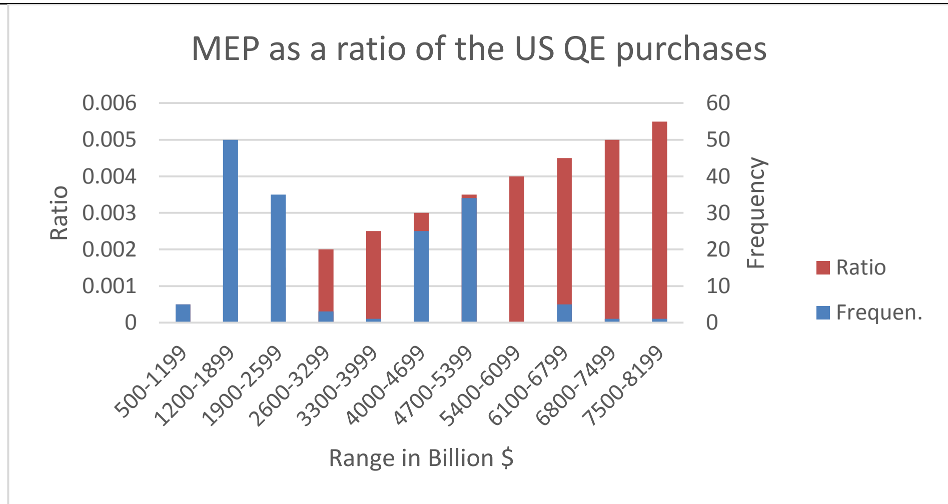


Figure 6d

The summary statistics for the returns series, in Table 6, show that the daily mean returns for the US and UK equity markets for the sample period are 0.020 and 0.013 per cent per trading day or about 5.04 and 3.34 percent per year, respectively. While the US and UK markets were both negatively skewed implying a negative distribution of daily equity returns over the sample period, overall both skewness are small. However, both return series are leptokurtic, reflecting the fat-tailed nature of the distribution of asset returns.

In addition to the summary statistics computed for the daily returns, the study also computed the correlation coefficient between the daily equity market returns, dividing the sample into three sub-periods thus providing comparative statistics for periods before and during QE, and a period encompassing both periods. Table 7 shows the daily equity market correlation between the US and UK equity market returns for each of the three periods. The correlation coefficients were verified for significance, by regressing the UK equity market returns on the US equity market returns and using the P-values of the F-statistic from the regression outputs, which were all highly significant. The correlation between the markets increased from 54 percent prior to the start of QE to 67 percent afterwards.

3.3 Hypothesis Development

In the portfolio balance channel, it is the quantity of asset purchases that affects prices and yields. Specifically, QE bond purchases by the monetary authorities reduce the supply of the asset available to the private sector, increasing the prices while lowering the yields on the asset bought as well as those of other imperfect substitutes like equities. To test the QE portfolio balance channel, the quantum of LSAPs by the BoE and Fed are directly measured and calibrated into the empirical models (mean equations) specified in the thesis and the hypothesis tested is:

Ho_1: the actual LSAPs do not generate significant reduction in equity market yields.

Hi_1: the actual LSAPs do generate significant reduction in equity market yields.

Forward-looking investors may however react to news of future asset purchases even before the actual purchases occur. Because these reactions to news of future asset purchases are priced immediately, credible announcement of future bond purchases can have the immediate impact of affecting the prices and yields of the assets involved and those of other imperfect substitutes outside of the bond markets such as the equity markets which are focus of the analysis in this chapter. It is worth re-emphasis, that the LSAPs by the monetary authorities in both the UK and US were not used to signal that the future path of short-term interest rate would remain low. In fact, the Fed while expanding its balance sheet through LSAPs was simultaneously informing the investing public that it would still be able to raise short-term interest rates at the appropriate time. While the MPC of the BoE explicitly stated that:

The *MPC's asset purchase programme was directed towards large-scale purchases of conventional gilts. The impact was expected to be seen in gilt markets, but also across a broader range of asset prices and in real activity and inflation. The MPC did not explicitly use these purchases to signal future intentions, emphasising its commitment to meeting the inflation target through the usual channels of monetary policy communications – including the MPC minutes and the quarterly Inflation Report. Nor were its actions focused on improving the functioning of gilt markets where liquidity premium, even in stressed times, were considered to be small'. (Joyce et.al. 2010:8).*

Nevertheless, it behoves, that the signalling is tested. A plausible approach to testing the signalling channel of QE is to carry out an event study analysis of the Fed and BoE official communications relating to their major QE announcements. In particular, the thesis examine the immediate reaction or changes in the equity market returns and the 10 year Treasury bond yield in the US, and the 10 year gilt yield in the UK to the major announcements relating to the QE purchases of the Fed and BoE respectively, and taking the cumulative changes as a measure of the impact of the signalling channel. This is in line with the approach used by Bernanke, Reinhart, and Sack (2004) examining specific news events concerning future Treasury issuance or purchases of longer-term securities which reported that yields dropped on days in which the financial markets heard of future declines in the net-supply of longer-term Treasury securities.

The hypothesis for the signalling channel tests the announcement impact of QE on equity returns and bond yields as follows

Ho_2: QE announcements have no impact on equity and bond market yields.

Hi_2: QE announcements have an impact on equity and bond market yields.

To test the QE liquidity channel, the thesis examined the direct impact of the actual LSAPs on trade volumes in the equity market. As mentioned in the discussion of the liquidity channel in the previous chapter, this channel may operate at times of financial market stress and relates to the beneficial market effects that LSAPs by the central bank may have in times of significant financial market strains or immediately following a financial crisis or market freeze, by providing liquidity which may encourage market participants to trade more actively thus improving volume.

Moreover, trading volume is frequently used as a liquidity measure, and can proxy for both market depth and trade immediacy, with lower volumes indicating adverse liquidity conditions

(Fleming, 2003). If the QE actions affects the equity markets in ways that increase the volume of trade, then these would be clear evidence of the QE liquidity effects which should be seen as beneficial. By contrast, if the monetary authorities QE actions engender a decrease or lower trade volumes, this would be seen as a cost of the QE liquidity channel. Thus the hypothesis tested for the QE liquidity channel is:

Ho_3: actual QE purchases have no significant impact on equity market trade volume.

Hi_3: actual QE purchases have a significant impact on equity market trade volume.

This is achieved by regressing daily changes in the trade volumes of the each of the UK and US equity market on respectively, the BoE and Fed QE purchases by period or phase.

3.4 Methodology

The generalised autoregressive conditional heteroscedasticity (GARCH) family of statistical processes (Engle, 1982 and Bollerslev, 1986) is used to model the variance processes of the returns in the US and UK equity markets.[17] The model for the US equation is

$$R_{i,t} = \alpha_{i,0} + \alpha_{i,2}\mathrm{EFFR}_{i,t} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\mathrm{D2}_{i,t} + \theta_{i,3}\mathrm{D3}_{i,t} \quad (3.1)$$

$$+\theta_{i,4}\mathrm{D4}_{i,t} + \phi_{i,1}\mathrm{QE1}_{i,t} + \phi_{i,2}\mathrm{QE2}_{i,t} + \phi_{i,3}\mathrm{QE3}_{i,t} + \phi_{i,4}\mathrm{MEP}_{i,t} + \varepsilon_{i,t} - d_1\varepsilon_{i,t-1}$$

where $\varepsilon_{i,t}\big|\,\Omega_{\,t-1} \sim N\big(0, h_{i,t}\big)$, and

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\mathrm{EFFR}_{i,t} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + \theta_{i,1}D1_{i,t}$$

$$+\theta_{i,,2}\mathrm{D2}_{i,t} + \theta_{i,3}\mathrm{D3}_{i,t} + \theta_{i,4}\mathrm{D4}_{i,t} + \phi_{i,1}\mathrm{QE1}_{i,t} + \phi_{i,2}\mathrm{QE2}_{i,t} + \phi_{i,3}\mathrm{QE3}_{i,t} +$$

$$\phi_{i,4}\mathrm{MEP}_{i,t} \quad (3.2)$$

While for the UK equation, the model is

$$R_{i,t} = \alpha_{i,0} + \alpha_{i,2}\mathrm{MPC}_{i,t} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\mathrm{D2}_{i,t} + \theta_{i,3}\mathrm{D3}_{i,t} \quad (3.3)$$

$$+\phi_{i,1}\mathrm{QE1}_{i,t} + \phi_{i,2}\mathrm{QE2}_{i,t} + \phi_{i,3}\mathrm{QE3}_{i,t}$$

where $\varepsilon_{i,t}\big|\,\Omega_{\,t-1} \sim N\big(0, h_{i,t}\big)$, and

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}MPC_{i,t} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} \quad (3.4)$$

$$+\theta_{i,2}\mathrm{D2}_{i,t} + \theta_{i,3}\mathrm{D3}_{i,t} + \phi_{i,1}\mathrm{QE1}_{i,t} + \phi_{i,2}\mathrm{QE2}_{i,t} + \phi_{i,3}\mathrm{QE3}_{i,t}$$

[17]. See also the survey paper by Bollerslev et al. (1992). Pre-testing of the returns series strongly rejected the null hypothesis of no ARCH effects.

The above empirical methodology implements a modification to and extends the approach of Steeley (2015). In the above, $R_{i,t}$ is the daily return from market i in week t, $i \in$ US, UK. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} + < 1$. Pre-testing of the model indicated the presence of residual autocorrelation in the returns equation for the US equity market. So, in line with the approach of Bollerslev (1987) and French, Schwert, and Stambaugh (1987), who had similar findings, the study include a first order moving average MA(1) in the returns equation in the US model to remove any serial correlation. No residual autocorrelation was found for the UK stock market returns, during the sample period, consistent with the recent findings of Steeley (2015). As first observed by Fisher (1966), index returns will be characterized by autocorrelation where the component asset returns respond with different speed to new information.

The variable $\text{Lehman}_{i,t}$ is an indicator variable that takes the value one during the period starting with the collapse of Lehman Brothers on September 15, 2008. For the UK market, the study also included initially an indicator variable that takes the value 1 from the day of the Northern Rock rescue on September 14th, 2007 until the day before the Lehman collapse, but excluded this from the final model as it was not statistically significant.

The variables $D1_t$, $D2_t$ and $D3_t$ are also indicator variables capturing the effects of the different phases of QE activity. Thus, for the UK, the variables take the value of one during the following periods, and are zero otherwise: $D1_{i,t}$ (QE1) from 11th March 2009 to 26th January 2010, $D2_{i,t}$ (QE2) from 10th October 2011 to 2nd May 2012, and $D3_{i,t}$ (QE3) from 9th July 2012 to 1st November 2012. Similarly, the corresponding periods for which these variables take the value of one for the US phases of QE are: $D1_{i,t}$ from 25th March 2009 to 29th October 2009, $D2_{i,t}$ from 3rd November 2010 to 30th June 2011 and the $D3_{i,t}$ from 13th Sep. 2012 to 31st Oct. 2014. The variable $D4_{i,t}$, which is only used in the US market equations, is an indicator variable for the maturity extension programme conducted between 21st September 2011 and 30th Jun. 2012, prior to the US QE3 phase. The intensity (actual bond purchases) of QE activity on a particular day is measured by the variables $QE1_t$, $QE2_t, QE3_t$ and MEP_t (in the US equations only) and are similarly separated by the phases of QE. The value of this variable on a given day *t* is the actual value of purchases on that day relative to the total value of purchases over the entire QE period.

Although the focus of the thesis is the unconventional monetary policy of QE or LSAPs implemented by the BoE and the Fed in response to the great recession, to incorporate the monetary policy stance, during or within the estimation period when QE bond purchases were not underway, the study include the policy rates i.e. the effective Federal Fund Rate (EFFR) in the US and the MPC Bank Rate in the UK in the relevant model specification.

The form of the variance equations in (3.2 & 3.4)) is a standard GARCH(1,1) specification, where the conditional variance is a function of its immediate past values and past squared residuals, augmented with the same QE exogenous variables and indicators as in the returns equation. Using this model as the null hypothesis, likelihood ratio tests could not reject this model in favour of more complex alternative specifications involving asymmetries, variance-in-mean terms, or higher order ARCH terms. In the variance equation, the coefficient *b* measures the tendency of the conditional variance to cluster, while the coefficient *c* (in combination with *b*) measures the degree of persistence in the conditional variance process.

Furthermore, to test the QE liquidity channel of the BoE and Fed QE purchases, the actual bond purchases as implemented by the monetary authorities are expressed in relation to daily trading volume by estimating the following regression 3.5 and 3.6 for the US and UK respectively:

$$\Delta\ln(Trade\ volume_{it}) = \alpha + (\phi_{i,1}\text{QE1}_{i,t})\, D1_{i,t} + (\phi_{i,2}\text{QE2}_{i,t})\, D2_{i,t} + (\phi_{i,3}\text{QE3}_{i,t})\, D3_{i,t} + (\phi_{i,4}\text{MEP}_{i,t})\, \text{D4}_{i,t} + \varepsilon_{i,t} \quad (3.5)$$

$$\Delta\ln(Trade\ volume_{it}) = \alpha + (\phi_{i,1}\text{QE1}_{i,t})\, D1_{i,t} + (\phi_{i,2}\text{QE2}_{i,t})\, D2_{i,t} + (\phi_{i,3}\text{QE3}_{i,t})\, D3_{i,t} + \varepsilon_{i,t} \quad (3.6)$$

In this first chapter of the empirical analysis, each of the equity market i.e. in the UK and the US is modelled separately or individually for an assessment of the impact of the QE operations on the equity markets within these countries. Also in order to enable an assessment of whether the QE operations had any spill-over effects beyond the equity markets in the US and UK where the QE operations took place, or in other to distinguish between the impact of QE on the equity markets in other economies that did not implement such a measure at the time, two equity markets within the Eurozone i.e. France and Germany and the Australian equity market are modelled incorporating either the UK or the US QE variables.

3.5 Event-study results

It is not unlikely that some of the impact of QE or LSAPs on the bond and equity markets occurs not when the actual purchases are made by the monetary authorities but when the purchase announcement is made or when expectations of such future purchases are formed. To examine this announcement impact, this study carried out an event study looking at the immediate reaction of the bond and equity market yields in the UK and US to announcements relating to major QE purchases by the relevant monetary authority.

Important for the LSAPs or QE event study is that the event phase captures all announcements that have impacted LSAPs or QE expectations, and with the implicit assumption that the LSAP expectations were not affected by anything else other than the announcements. This obviously is a very strong assumption particularly factoring into consideration the prevailing financial and economic circumstances that warranted the QE in the first place, and other political events including the impending presidential elections in US at the time, all of which may have played some impacts on the financial market expectations of future policy trajectory. Needless to say that a major difficulty in isolating the signalling effect of the QE is that asset prices or yields could also have reacted to other non-LSAP or QE information around the period such as updates on the MPC and FOMC's economic outlook and other major political events other than announcement of QE policies. In the light of this glaring limitation of the event study approach and to mitigate the risk of contamination a one day window period is used for the event study.

The one day window(s) is constructed as starting from the closing level of the day prior to the announcement to the closing level on the day of the announcement. The focus here are on the dates of official communications or releases by the Fed and BoE, which contained new information concerning potential LSAPs. For the Fed's QE1 for example, these are November

25, 2008, December 1, 2008, December 16, 2008, January 28, 2009, March 18, 2009, August 12, 2009, September 23, 2009 and the November 11, 2009 (see Table 1 for the descriptions). While for the BoE's QE1, these are the February 11, 2009, March 5, 2009, May 7, 2009, August 6, 2009, November 5, 2009 and February 2, 2010 (see Table 2 for the descriptions).

Starting with the US, Table 8 shows the cumulative changes in the equity and bond yields following the US QE1, QE2, MEP and QE3 operations. Across the eight announcements contained in the event set for the QE1, both the US equity (S&P500) and the US Treasury 10 year bond yields declined significantly, with the equity and bond yields declining by 72 and 75 basis points, respectively. Perhaps not surprising, the decline in both the US equity and bond yields were greater following the QE1 announcements in comparison to the subsequent announcements of QE2, the MEP and US QE3 operations which to a very large extent were widely envisaged by the financial markets and thus contained little to no news or surprises for prices and yields in the financial markets. Specifically, equity and bond yields declined by 6 basis points following the US QE2 announcements, 3 basis points and 5 basis points respectively following the maturity extension programme or operation twist and by 4 basis points following the QE3 announcements.

The event study results of the US QE1 announcements appear consistent with earlier event studies from the literature of the impact of the US QE1 announcements on bond yields decline, totalling around 80bps. Furthermore, by considering the impact beyond the bond markets of the QE announcements, this study is able to broaden or generalise the findings to an imperfectly substitutable asset to bonds i.e. equity. The change in the equity and bond yields especially following the QE1 announcements may be considered as evidence of a significant signalling channel or mechanism for the US QE operations. Suggesting in fact that some of the impact of QE or LSAPs on the financial markets may occur not when the actual purchases are made by the monetary authorities but when the purchase announcement is made or when expectations of such future purchases are formed.

For the BoE QE announcements, again the decline in equity (FTSE100) and the UK 10 year gilt yields were highest following the QE1. The cumulative decline in the 10 year gilt yields was 44 basis point. Compared to some of the earlier event study in the literature for the UK QE1 announcements, finding of a cumulative 85 to 100 basis points decline in bond yields (using a two-day window) seems to suggest that doubling the event window appears to double the amount by which the yields decline. This assertion is further corroborated by other studies of the impact of the UK QE1 announcements on gilt yields using a one-day window, like Meaning and Zhu (2011) and Glick and Leduc (2012) who like this study found smaller effects closer to 50 basis points. For the UK equity (FTSE100), the cumulative decline following the BoE QE1 announcements was 35 basis points. This study also considered the UK BoE QE2 and QE3 announcements impacts on the UK equity and bond yields. Generally, the effects of these later announcements were much smaller in size compared to the QE1, with yields falling by only -5bps-7bps following the QE2 announcements and for the UK QE3 announcement by 1-3bps.

In summary, the event study of the announcement impact of the QE bond purchases reject the null hypothesis (***Ho_2)*** as they show that the LSAPs announcements had impacted yields even before the actual purchases of the bonds were executed by the monetary authorities. Thus confirming the existence of a signalling effect. But to the extent the yields on equity also declined following these QE announcements as expected given the imperfect substitutability doctrine or portfolio balance mechanism strongly suggest that the signalling and portfolio balance channels are not necessarily mutually exclusive and may in fact work in tandem.

Table 8: Event Study Results for the US and UK QE announcements

US Event Study Results		
Event Phase	**US Equity (S&P500)**	**US Bond (10-year maturity)**
QE1	-72bp	-75bp
QE2	-6bp	-6bp
MEP	-3bp	-5bp
QE3	-4bp	-4bp
UK Event Study Results		
	UK Equity (FTSE100)	**UK Gilt(10-year maturity)**
QE1	-35bp	-44bp
QE2	-7bp	-5bp
QE3	-1bp	-3bp

Table 8 shows the event study results of the impact of the QE announcements on the US and UK equity and bond markets. The expected returns on each of the event day are deducted from the actual return to get the abnormal return i.e. $AR_{it} = R_{it} - \overrightarrow{Ri}$ on each day in the event window. The abnormal return (AR_{it}) are then added up to get the aggregate or cumulative abnormal return CAR_i $(T_1, T_2) = \sum_{t=}^{T2} T1\, AR_{it}$

3.6 Empirical Results

In this section, maximum likelihood estimates of the parameters of the specified GARCH models are reported. This is preceded however by performing tests for structural breaks in the sample data (01:2004-10:2014) using the Quandt-Andrews (1993) and Andrews-Ploberger (1994) structural break tests. These tests are used to test for structural break at an unknown point within the sample.

For the US data, both structural break tests detect a significant break on the 01:21:2009 *(p-value< 0.01)*. While for the UK, both tests detect a significant break on the 13:08:2008 *(p-value<0.01)* (see appendix). Consequently, the specified models for the US and UK are estimated in sub-samples taking into account these break dates and with the relevant variables per the sub-samples i.e. the monetary policy stance variable(s) prior to the start of QE, and the QE variables.

Table 9 shows the coefficients of the parameters of the estimated model (i.e. before the date of the structural break) for the UK. The upper panel (Panel A) of the table shows the estimates from the mean equation, while the estimates from the variance equation are shown on the lower panel (Panel B). In the mean equation, both the intercept or constant term and the coefficient of the variable (MPC) capturing the monetary policy stance in the UK prior to the commencement of the QE operations in the UK are insignificant. On the lower panel of that table showing the coefficients from the variance equation, the coefficients of the lag squared residual term (ARCH) and the lagged conditional variance (GARCH) term are highly significant and within the expected range, with the bulk of the effect coming from the previous conditional variance coefficient. Again the variable (MPC) capturing the impact of the monetary policy stance in the UK prior to the commencement of the QE operations on the volatility of the UK's equity market is insignificant.

Table 9: Univariate GARCH results (UK): January 2nd 2004 – August 11th 2008

Number of Observation: 1196 Log-likelihood: 4055.6457		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00027	0.00024
MPC	0.00003	0.00052
Panel B		
(ω)	< -0.00001	< 0.00001
(*b*)	0.1166***	0.0208
(c)	0.8705***	0.0238
MPC	-6.47×10^{-7}	-5.93×10^{-7}

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{MPC}_{i,t} + \varepsilon_{i,t}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{MPC}_{i,t}$ where $R_{i,t}$ is the daily return from market i in week$t$, $i =$ UK. The information set, Ω_{t-1} includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $MPC_{i,t}$ represent BoE or MPC Bank rate incorporating the stance of monetary policy within this estimation period when QE bond purchases were not underway. *** indicate statistical significance at the 1%.

Table 10 shows the results of the parameters of the estimated model (i.e. after the date of the structural break) for the UK and thus incorporating the QE intensity and periodic variables in the model. The upper panel of the table contains the estimated coefficients for the return equation. As can be seen from this segment of the table, the constant term in the equation is significant. The coefficient of the Lehman dummy variable capturing the effect of the financial crisis as measured in the specified model by the collapse of Lehman brothers is found to be insignificant.

Moving on to the QE variables i.e. the QE intensity and periodic variables in the mean equation, although the UK QE1, QE2 and QE3 appear to have the expected negative signs as suggested by the portfolio rebalance channel effects of LSAPs, only the UK QE3 is found to be significant. Juxtaposed against the earlier stated hypothesis (***Ho$_1$*),** this imply an inability to reject the null hypotheses for the UK QE1 and QE2 operations but a rejection of the null hypothesis in the case of the QE3. In other words, for the QE1 and QE2 operations, the portfolio rebalance channel is not found to be significant. This may be explained by the fact that significant portfolio rebalancing or adjustments may have already taken place by forwarding looking investors following the announcements of these earlier QE phases rather than during the actual bond purchases by the BoE. All three QE phase variables for the UK in the mean equations were insignificant.

Turning to the variance equation, i.e. Panel B of Table 10, the coefficients of the lag squared residual and the previous conditional variance terms are once again significant and within the expected range for this sub-sample, with the bulk of the effect coming from the previous conditional variance. The Indicator variable for the financial crisis incidence is significant in the variance equation unlike in the mean equation and positive as expected implying that the financial crisis engendered an increase in the UK equity market volatility as shown in Figure 7 below.

The coefficient of the QE variables in the variance equation although all significant, revealed mixed results. For instance, while the coefficients of the QE1 and QE2 actual purchases (intensity) variables in the variance are positive, the coefficient of the QE3 variable is negative. Conversely, while coefficients of the QE1 and QE2 phase or period variables (i.e. D1 and D2) are negative, the coefficient of QE3 period variable (D3) is positive. Taking as a whole, the QE intensity and period coefficients in the variance equations capture the effects of the BoE QE or LSAPs on purchases auction days and over the entire QE period on the volatility of the UK equity market.

That the actual QE purchases particularly the QE1 and QE2 coefficients are positive in the variance equation in contrast to their periodic counterparts suggest that the UK equity market became more adept at accommodating the purchase activity as the BoE QE interventions progressed.

Table 10: Univariate GARCH results (UK): August 15th 2008 – October 31st 2014

Number of Observation: 1508 Log-likelihood: 4815.6649		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00060***	0.00006
Lehman	-0.00005	0.00323
QE1	-0.2077	0.2658
QE2	-0.1869	0.4494
QE3	-0.1869***	0.0544
D1	0.0013	0.0001
D2	0.0011	0.0012
D3	-0.0012	0.0001
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0910***	0.0005
(c)	0.8905***	0.0001
Lehman	0.0002***	0.0001
QE1	0.0026**	0.0018
QE2	0.0049***	0.0018
QE3	-0.0038***	7.28×10^{-6}
D1	-3.76×10^{-6}*	2.17×10^{-6}
D2	-9.70×10^{-6}***	3.36×10^{-6}
D3	6.13×10^{-6}***	2.41×10^{-6}

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t}$ where $R_{i,t}$ is the daily return from market i in week t,. $i =$ UK. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE phase's dummy variables for the UK. These dummy variables take the value of one during their respective periods and zero otherwise. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the QE period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The results of the estimated coefficients for the US model specifications are reported next starting with Table 11 (i.e. before the date of the structural break) in the US specification. The upper panel (Panel A) of the table shows the estimates from the mean equation, while the estimates from the variance equation are shown on the lower panel (Panel B). In the mean equation, and similar to the UK estimation results, both the intercept or constant term and the coefficient of the variable (EFFR) capturing the monetary policy stance in the US prior to the commencement of the QE operations in the US are insignificant. The moving average term (ε_{t-1}), included in the US model, is significant justifying its inclusion in the US GARCH model.

On the lower panel of that table showing the coefficients from the variance equation, the ARCH coefficient and the GARCH coefficient are significant and within the expected range, with the bulk of the effect coming from the previous conditional variance or GARCH coefficient. Again the coefficient of the variable (EFFR) capturing the impact of the monetary policy stance in the US prior to the commencement of the QE operations on the US's equity market is insignificant.

As these variables i.e. the EFFR and MPC included in the relevant model specifications to incorporate the impact on the financial markets of the stance of monetary policy during the period within the estimation when QE bond purchases, are found to be insignificant in both the mean and variance equations, they are dropped from the model specifications going forward.

Additional GARCH models for smaller samples based on the individual or specific QE purchases for both the US and UK QE operations are estimated. Comparing the results of the smaller sample re-estimations with the lager sample results, reveal no significant changes in the signs of the estimated coefficient. Thus the results of the smaller or individual re-estimations are shown in the appendix.

Table 11: Univariate GARCH results (US): January 2nd 2004 – January 19th 2009

Number of Observation: 1317 Log-likelihood: 4281.1509		
Panel A		
Variable	Coefficient	Std. Error
constant	-0.00027	0.00058
EFFR	0.00001	0.00014
$\varepsilon_{i,t-1}$	-0.09846***	0.03192
Panel B		
(ω)	< 0.00001	< 0.00001
(b)	0.0770***	0.0123
(c)	0.9175***	0.0135
EFFR	1.34×10^{-7}	1.15×10^{-7}

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{EFFR}_{i,t} + \varepsilon_{i,t} - d_1\,\varepsilon_{i,t-1}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{MPC}_{i,t}$ where $R_{i,t}$ is daily the return from market i in week t, $i =$ US. The information set, Ω_{t-1} includes all information known at time $t-1$, and $\omega_{i,i} > 0, b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $EFFR_{i,t}$ represents the Effective Fed Fund Rate (the policy rate) incorporating the stance of monetary policy within this estimation period when QE bond purchases were not underway. *** indicate statistical significance at the 1%.

Table 12 shows the estimates of the parameters of the estimated model (i.e. after the date of the structural break) for the US, incorporating the QE intensity and periodic variables in the model. The upper panel of the table contains the estimated coefficients for the return equation. Clearly the coefficients of the actual QE purchase variables measuring and testing the effect of the portfolio balance channel in the US model following the LSAPs, have the negative signs as envisaged by the portfolio balance channel, but only the US QE3 is significant, implying that while the null hypothesis (***Ho₁)*** could not be rejected for the QE1, QE2 and the MEP operations, it is rejected for the US QE3 LSAPs. All the QE phase or period variables and the financial crisis indicator variable in the mean equation are found to be insignificant.

Turning to the variance equations, Panel B, the coefficients of the lag squared residual and the previous conditional variance terms are significant and within the expected range, with the bulk of the effect coming from the previous conditional variance. The financial crisis indicator variable is significant also in the variance equation for the US and, not surprisingly positive implying that this incident engendered an increase in the volatility of the US equity market as earlier reported also for the UK equity market (see Figure 7 below).

Of the QE intensity variables and MEP variable in the variance equations for the US, the coefficient of the US QE1 is found to be significant and positive. However, those for the QE2, QE3 and MEP are found to be insignificant. In sharp contrast, the QE period variables measuring the effect of the market being in the QE period as distinct from the effect of the actual FOMC purchases on specific purchase days (QE intensity) are found to be mostly significant and with negative signs implying that the period of QE did in fact alleviate some of the volatility in the US equity market in the aftermath of the financial crisis.

Table 12: Univariate GARCH results (US): January 23rd 2009 –October 31st 2014

Number of Observation: 1393 Log-likelihood: 4562.1190		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00123***	0.00032
Lehman	-0.00005	0.00323
QE1	-0.7632	0.8972
QE2	-0.1391	0.3491
QE3	-0.7550*	0.3986
MEP	-0.0649	0.5667
D1	0.0011	0.0013
D2	0.0001	0.0009
D3	-2.08×10^{-5}	8.25×10^{-4}
D4	2.03×10^{-4}	9.61×10^{-4}
$\varepsilon_{i,t-1}$	-0.1015***	0.0310
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.1131***	0.0164
(c)	0.8357***	0.0242
Lehman	0.0002**	0.0001
QE1	0.0085*	0.0048
QE2	4.03×10^{-5}	6.20×10^{-4}
QE3	-0.0015	0.0012
MEP	-8.56×10^{-4}	1.48×10^{-3}
D1	4.07×10^{-6}	3.75×10^{-6}
D2	-3.66×10^{-6}*	1.89×10^{-6}
D3	-5.00×10^{-6}***	1.93×10^{-6}
D4	-3.82×10^{-6}*	1.97×10^{-6}

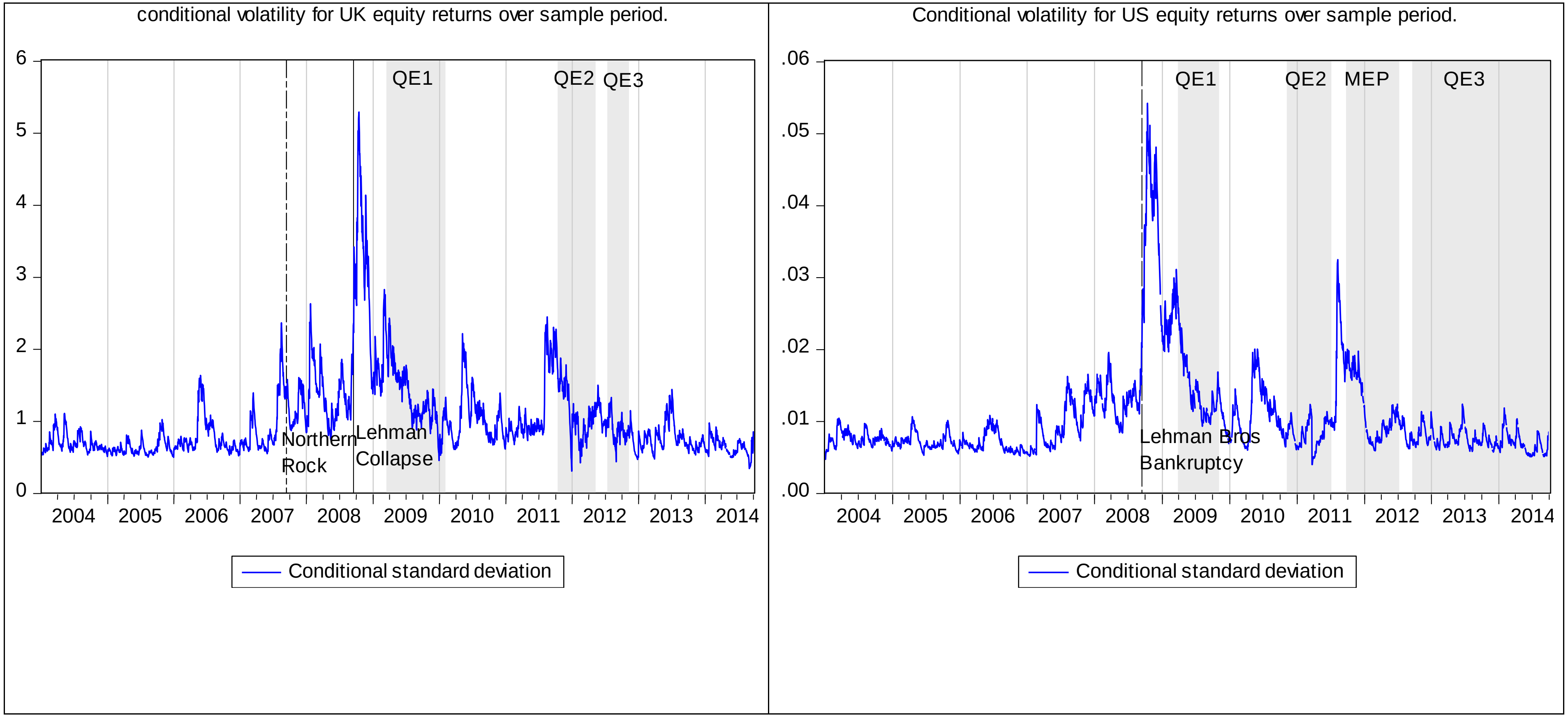
This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t} - d_1\,\varepsilon_{i,t-1}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t}$, where $R_{i,t}$ is the daily return from market i in week t, i=US. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE phase's dummy variables for the US. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. The variables $QE1_{i,t}$, $QE2_{i,t}$ and$QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Generally, the UK and US estimation results appear largely similar but one difference between the UK and US estimation results relates to the significance of the QE intensity coefficients, with mainly more positive significance of these coefficients in the variance equations in the UK results, relative to the US estimation results. It is pertinent to point out that perhaps one major reason that may be responsible for this, could be the conscious decision made by the Fed to avoid QE purchase operations conflicting with other operations such as the Treasury debt auctions, and agency.

Figure 7 plots the estimated conditional volatility for the UK and US equity market over the full sample period. Clearly the period depicted can be subdivided further into a pre-crisis and QE period. The pre-crisis period starting from 2004 recorded low equity market volatility in both the UK and US markets. Although there appeared to be a spike in the UK equity market volatility in the last quarter of 2007 to the first quarter of 2008 following the run and subsequent state take-over of Northern Rock, no such spike was observed for the US equity market implying that the US market was unaffected by the event. Not until mid-September 2008, following the bankruptcy of Lehman Brothers that both equity markets simultaneously witnessed a gargantuan surge in volatility officially signalling the beginning of the financial crisis or the great recession.

Part of the BoE and Fed's response which came in the form of large scale bond purchases or QE1 around the first quarter of 2009, coincided with a lowering of equity market volatility in both markets. The termination of QE1 by both monetary authorities almost immediately saw a rise in volatility in both equity markets which was responded to by further QE operations (QE2) which again appeared to have calmed equity market volatility. There were noticeable spikes in the equity markets' volatility particularly for the US market around the last quarter of 2011. However barring this spike, equity market volatility had largely returned to pre-crisis levels in both markets.

Figure 7: Estimated Conditional Volatility for UK and US Equity Returns Jan.04-Oct.14



3.7 QE Liquidity Channel Test Results

In this section, estimates of the effect of the Fed and BoE QE or LSAP operations on the liquidity conditions in the US and UK equity markets are presented. The estimates are obtained by regressing daily changes in the equity market trade volume as a measure or indicator of liquidity, on the Fed and BoE actual QE purchases or interventions. As the effect of the Fed and BoE QE purchases on the equity market trading volume may vary given the different QE phase purchase amounts, a multiple regression analysis to capture the differential effects of the Fed and BoE QE purchases across phases is reported.

Table 13: The effect of Fed QE purchases on equity market trade volume

Number of Observation: 1397
R-squared: 0.32089
Adjusted R-squared: 0.31894

Variable	Coefficient	Std. Error
constant	21.95998***	0.01424
QE1	0.47278***	0.02311
QE2	-0.04507**	0.02081
QE3	0.18457***	0.01729
MEP	0.01978	0.02020

This table contains the estimated coefficients from the model $\Delta\ln(Trade\ volume_{it}) = \alpha + (\phi_{i,1}\text{QE1}_{i,t})\, D1_{i,t} + (\phi_{i,2}\text{QE2}_{i,t})\, D2_{i,t} + (\phi_{i,3}\text{QE3}_{i,t})\, D3_{i,t} + (\phi_{i,4}\text{MEP}_{i,t})\, \text{D4}_{i,t} + \varepsilon_{i,t}$. The dependent variable in the model is the change in the daily trade volume for the US equity market. $(\phi_{i,1}\text{QE1}_{i,t})\, D1_{i,t}$, $(\phi_{i,2}\text{QE2}_{i,t})\, D2_{i,t}$, $(\phi_{i,3}\text{QE3}_{i,t})\, D3_{i,t}$, and $(\phi_{i,4}\text{MEP}_{i,t})\, \text{D4}_{i,t}$ are the Fed purchase representing total Fed QE purchases in each phase in $ billions multiplied by their respective dummies which take a value of 1 for that phase in the QE programme.

Table 13 shows the results for the US estimation. The results indicates that the Fed QE1 LSAPs is associated with a statistically significant increase in the US equity market trade volume of about 0.47 percent. Conversely the impact of the Fed QE2 LSAPs on the equity market trade volume is a statistically significant decline of about 0.05 percent. The Fed's QE3 operation also appear to have impacted positively on the liquidity conditions in the US equity market going by the statistically significant increase of the equity market trade volume of 0.18 percent.

The Fed MEP brought about a statistically insignificant increase in the US equity market trade volume. Taking as a whole, the result of the estimates in Table 13 suggests that the marginal effects of the Fed QE purchases on the equity market liquidity as measured by the volume of trade were most profound at the start of QE operations i.e. QE1. This is not surprising and in fact underscores that the Fed QE actions immediately following the financial crisis encouraged investors (perhaps having been crowded out of the bond market, to purchase or switch to the equity market and thereby improving liquidity conditions in the equity market.

Table 14: The effect of BoE QE purchases on equity market trade volume

Number of Observation: 1449 R-squared: 0.04017 Adjusted R-squared: 0.03818		
Variable	Coefficient	Std. Error
constant	15.10332***	0.00899
QE1	0.09125***	0.02068
QE2	-0.10169***	0.02489
QE3	-0.12891***	0.03210

This table contains the estimated coefficients from the model $\Delta \ln(Trade\ volume_{it}) = \alpha + (\phi_{i,1}\text{QE1}_{i,t})\ D1_{i,t} + (\phi_{i,2}\text{QE2}_{i,t})\ D2_{i,t} + (\phi_{i,3}\text{QE3}_{i,t})\ D3_{i,t} + (\phi_{i,4}\text{MEP}_{i,t})\ D4_{i,t} + \varepsilon_{i,t}$. The dependent variable in the model is the change in the daily trade volume for the UK equity market. $(\phi_{i,1}\text{QE1}_{i,t})\ D1_{i,t}$, $(\phi_{i,2}\text{QE2}_{i,t})\ D2_{i,t}$, $(\phi_{i,3}\text{QE3}_{i,t})\ D3_{i,t}$, are the BoE purchase representing total BoE QE purchases in each phase in £ billions multiplied by their respective dummies which take a value of 1

The result of the UK QE channel liquidity test is presented in Table 14. The table shows that similar to the US estimation, the BoE QE1 had a statistically significant increase on the UK equity market trade volume of 0.09 percent. However, the coefficient estimates of the BoE QE2 and QE3 operations revealed that these operations in fact engendered a statistically significant decline in the equity trade volume of about 0.10 and 0.13 percent respectively. Thus, for the UK, it appears the BoE purchases in the latter rounds had an adverse effect on the equity market trade volume.

Overall, the results presented in this section relating to the hypothesis on the QE liquidity effects suggest that they were significant liquidity effects on the equity markets following the US and UK monetary authorities QE actions albeit with different impacts from the different QE phases on the volume of trade in the US and UK equity markets.

3.8 Other Equity Markets' Response to the UK and US QE Actions

It is evident from the preceding section that the LSAPs in the US and the UK indeed impacted significantly on the US and UK equity markets. This section expands or broadens the analysis beyond the US and UK equity markets. This not only enables an investigation of whether the LSAPs of the Fed and BoE had a spill-over effects on other equity markets in countries that did not implement the QE at the time or at all. This investigation is justified, taking into consideration that the financial crisis although starting in the US with the collapse of Lehman brothers, was characterised by increased instability across financial markets and the contagion of its effects across markets and countries.

This section includes or considers other economies that did not implement QE at the time. To this end, this study looks at the equity markets in the Euro-area i.e. Germany proxy by the DAX30 and the equity market in France proxy by the CAC40 and the Australasian equity markets proxy by the ASX (Australia), the Nikkei (Japan) and the Hang Seng (Hong-Kong). Although the ECB in responding to the financial crisis would embark on what it called the credit enhancement programme (see chapter 2), LSAPs of the QE kind were not conducted by the ECB around this period in contrast to its counterparts in the US and UK, neither were the aforementioned Australasian economies hit with temerity of the financial crisis and nor, did their monetary authorities embark on QE operations as a result. Hence these economies provides a veritable platform to exam effects of QE outside of the US and UK equity markets.

Similar GARCH models as earlier specified above are re-estimated for the CAC40, DAX30, the ASX, Nikkei and Hang-Seng indices including an additional variable, lagged return ($R_{i,t-1}$) in the variance equation as control for any local effect within the respective equity markets. Like in the analysis in the preceding section, tests for structural breaks in the sample period (01:2004-10:2014) are performed using the Quandt-Andrews (1993) and Andrews-Ploberger (1994) structural break tests. Unlike the results of these tests for the US and UK sample, these show no significant breaks in these other equity market indices (see appendix).

If several regressors in a model are highly correlated, there is the issue of collinearity or multicollinearity. To investigate the issue of collinearity, the correlation coefficients between the QE regressors i.e. the QE intensity (actual purchases) and the QE period variables, are computed separately for both the US and UK QE variables included in these other equity market GARCH specifications. The coefficient of correlation is a value of +1 and -1 in the case of perfect multicollinearity. As can be seen from the matrices i.e. Table 15 and 16, none of the coefficients is anywhere the +1 or -1 value; in fact they are all way of magnitudes that may suggest a high correlation amongst them

In addition, separate model estimations (i) including USQE1-QE3 and MEP, and omitting US D1-D4, (ii) including US D1-D4 and omitting USQE1-QE3 and MEP (iii) including UKQE1-QE3 and omitting UK D1-D3 (iv) including UK D1-D3 and omitting UK QE1-QE3, are estimated and reported for the equity markets investigated in this section.

Table 15: US QE Regressors Correlation Matrix

	QE1	QE2	QE3	MEP
QE1	1.0000			
QE2	-0.0312	1.0000		
QE3	-0.0484	-0.0813	1.0000	
MEP	-0.02916	-0.0489	-0.0758	1.0000
	D1	D2	D3	D4
D1	1.000	0.033		
D2	-0.0701	1.0000		
D3	-0.0669	-0.0527	1.0000	
D4	-0.0341	-0.0268	-0.0256	1.0000

This table shows the correlation coefficients between the US QE1-QE3 and MEP and the US D1-D4 variables.

Table 16: UK QE Regressors Correlation Matrix

	QE1	QE2	QE3
QE1	1.0000		
QE2	-0.0301	1.0000	
QE3	-0.0285	-0.0278	1.0000
	D1	D2	D3
D1	1.0000		
D2	-0.0725	1.0000	
D3	-0.1201	-0.1459	1.0000

This table shows the correlation coefficients between the UK QE1-QE3 and the UK D1-D3 variables.

Starting with the Germany equity market estimation result with the US QE1- QE3 and MEP variables, in Table 17, it is clear that these variables had no significant impact on the German equity market returns. Also the financial crisis/Lehman crash dummy variable in the mean equation is also found to be insignificant. For the variance equation (Panel b) of the same table, the financial crisis/Lehman impact variable is significant and positive as found also in the estimation results for the US and the UK earlier reported. This simply means that the financial crisis engendered significant increase in the German equity market volatility as well. Of the QE1-QE3 and the MEP variables in the variance equation, only the MEP appear to have a significant effect (positive) on the volatility of the German equity market.

Table 17: Univariate GARCH results (Germany): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8299.1843		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00077***	0.00022
Lehman	-0.00231	0.00406
QE1	-0.47203	1.02062
QE2	0.09962	0.33396
QE3	-0.02258	0.47011
MEP	0.19617	1.07935
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0822***	0.0085
(c)	0.8914***	0.0114
Lehman	0.0005**	0.0001
QE1	0.0083	0.0055
QE2	0.0001	0.0005
QE3	-0.0009	0.0006
MEP	0.0064**	0.0027
$R_{i,t-1}$	-0.0018***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \varphi_{i,1}\text{QE1}_{i,t} + \varphi_{i,2}\text{QE2}_{i,t} + \varphi_{i,3}\text{QE3}_{i,t} + \varphi_{i,4}\text{MEP}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, i=Germany. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0, b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

For the Germany equity market estimation results including the US D1-D4, and omitting the US QE1-QE3 and MEP (Table 18), the results are consistent in significance with the earlier results in Table 17. Note that D4 is the indicator or period variable for the US MEP, and like its precursor in Table 17, this variable is the only significant variable among the set of the US QE and MEP phase or period variables in the model.

Table 18: Univariate GARCH results (Germany): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8299.1843		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00077***	0.00025
Lehman	-0.00231	0.00409
D1	0.00128	0.00133
D2	0.00027	0.68463
D3	-0.00006	0.00044
D4	0.00064	0.00011
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.0805***	0.0086
(c)	0.8917***	0.0114
Lehman	0.0005**	0.0001
D1	5.35×10^{-6}	3.59×10^{-6}
D2	1.04×10^{-7}	8.61×10^{-7}
D3	-2.94×10^{-7}	4.566×10^{-7}
D4	6.88×10^{-6}***	2.53×10^{-6}
$R_{i,t-1}$	-0.0017***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Germany. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the US and. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Separate model estimation results for the German equity market with the UK QE intensity (actual purchases) and QE period variables are also reported. Starting with the estimation results incorporating the UK QE1-QE3 in Table 19 (panel A) showing the mean estimation results, only the UK QE3 variable appear to have a significant and negative effect on the German equity returns suggesting spill-over portfolio balancing effects of the UK QE3 on the German equity market. Neither the UK QE1 and QE2 nor the financial crisis dummy variables were significant in the mean equation.

In the variance equation result reported on the lower panel of the table, a significant and positive effect on volatility coming from the financial crisis is documented. Also the UK QE3 appear to have had a positive impact on the German equity market volatility as well. The ARCH, GARCH and the domestic control variable included in the model are all strongly significant.

Table 19: Univariate GARCH results (Germany): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8302.2742		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00079***	0.00019
Lehman	-0.00233	0.00406
QE1	0.5241	0.3694
QE2	0.1768	0.5070
QE3	-0.9017*	0.4703
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0821***	0.0081
(c)	0.8934***	0.0109
Lehman	0.0004**	0.0001
QE1	0.0018	0.0012
QE2	0.0019	0.0012
QE3	0.0024*	0.0012
$R_{i,t-1}$	-0.0017***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week$t$, *i*=Germany. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and$QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The estimation results including the UK D1-D3 are reported in Table 20, with none of the UK D1-D3 (UK QE period) significant neither in the mean nor variance equations. In the variance equation however, the financial crisis variable, the ARCH, GARCH and the domestic control variable are significant as earlier documented.

Table 20: Univariate GARCH results (Germany): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8300.0777		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00074***	0.00020
Lehman	-0.00228	0.00405
D1	0.00077	0.00105
D2	0.00182	0.00147
D3	-0.00049	0.00102
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0826***	0.0081
(c)	0.8933***	0.0109
Lehman	0.0004**	0.0001
D1	3.70×10^{-6}	2.66×10^{-6}
D2	3.45×10^{-6}	2.10×10^{-6}
D3	-3.86×10^{-6}	1.98×10^{-6}
$R_{i,t-1}$	-0.0017***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + +\varepsilon_{i,t}$, where $\varepsilon_{i,t}\big|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Germany. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the UK. These event variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The estimation results for the French equity market are reported next, starting with estimation results from the model including the US QE1-QE3 and MEP shown in Table 21. Of the included QE and MEP variables, only the MEP is significant i.e. in the variance equation with a positive effect. Neither the QE1-QE3, the MEP nor the financial crisis variables were significant in the mean equations as can be seen from the table.

Table 21: Univariate GARCH results (France): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8236.5720		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00048**	0.00022
Lehman	-0.00127	0.00508
QE1	0.6174	0.9528
QE2	0.1426	0.3822
QE3	0.3295	0.5329
MEP	-0.1740	0.9944
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0914***	0.0086
(c)	0.8842***	0.0114
Lehman	0.0006**	0.0002
QE1	0.0078	0.0054
QE2	0.0005	0.0007
QE3	0.0010	0.0007
MEP	0.0077***	0.0028
$R_{i,t-1}$	-0.0018***	0.0005

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, i=France. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}$, $QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The counterpart results for the French equity market equation including the US D1-D4 are shown in Table 22. Only the D4 i.e. the MEP period variable is significant and only in the variance equation. Likewise the variable capturing the impact of the financial crisis in the variance equation is significant and positive implying that this period or the crisis also impacted significantly on the volatility of the French equity market.

Table 22: Univariate GARCH results (France): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8237.8027		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0005**	0.0002
Lehman	-0.0013	0.0051
D1	0.0014	0.0013
D2	0.0004	0.0007
D3	0.0001	0.0004
D4	-0.0004	0.0011
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0891***	0.0085
(c)	0.8867***	0.0112
Lehman	0.0006**	0.0002
D1	3.97×10^{-6}	3.15×10^{-6}
D2	1.08×10^{-6}	1.27×10^{-6}
D3	6.56×10^{-7}	5.31×10^{-7}
D4	7.13×10^{-6}***	2.46×10^{-6}
$R_{i,t-1}$	-0.0021***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=France. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the US and. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The estimation results for the French equity market including the UK QE1-QE3 are reported in Table 23. In the mean equation, a significant effect on the returns in the equity market in France is documented for the UK QE3. In the variance equation however, two of the three included UK QE (intensity) variables i.e. QE2 and QE3 are found to be significant. The dummy incorporating the impact of the financial crisis also appear to be a significant source of increase equity market volatility in the French equity market.

Table 23: Univariate GARCH results (France): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8235.9973		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0005**	0.0002
Lehman	-0.0013	0.0051
QE1	0.3534	0.2794
QE2	0.3713	0.6086
QE3	-0.3234*	0.6653
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0864***	0.0079
(c)	0.8934***	0.0109
Lehman	0.0006**	0.0002
QE1	0.0012	0.0011
QE2	0.0021***	0.0009
QE3	0.0026*	0.0014
$R_{i,t-1}$	-0.0043***	0.0004

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, *i*=France. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 24 displays the estimation results including the UK D1-D3 periods. It is clear at a glance that the estimation results in this table mirrors the estimation results in table 23 including the UK QE1-QE3 purchases. Thus, the results are robust regardless of whether the variables included in the model specifications are either the QE actual purchases or QE period variables. For instance, the variance equation results from Panel b of Table 24 confirms the earlier results obtained for the same section of the table from the previous table i.e. the UK QE2 and QE3 period as captured by D2 and D3 are significant in tandem with their actual purchase counterparts in the previous table.

Table 24: Univariate GARCH results (France): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8235.5940		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0005**	0.0002
Lehman	-0.0013	0.0051
D1	0.0007	0.0010
D2	0.0007	0.0015
D3	0.0001	0.0017
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.0854***	0.0078
(c)	0.8939***	0.0102
Lehman	0.0006**	0.0001
D1	2.96×10^{-6}	2.40×10^{-6}
D2	4.19×10^{-6}**	2.02×10^{-6}
D3	4.62×10^{-6}**	2.10×10^{-6}
$R_{i,t-1}$	-0.0024***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + +\varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=France. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the UK. These event variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Overall, the separate estimation results for the Germany and France markets with the US QE variables and the UK QE variables tend to suggest, that the UK QE operation particularly impacted more on these Euro-area equity markets especially the French equity market, compared to the US QE operations. This finding of the impact coming from the UK QE operations on the Euro-area markets, corroborates some earlier findings in the literature including (Chelley-Steeley and Steeley, 1996; Maish and Maish, 1997; Meric and Meric 1997) of strong linkages between the UK equity market and these European equity markets particularly following the abolition of exchange controls and the creation of the single market in 1992.

Results for the Australian equity market is reported including the US QE1-QE3 and the MEP Table 25). The results reveal marginal significance only in the variance equation on the lower panel of the table for the US QE1 variable. None of the QE1-QE3 and MEP coefficients were significant in the mean equation.

Table 25: Univariate GARCH results (Australia): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8972.3333		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0007***	0.0002
Lehman	-0.002	0.004
QE1	-0.9803	0.8487
QE2	-0.4000	0.2815
QE3	0.0369	0.3377
MEP	0.3625	0.5646
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0918***	0.0082
(c)	0.8951***	0.0094
Lehman	0.0003*	0.0002
QE1	0.0054*	0.0032
QE2	0.0003	0.0004
QE3	0.0004	0.0003
MEP	0.0007	0.0008
$R_{i,t-1}$	-0.0011***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, i=Australia. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0, b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

In the model estimation results including the US D1-D4 for the various phases or periods of the QE and MEP, shown on Table 26, none of the D1-D4 variables were significant in the mean or variance equations. The estimation results for the Australian equity market are insightful compared to the other equity markets estimation results. Of course this is not surprising considering that the unlike the US and UK and even the Euro-area economies, the Australian economy was not significantly affected during the financial crisis or great recession (the economy actually grew during the period) and hence while the monetary authority there did not execute any LSAPs or QE in response. Notwithstanding, the marginal significance of the financial crisis and US QE1 variables on the Australian equity market perhaps is more akin to global centre hypothesis whereby financial markets react to event(s) happening in the US.

Table 26: Univariate GARCH results (Australia): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8237.8027		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0007***	0.0001
Lehman	-0.0017	0.0042
D1	0.0015	0.0010
D2	-0.0004	0.0005
D3	-0.0001	0.0003
D4	-0.0003	0.0006
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.0908***	0.0081
(c)	0.8965***	0.0092
Lehman	0.0004*	0.0002
D1	3.35×10^{-6}	2.20×10^{-6}
D2	5.65×10^{-7}	6.15×10^{-7}
D3	4.02×10^{-7}	6.55×10^{-7}
D4	7.95×10^{-7}	2.19×10^{-7}
$R_{i,t-1}$	-0.0011***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Australia. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the US and. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

The estimation results for the Hong-Kong and Japan equity markets including either the QE variables or their corresponding phase dummies are presented below in Tables 27-32. The results show that the UK and US QE operations had no significant effects on the Asian equity markets.

Table 27: Univariate GARCH results (Japan): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 7921.8996		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0007***	0.0002
Lehman	-0.0035	0.0067
QE1	-0.4948	1.0185
QE2	-0.6971	0.4952
QE3	0.2809	0.6960
MEP	0.0289	0.6377
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.1108***	0.0094
(c)	0.8710***	0.0121
Lehman	< 0.0001	<0.0001
QE1	0.0021	0.0036
QE2	0.0010	0.0009
QE3	0.0038**	0.0018
MEP	<- 0.0001	0.0017
$R_{i,t-1}$	-0.0018***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, i=Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0, b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 28: Univariate GARCH results (Japan): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 7920.4169		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0005**	0.0002
Lehman	-0.0033	0.0067
D1	0.0001	0.0011
D2	-0.0001	0.0008
D3	0.0002	0.0006
D4	0.0004	0.0007
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.1067***	0.0111
(c)	0.8500***	0.0136
Lehman	< 0.0001	< 0.0001
D1	4.56×10^{-6}	3.22×10^{-6}
D2	1.44×10^{-7}	1.75×10^{-6}
D3	7.12×10^{-6}***	1.79×10^{-6}
D4	-2.21×10^{-7}	1.30×10^{-7}
$R_{i,t-1}$	-0.0017***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the US and. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 29: Univariate GARCH results (Hong-Kong): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8104.9806		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0006***	0.0002
Lehman	0.0027	0.0073
QE1	-0.4179	1.2147
QE2	-0.2544	0.4632
QE3	-0.1167	0.4371
MEP	0.6911	0.6679
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.0641***	0.0070
(c)	0.9168***	0.0081
Lehman	< 0.0001	<0.0001
QE1	0.0042	0.0043
QE2	0.0001	0.0006
QE3	-0.0007	0.0005
MEP	-0.0002	0.0009
$R_{i,t-1}$	-0.0009***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \phi_{i,4}\text{MEP}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t, i=Hong-Kong. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0, b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}, QE2_{i,t}$ and $QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the Fed. The variable $MEP_{i,t}$ represent the QE operation twist in the US. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 30: Univariate GARCH results (Hong-Kong): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 8105.9875		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0006**	0.0002
Lehman	0.0034	0.0037
D1	0.0007	0.0014
D2	-0.0008	0.0008
D3	-0.0004	0.0004
D4	0.0002	0.0007
Panel B		
(ω)	< 0.00001***	< 0.00001
(b)	0.0614***	0.0061
(c)	0.9308***	0.0073
Lehman	< 0.0001	< 0.0001
D1	1.15×10^{-6}	1.98×10^{-6}
D2	1.29×10^{-6}	8.71×10^{-7}
D3	2.35×10^{-7}	3.38×10^{-7}
D4	-2.13×10^{-7}	7.23×10^{-7}
$R_{i,t-1}$	-0.0009***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Hong-Kong. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the US and. $D4_{i,t}$ is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 31: Univariate GARCH results (Japan): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 7920.2659		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0006***	0.0002
Lehman	-0.0034	0.0066
QE1	-0.3013	0.2446
QE2	0.2112	0.3573
QE3	0.6340	0.5423
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.1124***	0.0084
(c)	0.8717***	0.0111
Lehman	< 0.0001	< 0.0001
QE1	0.0007	0.0008
QE2	-0.0002	0.0007
QE3	-0.0001	0.0001
$R_{i,t-1}$	-0.0013***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \phi_{i,1}\text{QE1}_{i,t} + \phi_{i,2}\text{QE2}_{i,t} + \phi_{i,3}\text{QE3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week$t$, i=Japan. The information set, Ω_{t-1}, includes all information known at time$t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $QE1_{i,t}$, $QE2_{i,t}$ and$QE3_{i,t}$ represents the individual QE operations or actual purchases during the respective QE period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Table 32: Univariate GARCH results (Japan): January 2nd 2004 – October 31st 2014

Number of Observation: 2713 Log-likelihood: 7919.2213		
Panel A		
Variable	Coefficient	Std. Error
constant	0.0005**	0.0002
Lehman	-0.0033	0.0066
D1	0.0002	0.0009
D2	< 0.0001	0.0010
D3	0.0014	0.0010
Panel B		
(ω)	< 0.00001***	< 0.00001
(*b*)	0.1126***	0.0090
(c)	0.8718***	0.0111
Lehman	< 0.0001	< 0.0001
D1	1.30×10^{-6}	1.94×10^{-6}
D2	9.40×10^{-8}	1.62×10^{-6}
D3	1.65×10^{-7}**	2.20×10^{-7}
$R_{i,t-1}$	-0.0013***	0.0001

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + +\varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,2}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \mu_2 R_{i,t-1}$, where $R_{i,t}$ is the daily return from market i in week t. i=Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variables $D1_{i,t}$, $D2_{i,t}$ $D3_{i,t}$ are QE period dummy variables for the UK. These event variables take the value of one during their respective periods and zero otherwise. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

3.9 Chapter Conclusion

The objective in this chapter is to identify the effects of the QE or LSAPs on the equity markets within and outside of the economies within which the operations took place. Although the government bond markets i.e. the US Treasury bond market and the UK gilt-edged or gilts market were the main financial markets within which the Fed and BoE conducted their QE operations, however, since the pioneering work by Tobin on financial asset imperfect substitutability (1958, 1961, 1963), it has long been understood that changes in the supply of one asset class can influence the price (yield) of that and other assets.

The direct upward pressure on bond prices that may come from the central bank's bond purchases can give rise to an additional effect to increase the prices of other assets (implying reduction in yields) if the sellers of bonds do not regard the cash received as a perfect substitute for the bonds sold, and use the cash proceeds to purchase other assets, such as equity. This is the portfolio balance mechanism, which motivates this study of the effects of QE on the equity markets and the approach taken to test this channel, is to examine the equity market return and volatility behaviour conditioning on the QE operations. An area overlooked by previous studies.

In meeting the above objective, this chapter of the thesis makes a number of contributions to knowledge or an understanding of effects of QE and especially of the equity markets reaction to the QE operations. While earlier studies have mostly considered the immediate bond market or bond yields reactions to the early phase of the QE operations, the study not also considered that for all the QE phases in the UK and US, but in addition also examined more broadly the equity market returns and volatility behaviour over the entirety of the QE periods. Also, this study is the first to investigate all three phases of QE and the MEP in the US, and all three phases of the QE operations in the UK, thus permitting comparisons to be made across the entirety of the QE operations not only within or between these two economies but others as well.

For each of the QE transmission channels, the chapter created and tested some hypothesis identifying the effects on equity returns and bond yields at the time policy was originally announced, and over the period of implementation. The most distinguishing contribution is the examination of the effects of QE on the US and UK equity markets conditioned on the actual purchases and calibration of the Fed and BoE actual LSAPs or QE actions into the modelling framework.

Previous studies that have mostly relied on the event study methodology have implicitly assumed that the event period have not been affected or influenced by anything other than the LSAPs announcements. However, this is a strong assumption especially juxtaposed against the fact that doubling an event window ostensibly doubles the purported impact of the QE announcement on financial market yields. Thus a particular drawback of the event study methodology is that the event window may contain other non-QE announcements, or happenings that may have impacted on yields and returns.

The empirical models used in the analysis remedies the event study shortcomings, as the actual measure of the QE actions or bond purchases are directly included in the GARCH models, thus permitting the examination of the QE effects on the return and volatility of the markets examined. Using this empirical framework accommodating the QE intensity and period variables in both the mean and variance equations, and controls for event such as the financial crisis, this chapter is able to empirically establish the equity markets' reaction function to the QE operations *prima facie*. This chapter to the best of the author's knowledge is the first to test for the portfolio balance and liquidity effects conditioning on the actual QE or LSAPs. The liquidity effects of QE, measured through the direct impact on the trade volume in the equity markets as result of the actual QE operations of the BoE and Fed.

Chapter 4. The Impact of QE on the Covariance of the Stock and Bond Markets

4.1 Introduction

This chapter investigates the effects of the QE operations on the interactions between the bond and stock markets by modelling the time-varying conditional covariance between the stock and bond markets in the UK and the US. As the bond markets were the major vehicle through which the BoE and the Fed carried out their quantitative easing operations, this chapter focuses on the effect of quantitative easing from both the intra and international financial market perspectives and looks in particular at whether the variance-covariance structure between the stock markets in the UK and US (inter) on the one hand, and the stock and bond markets within the UK and US (intra) on the other were affected by the individual large scale asset purchase operations of the BoE and Fed.

Studies of the covariation between asset markets were greatly advanced by the development of multivariate generalised autoregressive conditional heteroscedasticity (MV-GARCH) time series models, as applied, for example, by Hamao et al. (1990), Koutmos and Booth (1995), Bekaert and Harvey (1995) and Bekaert and Wu (2000). For example, Hamao et al. (1990) discovered that shocks to the volatility of financial market returns in one country could influence both the conditional volatility and the conditional mean of the returns in another country, while Koutmos and Booth documented asymmetric volatility relations between the financial markets of the USA, the UK and Japan.

Berben and Jansen (2005a) pioneered the use of time varying correlation structures within the MV-GARCH model to study changes in the level of international integration of equity markets. Capiello et al (2006) used the dynamic conditional correlation (DCC) model of Engle (2002) to explore the asymmetries in the dynamics of global equity and bond markets. Johansson (2010) examined asset markets in both the Asia-Pacific region and Europe, and found during the recent financial crisis, that there were increases in correlation among stocks in both regions, but also there were increases in markets that were relatively more insulated during these times, such as China.

While over time, a number of studies have examined the covariance or interdependence between stock markets, only since the last decade have studies begun to explicitly examine the covariance or interactions between the stock and bond markets. For example Fleming et.al. (1998) examined the volatility interaction of stock, bond, and money markets using a stochastic volatility model. They found a strong link in volatility between all three markets, but did not consider the conditional covariance between the bond and stock market returns. Bollerslev, Engle and Wooldridge (1988), consider time-varying conditional covariances, using a multivariate GARCH model, their focus was on testing the capital asset pricing model (CAPM) and did not explicitly examine the interactions between the stock and bond markets.

A few studies that have explicitly examined the interactions between the stock and bond markets include Marquering and De Goeij (2004), Cappiello et.al (2006), Steeley (2006), and Dean et.al. (2010). Marquering and De Goeij (2004) analysed the bond and stock market interactions in the US, modelling the asymmetric time-varying covariance between stock and bond market returns using daily returns on the S&P 500 index, NASDAQ composite index, and short and long Treasury bonds. They found that the conditional covariance change substantially over time, with respect to asymmetric effect, they reported that covariance between stock and bond returns tend to be relatively low after bad news in the stock market and good news in the bond market.

Steeley (2006) analysed the volatility transmission between the stock and bond markets in the UK using daily closing observations on the FTSE-100 share price, to represent stock returns, the price index of long term government bonds, to represent the return on long term bonds, he reported the correlation between short-term yield shocks and long term bond yield shocks to be relatively stable during the sample period from June 1984- June 2004.

To explore the interdependence between the Australian stock and bond markets, Dean et.al (2010), estimates a bivariate GARCH model with asymmetric effects. They use the bivariate asymmetric BEKK model of Kroner and Ng (1998) to parameterise the conditional covariance matrix. Using daily returns from the ASX All Ordinaries Total Return Index and the All Lives Government Bond Total Return Index from June 1992 to November 2006, they argue that volatility asymmetries and spill-over effects occur in returns to the equity market but not to the bond market returns.

Several explanations are advanced for the covariance and existent of spill-over effects in return and volatility within and between the stock and bond markets in the literature. Notable explanations include asset substitution, financial contagion and hedging demand shifts. The asset substitution perspective sees stocks and bonds as substitute assets. News that favours stocks relative to bond drives investors to buy or switch to stocks or equities, conversely news favouring bonds leads investors to buy bonds and sell stocks. Therefore, a positive return shock in one market spill-over as a negative return shock in the other market.

Understanding the evolution of the covariance or the nature of linkages between financial markets, whether intra- or international is central to establishing the limits of diversification, to security pricing, and to successful asset allocation. While there is a sizeable literature examining the international transmission of stock market volatility, and a few examining the intra-national transmission or covariance between the stock and bond markets, this chapter not only contributes to the literature by investigating both the intra- and inter-financial market volatility transmission, but distinguishes itself by specifically examining these from the prism of the QE operations. It assesses the impact of QE by the BoE and the Fed on the covariance structure between the international equity markets in the UK and US and the covariance structure within the UK and US intra-financial markets i.e. the domestic stock and bond markets.

The model used for the empirical investigation in this chapter has threshold changes corresponding to the financial crisis and the subsequent QE operations by the UK and US monetary authorities. Within this framework, the fundamental question of how the covariance structure between the UK and US equity markets; and within the UK and US equity and bond markets are affected following the QE operations can be addressed. The organization of this chapter is as follows. Section 4.2 describes the methodology and data used for the empirical analyses. Section 4.3 presents descriptive statistics of the data. The empirical results are presented in sections 4.4 and 4.5 while section 4.6 concludes.

4.2 Methodology and Data

This chapter estimates the temporal interaction between the UK and US stock and bond markets following the QE operations. Specifically, a diagonal VECH (DVECH) model is used to examine the conditional covariance structure between the stock markets of the UK and US, and the stock and bond markets in the UK and US separately against the backdrop of the QE operations. In the first stage of the empirical analysis, the covariation between the UK and US equity markets is modelled to see whether this are affected by the QE operations in the UK and the US. It is not parsimonious to include the individual QE intensity and phase variables, as done in univariate analysis in the previous chapter, into the model in a multivariate setting, as this would further compound the curse of dimensionality, which afflicts multivariate GARCH models.

The solution adopted to enable an examination of the impact of QE and that of the financial crisis across the two markets, whilst still making the models relatively parsimonious is to include only the QE intensity variables (actual purchases), and combine these on a per country basis, into one single variable or index that captures daily QE intensity in that country throughout the entire sample period rather than on an individual or periodic basis. Thus two new variables, $\text{QE}_{UK,t}$, and $\text{QE}_{US,t}$ are created as:

$$\text{QE}_{us,t} = [\text{QE1}_{i,t}; \text{QE2}_{i,t}; \text{QE3}_{i,t}; \text{MEP}_{i,t}] \qquad i \in UK, US \qquad (4.1)$$

$$\text{QE}_{uk,t} = [\text{QE1}_{i,t}; \text{QE2}_{i,t}; \text{QE3}_{i,t}] \qquad (4.2)$$

Thus including both of them in the multivariate specifications of the variances and covariance. In this case, the variance processes are similar but aggregated versions of the processes specified in the previous empirical chapter, that is

$$h_{i,t} = \omega_{i,i} + \alpha_{i,1}\text{Lehman}_{i,t} + b_{i,i}\varepsilon_{i,t-1}^{2} + c_{i,i}h_{i,t-1} + e_{i,i,UK}\text{QE}_{UK,t} + e_{i,i,US}\text{QE}_{US,t-1} \quad (4.3)$$

The variable $e_{i,m,US}\text{QE}_{US,t-1}$ measuring the impact of the US QE operations is lagged by one day to address the issue of the overlap or non-synchronous trading times between the US and UK stock markets. While the companion inter-market (UK and US equity markets) covariance processes are specified as:

$$h_{i,m,t} = \omega_{i,m} + \alpha_{i,1}\text{Lehman}_{i,t} + b_{i,m}\varepsilon_{i,t-1}\varepsilon_{m,t-1} + c_{i,m}h_{i,m,t-1} + e_{i,m,UK}\text{QE}_{UK,t} + e_{i,m,US}\text{QE}_{US,t-1} \quad (4.4)$$

Asymmetric effects in conditional covariance have been used by some studies in modelling the covariance between stock and bond returns. Kroner and Ng (1998) identify three possible forms of asymmetric behaviour-(i) the covariance matrix displays own variance asymmetry if $h_{ii,t}$ (the conditional variance of $\varepsilon_{i,t}$) is affected by the sign of the innovation in $r_{i,t-1}$; (ii) cross variance asymmetry if $h_{ii,t}$ is affected by the sign of the innovation in $r_{m,t-1}$;(iii) covariance asymmetry if $h_{i,m,t}$ (the conditional covariance) is affected by the sign of the innovation in either $r_{i,t-1}$ or $r_{m,t-1}$.

For robustness and to accommodate possible asymmetric effects, in modelling the conditional covariance between the stock and bond markets i.e. the second stage in the empirical analyses in this chapter, two alternate DVECH models i.e. a symmetric and the asymmetric DVECH following the approach of Glosten et.al. (1993), allowing explicitly for asymmetric conditional covariance terms are estimated.

The choice of the DVECH for the analyses in this chapter is justified on the basis that unlike the BEKK model where it may be difficult to track responses in the conditional variances and covariance to specific or individual parameters, due to the quadratic form of the BEKK specification, this is not the case with the DVECH specification. This permit with the DVECH, an investigation of the effect of specific variable(s) of interest on the variance-covariance matrix. The DVECH model used to model the intra-market (equity and bond markets) covariance is specified as:

$$h_{e,b,t} = \omega_{e,b} + \alpha_{i,1}\text{Lehman}_{i,t} + b_{e,b}\varepsilon_{e,t-1}\varepsilon_{b,t-1} + c_{e,b}h_{e,b,t-1} + d_{1e,b}I_{,\varepsilon_{e,t-1}}\varepsilon_{e,t-1}I_{,\varepsilon_{b,t-1}}\varepsilon_{bt-1} + + e_{e,b,UK}\text{QE}_{UK,t} \ or \ e_{e,b,US}\text{QE}_{US,t} \quad (4.5)$$

with $h_{e,b,t}$ = cov$_t$ $\{r_{e,t-1}, r_{b,t-1}\}$ i.e. covariance respectively of the equity and bond markets returns. The indicator variable $I\varepsilon_{k,t-1}$ is equal to one if $\varepsilon_{k,t-1} < 0$ (and zero otherwise), $k = e, b$. It permits the effect of lagged return shocks in the both equity and bond markets to depend on their signs. In the above equation, $I_{,\varepsilon_{e,t-1}}\varepsilon_{e,t-1}I_{,\varepsilon_{b,t-1}}\varepsilon_{b,t-1}$ is nonzero for negative pairs of $\varepsilon_{e,t-1}$ and $\varepsilon_{b,t-1}$. This term assigns an asymmetric covariance effect to the covariance matrix. As the sample period begins prior to the financial crisis, an indicator variable $\alpha_{i,1}\text{Lehman}_{i,t}$ starting from the period of the crisis is included in the model. We start this period on September 15, 2008, the date that Lehman brothers collapsed or declare bankruptcy. In addition, one broad indicative measure of the intensity of the QE operations in either the UK or US is included in the relevant model(s).

The covariance equations are estimated by maximum likelihood assuming conditional normality about the error terms i.e. $\varepsilon_{k,t} | \Omega_{t-1} \sim N(0, H_t)$, the log-likelihood function (for the sample $1 \ldots\ldots T$) is given by

$$\ell(\theta) = -\frac{1}{2} TN \log 2\pi - \frac{1}{2}\sum_{t-1}^{T} \log\det H_t(\theta) - \frac{1}{2}\sum_{t-1}^{T} \varepsilon'_t(\theta)\, H_t^{-1}(\theta)\, \varepsilon_t(\theta), \quad (4.5)$$

where θ denotes the vector of unknown parameters, the N × 1 vector $\epsilon_t(\theta)$ contains the error elements $\varepsilon_{k,t}(\theta)$, and $H_t(\theta)$ contains the covariance terms $h_{e,b,t}$, as defined in equation (4.4). The conditions under which the maximum likelihood is consistent and asymptotically normal are derived in Bollerslev and Wooldridge (1992), and they also derived the formulae for asymptotic standard errors that are robust to departures from the normality assumption. These robust standard errors are used to compute the t-statistics of the reported estimates which are obtained using the Berndt et.al (1974) algorithm.

The data employed for the analyses in this chapter consist of the daily closing observations, adjusted for dividends, of the FTSE100 and the S&P500 equity indices as proxy for the stock markets in the UK and US respectively, and the DataStream-constructed 10-year maturity UK and US government bond indices as proxy for longer-term UK and US Treasury bonds respectively. The DataStream 10-year Benchmark bond indices are composed of the most liquid government bonds and calculated using the European Federation of Financial Analysts (EFFAS) methodology. The benchmark indices are based on single bonds and the bond chosen for each series is the most representative bond available for the given maturity band at each point in time; consideration is also given to yield, liquidity, issue size and coupon.

In addition, to the bond indices, the 10 year yields i.e. the Treasury (US) and Gilt (UK) are used for robustness of the empirical analysis. The daily closing data or observations are collected from DataStream, and are used to calculate returns as the log daily change in index level for the stock and bond indices excluding days when either one or both of the markets were closed.

4.3 Descriptive Statistics.

Summary statistics for the daily returns to each of the equity and bond markets in the UK and US are contained in Table 33. Allowing for the differences in sample size, the mean return and standard deviations for the equity markets exceed their counterpart measures for the bond markets as expected. The skewness and kurtosis of returns show departure from a normal distribution, particularly for the excess kurtosis. The kurtosis is greater for the equity markets relative to the bond markets.

Table 33: Descriptive Statistics UK and US Equity and Bond Markets Return

Returns.	No. obs.	Mean	Std. Dev.	Skewness	Kurtosis
UK equity	2803	0.00012	0.01161	-0.15386	12.4667
UK bond	2803	0.00010	0.00390	0.08590	5.30282
US equity	2727	0.00022	0.01252	-0.33942	14.4908
US bond	2727	7.52×10^{-5}	0.00495	0.10263	6.26247

This table contains summary statistics for daily equity and bond returns in the US and UK.

Table 34 presents the correlation coefficients for equity and bond returns for both countries, for US and UK equity returns, and for the US and UK bond returns. The table shows that the correlation between equity markets' returns is much higher than the correlation between equity and bond markets' returns and slightly higher than the bond markets' return correlations. While both US and UK equity market returns and the US and UK bond market returns are positively correlated, both the UK and US bond market returns are negatively correlated with their own equity market as well as the other equity market.

Table 34: Sample correlation coefficients for equity & bond returns for the UK and US.

	UK equity	US equity	UK bond	US bond
UK equity	1.0000			
US equity	0.5926	1.0000		
UK bond	-0.0069	-0.0396	1.0000	
US bond	-0.0275	-0.0421	0.5426	1.0000

4.4 Empirical Result from the Equity Markets Variance-Covariance Estimation

In this section, the DVECH estimation result for the variance-covariance of the UK and the US equity markets is presented. From the estimation output in Table 35 below, the matrix ω captures the unconditional variance, with the element ω_{11} measuring the unconditional variance for the US, with ω_{22} capturing the unconditional variance for the UK. The off-diagonal element ω_{21} captures the unconditional covariance between both equity markets. The matrix b measure the effects of past errors or domestic shocks on the conditional variance-covariance of the equity markets, with the diagonal elements measuring the effects of a domestic shock on the own country and the other country equity market variance and the off-diagonal element measuring the effects of both countries domestic shocks on the covariance of the equity markets.

The lagged conditional variance effects are measured in the matrix c, with the diagonal elements of this matrix i.e. c_{11} and c_{22} measuring the impact of lagged domestic volatility on the conditional variances of the US and UK equity markets respectively. Again the off-diagonal element c_{12} measures the effect of the lagged conditional covariance between the two markets on the current conditional covariance between the two equity markets.

As can be seen from the table below, the diagonal and off-diagonal elements of both the B and C matrices are all very significant. This would imply that own past shocks and own past volatility account very significantly for the conditional variance of the US and UK equity markets. In the same vein, volatility spill-overs between both equity market also accounts very significantly for the covariance between the UK and US equity markets. Furthermore, the magnitudes of the estimates of the matrix C are all closer to unity, characterising the usual high degree of volatility clustering or persistence as first identified by Fama (1965) and Mandelbrot (1963).

In addition to these standard GARCH matrices, three additional matrices (e_{QEUS}, e_{QEUK} , α) measuring the effects of the exogenous variables included in the model capturing the totality of the US QE operations, the UK QE operations, and the impact of the financial crisis respectively are reported. The elements of the e_{QEUS} measures the effect of the US QE operations on the variance-covariance of the US and UK equity markets, with the diagonal elements of this matrix measuring the effect on the variance of the US and UK equity markets, and the off-diagonal measuring the effect on the covariance between the equity markets. It can be seen that all three elements of this matrix are insignificant.

For the e_{QEUK} matrix measuring the effect of the UK QE operations on the variance-covariance of the US and UK equity markets, the first diagonal element $e_{QEUK}(1,1)$, measuring the effect of the UK QE operations on the variance of the US equity market is found to be insignificant. However, the second diagonal element $e_{QEUK}(2,2)$, showing the effect of the UK QE operations on the variance of the UK equity market is significant. Interestingly, the off-diagonal element $e_{QEUK}(2,1)$, of this matrix measuring the impact of the UK QE operations on the covariance between the US and UK equity market is strongly significant. Implying that the BoE QE operations did in fact bring about an increased or positive covariance between the US and UK equity markets.

The elements of the matrix α measuring the impact of the financial crisis on the variance-covariance of the US and UK equity markets are all significant. Suggesting that the financial crisis increased the variance in both equity markets, as well as the covariance between both equity markets.

Table 35: DVECH estimation of the US and UK equity markets covariance

Variables	Estímate	Standard Error
$\omega_{(11)}$	2.197×10^{-6} ***	(2.761×10^{-7})
$\omega_{(21)}$	9.006×10^{-7}***	(1.490×10^{-7})
$\omega_{(22)}$	1.716×10^{-6}***	(2.749×10^{-7})
$b_{(11)}$	0.0726***	(0.0062)
$b_{(21)}$	0.0459***	(0.0046)
$b_{(22)}$	0.0715***	(0.0063)
$c_{(11)}$	0.8983***	(0.0081)
$c_{(21)}$	0.9242***	(0.0072)
$c_{(22)}$	0.9028***	(0.0074)
$\alpha_{(11)}$	2.148×10^{-4} **	(8.553×10^{-5})
$\alpha_{(21)}$	1.113×10^{-4}**	(4.341×10^{-5})
$\alpha_{(22)}$	1.598×10^{-4}***	(5.125×10^{-5})
eQE_{US} (11)	3.396×10^{-5}	(2.108×10^{-4})
eQE_{US} (21)	2.851×10^{-4}	(1.914×10^{-4})
eQE_{US} (22)	3.810×10^{-4}	(3.301×10^{-4})
eQE_{UK} (11)	4.915×10^{-4}	(3.234×10^{-4})
eQE_{UK} (21)	5.900×10^{-4}**	(2.501×10^{-4})
eQE_{UK} (22)	6.255×10^{-4}*	(3.689×10^{-4})

Log-Likelihood 18249.3791

Multivariate Q-stats	value	significance	X^2
Q (10)	60.4514	0.1535	40
Q (12)	65.4094	0.1162	48
Q (24)	101.1657	0.3394	96

This table reports estimation results of Equation (4.4) using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** * denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

The effect of the QE operations on the US and UK equity market covariation is also considered using an average of two days in lieu of the lag treatment used previously; and also without remedying for the non-synchronous timings between these financial markets[18]. The results of these re-estimations presented below in Tables 36 and 37 respectively reveal no major difference from the earlier estimation results above.

Table 36: DVECH estimation of the US and UK equity markets covariance

Variables	Estímate	Standard Error
$\omega_{(11)}$	$4.467\times10^{-6***}$	(5.186×10^{-7})
$\omega_{(21)}$	$6.868\times10^{-5***}$	(4.292×10^{-6})
$\omega_{(22)}$	$3.931\times10^{-6***}$	(4.594×10^{-7})
$b_{(11)}$	0.050^{***}	(0.0052)
$b_{(21)}$	0.015^{**}	(0.0067)
$b_{(22)}$	0.0486^{***}	(0.0051)
$c_{(11)}$	0.8990^{***}	(0.0097)
$c_{(21)}$	0.8397^{***}	(0.0844)
$c_{(22)}$	0.9014^{***}	(0.0089)
$\alpha_{(11)}$	$2.585\times10^{-4**}$	(1.020×10^{-4})
$\alpha_{(21)}$	$3.445\times10^{-4**}$	(1.407×10^{-4})
$\alpha_{(22)}$	$1.465\times10^{-4***}$	(4.398×10^{-5})
eQE_{US} (11)	7.062×10^{-4}	(4.108×10^{-4})
eQE_{US} (21)	1.731×10^{-3}	(1.841×10^{-4})
eQE_{US} (22)	1.258×10^{-4}	(2.490×10^{-4})
eQE_{UK} (11)	1.843×10^{-4}	(2.239×10^{-4})
eQE_{UK} (21)	$2.740\times10^{-3***}$	(6.510×10^{-4})
eQE_{UK} (22)	$4.427\times10^{-4**}$	(1.8139×10^{-4})
Log-Likelihood	18283.0812	

Multivariate Q-stats	value	significance	X^2
Q (10)	60.4514	0.1535	40
Q (12)	65.4094	0.1162	48
Q (24)	101.1657	0.3394	96

This table reports estimation results of the US and UK equity market covariation using the average of two days in lieu of the lag used in Equation (4.4) for the daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** * denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

[18] To alleviate the resulting nonsynchronous trading issues, returns at weekly frequency have also been used by some studies e.g. Cappiello et.al. 2006

Table 37: DVECH estimation of the US and UK equity markets covariance

Variables	Estímate	Standard Error
$\omega_{(11)}$	2.113×10^{-6}***	(2.748×10^{-7})
$\omega_{(21)}$	8.328×10^{-7}***	(1.454×10^{-7})
$\omega_{(22)}$	1.564×10^{-6}***	(2.747×10^{-7})
$b_{(11)}$	0.0805***	(0.0066)
$b_{(21)}$	0.0509***	(0.0048)
$b_{(22)}$	0.0778***	(0.0065)
$c_{(11)}$	0.8954***	(0.0083)
$c_{(21)}$	0.9241***	(0.0072)
$c_{(22)}$	0.9018***	(0.0078)
$\alpha_{(11)}$	2.148×10^{-4}**	(8.553×10^{-5})
$\alpha_{(21)}$	1.113×10^{-4}**	(4.341×10^{-5})
$\alpha_{(22)}$	1.598×10^{-4}***	(5.125×10^{-5})
$eQE_{US\ (11)}$	3.674×10^{-5}	(2.152×10^{-4})
$eQE_{US\ (21)}$	2.068×10^{-4}	(1.865×10^{-4})
$eQE_{US\ (22)}$	3.448×10^{-4}	(3.300×10^{-4})
$eQE_{UK\ (11)}$	4.303×10^{-4}	(3.264×10^{-4})
$eQE_{UK(21)}$	5.064×10^{-4}**	(2.454×10^{-4})
$eQE_{UK(22)}$	5.285×10^{-4}*	(3.661×10^{-4})

Log-Likelihood 18263.3512

Multivariate Q-stats	value	significance	X^2
Q (10)	60.4514	0.1535	40
Q (12)	65.4094	0.1162	48
Q (24)	101.1657	0.3394	96

This table reports estimation results of the US and UK equity market covariation without remedying for a synchronicity using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** * denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

It is important that non-linear models such as the ARCH types are correctly specified to ensure consistency. To this end, tests to evaluate the adequacy of the models are based on the standardized residuals defined as $\hat{z}_{i,t} = \hat{\varepsilon}_{i,t}\widehat{H}_t^{-1/2}$ for $i = e,b$. Correct specification entails that the distribution of the standardized residuals $\hat{\varepsilon}_t \sim$ *iid (0,I)* and that $[z_{i,t}]$ and $[z^2_{i,t}]$ are serially uncorrelated.

Table 38 reports the p-values associated with these tests. Multivariate generalisations of the Ljung-Box tests for *rth* order serial correlation are also provided on the lower panels of Table 37. The Ljung-Box test is a popular diagnostic for models with time-varying conditional second moments as it addresses whether the model has adequately captured the serial correlation in the second moments. As can be seen from these tables, there remains no autocorrelation in the models suggesting that the models provides adequate descriptions of the daily stock returns dataset.

Table 38: Standardized residual tests

	$E(z)$	$E(z^2)$
UK	0.1936	0.2984
US	0.1646	0.3444

This table presents specification and diagnostics tests for the DVECH equation. The rows of the lower panel are *p*-values from tests of (z) and (z^2) which are the standardized residuals and squared residuals from the equations for the UK and US.

Table 39 is the result from the re-estimation the sample excluding the structural breaks in the UK and US equations. As can be seen from the table the results are robust to the exclusion or provision for structural breaks. An increasing number of coefficients i.e. from the UK QE operations is revealed following the smaller sample size estimation.

Table 39: DVECH estimation of the US and UK equity markets covariance

Variables	Estímate	Standard Error
$\omega_{(11)}$	$3.916\times10^{-6***}$	(8.486×10^{-7})
$\omega_{(21)}$	$1.680\times10^{-6***}$	(5.022×10^{-7})
$\omega_{(22)}$	$2.295\times10^{-6***}$	(7.043×10^{-7})
$b_{(11)}$	0.0978^{***}	(0.0112)
$b_{(21)}$	0.0561^{***}	(0.0077)
$b_{(22)}$	0.0638^{***}	(0.0091)
$c_{(11)}$	0.8538^{***}	(0.0161)
$c_{(21)}$	0.9003^{***}	(0.0138)
$c_{(22)}$	0.9019^{***}	(0.0151)
$\alpha_{(11)}$	-	-
$\alpha_{(21)}$	-	-
$\alpha_{(22)}$	-	-
$eQE_{US\ (11)}$	1.202×10^{-4}	(4.369×10^{-4})
$e_{QEUS\ (21)}$	1.813×10^{-4}	(3.705×10^{-4})
$eQE_{US\ (22)}$	2.337×10^{-4}	(5.467×10^{-4})
$eQE_{UK\ (11)}$	$9.426\times10^{-4*}$	(4.981×10^{-4})
$eQE_{UK\ (21)}$	$8.227\times10^{-4**}$	(3.543×10^{-4})
$eQE_{UK\ (22)}$	$7.459\times10^{-4*}$	(4.198×10^{-4})

Log-Likelihood 9497.5498

Multivariate Q-stats	value	significance	X^2
Q (10)	197.6064	0.2399	40
Q (12)	205.9483	0.2118	48
Q (24)	241.63516	0.1375	96

This table reports estimation results of Equation (4.4) using daily data from January 23rd 2009, to October 31st 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** * denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

Table 40: Standardized residual tests

	$E(z)$	$E(z^2)$
UK	0.5470	0.7668
US	0.1604	0.4080

This table presents specification and diagnostics tests for the DVECH equation. The rows of the lower panel are *p*-values from tests of (z) and (z^2) which are the standardized residuals and squared residuals from the equations for the UK and US.

4.5 Empirical Result from the Equity and Bond Markets Covariance Estimation

In this section the estimation results of the parameters that govern the dynamics in the variances and covariance from a symmetric and asymmetric DVECH models, pertaining to the equation 4.5 (see above) are reported in Tables 41 and 42, respectively for the UK and US financial markets. Starting with the UK equity and bond markets, there is strong evidence in favour of strong effects on the covariance between the equity and bond markets, coming from the variables included in the models for both the symmetric and asymmetric DVECH.

Most of the corresponding estimated parameters are statistically significant at the 5% level. The estimates for the coefficients on the covariance of the returns' shocks or innovation (i.e., b_{21}) between the equity and bond markets in the symmetric (0.048) and asymmetric (0.038) models are positive and strongly significant. This positive estimate for the ARCH term in the covariance equation could be interpreted that two shocks of the same sign affect the conditional covariance between the UK equity and bond market positively. The estimates of the lagged volatility (i.e., c_{21}) on the covariance of the returns are also statistically significant in both models with values close to unity.

Moving on to the asymmetric terms in the asymmetric DVECH model, There is no evidence of any significant asymmetric or leverage effects on the covariance between the UK equity and bond markets. The coefficient for the asymmetric effect in covariance (i.e., d_{21}) is insignificant. The only significant asymmetric term is the asymmetric term (d_{11}) in the variance of the UK equity market returns, thus suggesting for the UK that asymmetric effects are only statistically significant in the stock market in line with existing evidence from the literature. [Glosten et.al. (1993), Engle and Ng (1993) and Dean et.al (2010)].

The exogenous variables in the model (i.e. indicator variables for the financial crisis and the QE operations) reveal some interesting results. We document evidence of significant covariance between the UK equity and bond markets following the financial crisis and the subsequent QE policy response or operations. The estimated coefficients for these two variables (i.e. d_{21} and $QEUK_{21}$) are statistically significant and negative in both the symmetric and asymmetric models.

That the QE operations engendered a negative covariance between the bond and equity markets sounds plausible or is compatible with the asset substitution hypothesis. If considered that that the QE operations represents a negative shock to the bond market which through the portfolio balancing mechanism and asset substitution filters into the stock market implies a negative covariance between the bond and equity market following such QE operations.

Table 41: Estimation results equity and bond market variance-covariance (UK)

	Symmetric DVECH		Asymmetric DVECH	
Variables	Estímate	Standard Error	Estímate	Standard Error
$\omega_{(11)}$	$1.423\times10^{-6***}$	(2.318×10^{-7})	$6.356\times10^{-7***}$	(1.566×10^{-7})
$\omega_{(21)}$	$-1.408\times10^{-7***}$	(4.246×10^{-8})	-6.210×10^{-8}	(4.888×10^{-8})
$\omega_{(22)}$	$1.285\times10^{-7***}$	(2.983×10^{-8})	$1.090\times10^{-7***}$	(2.789×10^{-8})
$b_{(11)}$	0.088^{***}	(7.504×10^{-3})	0.011^{*}	(5.779×10^{-3})
$b_{(21)}$	0.048^{***}	(5.158×10^{-3})	0.038^{***}	(4.618×10^{-3})
$b_{(22)}$	0.023^{***}	(4.178×10^{-3})	0.022^{***}	(4.334×10^{-3})
$c_{(11)}$	0.895^{***}	(7.864×10^{-3})	0.929^{***}	(5.936×10^{-3})
$c_{(21)}$	0.928^{***}	(7.377×10^{-3})	0.941^{***}	(6.704×10^{-3})
$c_{(22)}$	0.962^{***}	(5.910×10^{-3})	0.967^{***}	(5.729×10^{-3})
$d_{(11)}$	-	-	0.114^{***}	(0.011)
$d_{(21)}$	-	-	-0.012	(0.019)
$d_{(22)}$	-	-	-3.192×10^{-3}	(6.265×10^{-3})
$\alpha_{(11)}$	3.145×10^{-5}	(4.485×10^{-5})	9.732×10^{-7}	(2.040×10^{-5})
$\alpha_{(21)}$	$-6.490\times10^{-6**}$	(3.161×10^{-6})	$-4.689\times10^{-6**}$	(2.024×10^{-6})
$\alpha_{(22)}$	6.190×10^{-7}	(4.157×10^{-7})	4.922×10^{-7}	(3.846×10^{-7})
$e_{QEUK(11)}$	$1.249\times10^{-3***}$	(3.850×10^{-4})	$6.582\times10^{-4***}$	(2.515×10^{-4})
$e_{QEUK(21)}$	$-3.548\times10^{-4***}$	(1.017×10^{-4})	$-2.907\times10^{-4***}$	(8.283×10^{-5})
$e_{QEUK(22)}$	$1.847\times10^{-4***}$	(3.839×10^{-5})	$1.668\times10^{-4***}$	(3.508×10^{-5})
Log-Likelihood	21209.8795		21168.4073	

Multivariate Q-stats	value	significance	X^2	value	significance	X^2
Q (10)	42.4251	0.3668	40	42.0925	0.3804	40
Q (12)	49.2367	0.4234	48	48.6600	0.2272	48
Q (24)	108.6988	0.1770	96	106.0316	0.2272	96

This table reports estimation results of Equation (4.5) for the UK using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. ***, **, *, denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

Table 42 shows the estimation results for the US equity and bond markets. There are a few compelling observations to be made concerning the estimation results from the symmetric and asymmetric DVECH models. For instance, the parameter matrix b which reflects the ARCH components in the both the symmetry and asymmetry models, has the estimate for the coefficient on the variance of the own return shocks to the equity market (i.e. b_{11}) in the asymmetry model insignificant.

Furthermore, unlike for the UK, for the US the parameter matrix d reflecting the asymmetric components in the asymmetric DVECH model has two (i.e. d_{11} and d_{21}) of its three components significant. The variable d_{11} shows impact of the asymmetric effect on the variance of the US equity market returns. The variable d_{21} shows the impact of the asymmetric effects on the covariance between the US equity and bond markets. The coefficient or estimate for this variable is significant implying, that for the US, the covariance between the equity and bond markets exhibit significant leverage effects and the covariance is negative as shocks increase when the signs differ.

The estimates for the QE and the variable measuring the impact of the financial crisis are also presented. Similar to the estimated results for the UK, evidence of a significant negative covariance between the US equity and bond markets following the Federal Reserve QE operations is reported. The result is robust to both the symmetric and asymmetric models and thus a similar explanation as provided above for the UK is inferred here for the US also. The congruence or harmonization of the US and UK estimation results with regards to the exogenous QE variables robustly show the response of the conditional covariance between the equity and bond markets in the UK and US separately, to the large scale asset purchases or QE phenomena and thus is presented as strong evidence of the impact of QE on the covariation between the equity and bond markets.

Table 42: Estimation results equity and bond market variance-covariance (US)

Symmetric DVECH			Asymmetric DVECH	
Variables	Estímate	Standard Error	Estímate	Standard Error
ω_{11}	$1.362\times10^{-6***}$	(2.730×10^{-7})	$5.513\times10^{-7***}$	(1.601×10^{-7})
ω_{21}	-4.757×10^{-8}	(4.246×10^{-8})	5.442×10^{-8}	(4.973×10^{-8})
ω_{22}	$1.155\times10^{-8***}$	(4.853×10^{-8})	$1.125\times10^{-7***}$	(3.619×10^{-8})
b_{11}	0.083^{***}	(7.139×10^{-3})	-1.470×10^{-3}	(5.832×10^{-3})
b_{21}	0.056^{***}	(5.522×10^{-3})	0.045^{***}	(4.678×10^{-3})
b_{22}	0.042^{***}	(4.897×10^{-3})	0.036^{***}	(5.720×10^{-3})
c_{11}	0.902^{***}	(7.636×10^{-3})	0.937^{***}	(5.465×10^{-3})
c_{21}	0.926^{***}	(6.560×10^{-3})	0.939^{***}	(5.941×10^{-3})
c_{22}	0.951^{***}	(4.852×10^{-3})	0.953^{***}	(5.032×10^{-3})
d_{11}	-	-	0.136^{***}	(0.012)
d_{21}	-	-	-0.025^{*}	(0.014)
d_{22}	-	-	8.242×10^{-3}	(6.271×10^{-3})
$\alpha_{(11)}$	-5.867×10^{-6}	(3.882×10^{-5})	$-4.653\times10^{-5**}$	(4.456×10^{-6})
$\alpha_{(21)}$	-7.733×10^{-6}	(6.637×10^{-6})	5.412×10^{-7}	(8.985×10^{-7})
$\alpha_{(22)}$	6.969×10^{-7}	(9.599×10^{-7})	4.922×10^{-7}	(3.846×10^{-7})
$e_{US(11)}$	$5.112\times10^{-4*}$	(2.668×10^{-4})	2.354×10^{-5}	(1.598×10^{-4})
$e_{US(21)}$	$-3.908\times10^{-4***}$	(1.021×10^{-4})	$-2.386\times10^{-4***}$	(7.789×10^{-5})
$e_{US(22)}$	$1.194\times10^{-4**}$	(4.966×10^{-5})	$1.108\times10^{-4**}$	(4.762×10^{-5})
Log-Likelihood	19972.2008		21168.4073	

Multivariate Q-stats	value	significance	X^2	value	significance	X^2
Q (10)	49.0078	0.1554	40	49.0078	0.1554	40
Q (12)	51.8776	0.3252	48	53.9937	0.2561	48
Q (24)	107.8599	0.2413	96	108.8195	0.1750	96

This table reports estimation results of Equation (4.5) for the US using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** *, denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

Table 43: Standardized residual tests

Panel A: UK	DVECH	asymmetry DVECH
$E(z_e)$	0.1515	0.1295
$E(z_e^2)$	0.0742	0.3930
$E(z_b)$	0.1490	0.1423
$E(z_b^2)$	0.3140	0.2689
Panel B: US		
$E(z_e)$	0.1080	0.1338
$E(z_e^2)$	0.1467	0.2855
$E(z_b)$	0.1701	0.1674
$E(z_b^2)$	0.3080	0.3742

This table presents specification and diagnostics tests for the symmetric and asymmetric DVECH. The first four rows of Panel A are *p*-values from tests of (z_e) and (z_b) which are the standardized residuals from the equation for the UK equity and bond markets, respectively. The panel B shows the standardized residuals from the equations for the US equity and bond markets, respectively.

As a robustness check on the results from the equity and bond market covariation, an alternate measure to the bond indices i.e. the 10 year Treasury yield is also used in re-estimating the equity and bond market covariation for both the US and UK, with results reported in Tables 44 and 45 respectively. The results of the impact of QE on the covariance between the equity and bond markets, using the 10 year government bond yields is robust for both the US and UK estimation with no change in the sign nor significance of the parameters, earlier reported using the bond indices.

Table 44: Estimation results equity and 10 yield variance-covariance (US)

Variables	Estímate	Standard Error
ω_{11}	$4.792\times10^{-5***}$	(3.605×10^{-6})
ω_{21}	$5.106\times10^{-6***}$	(3.132×10^{-6})
ω_{22}	$1.228\times10^{-4***}$	(5.686×10^{-6})
b_{11}	0.240^{***}	(0.0122)
b_{21}	0.238^{***}	(0.0123)
b_{22}	0.239^{***}	(0.0125)
c_{11}	0.766^{***}	(0.0455)
c_{21}	0.765^{***}	(0.0451)
c_{22}	0.763^{***}	(0.0448)
$\alpha_{(11)}$	-5.867×10^{-6}	(3.882×10^{-5})
$\alpha_{(21)}$	-7.733×10^{-6}	(6.637×10^{-6})
$\alpha_{(22)}$	6.969×10^{-7}	(9.599×10^{-7})
$e_{US(11)}$	0.0425^{***}	(0.0086)
$e_{US(21)}$	-0.0837^{***}	(0.0128)
$e_{US(22)}$	0.0982^{***}	(0.0215)
Log-Likelihood	19972.2008	

Multivariate Q-stats	value	significance	X^2
Q (10)	49.0078	0.1554	40
Q (12)	51.8776	0.3252	48
Q (24)	107.8599	0.2413	96

This table reports estimation results for the US equity and bond yield covariation estimation using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** *, denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

Table 45: Estimation results equity and 10 yield variance-covariance (UK)

Variables	Estímate	Standard Error
ω_{11}	$5.198\times10^{-5***}$	(3.984×10^{-6})
ω_{21}	$2.310\times10^{-5***}$	(4.522×10^{-6})
ω_{22}	$9.917\times10^{-5***}$	(4.994×10^{-6})
b_{11}	0.228^{***}	(0.0132)
b_{21}	0.223^{***}	(0.0130)
b_{22}	0.2250^{***}	(0.0134)
c_{11}	0.7237^{***}	(0.0504)
c_{21}	0.7267^{***}	(0.0502)
c_{22}	0.7227^{***}	(0.0504)
$\alpha_{(11)}$	$-4.653\times10^{-5**}$	(4.456×10^{-6})
$\alpha_{(21)}$	5.412×10^{-7}	(8.985×10^{-7})
$\alpha_{(22)}$	4.922×10^{-7}	(3.846×10^{-7})
$e_{UK(11)}$	0.0314^{***}	(0.0079)
$e_{UK(21)}$	-0.0854^{***}	(0.0126)
$e_{UK(22)}$	0.1195^{***}	(0.0219)

Log-Likelihood	21168.4073

Multivariate Q-stats	value	significance	X^2
Q (10)	49.0078	0.1554	40
Q (12)	53.9937	0.2561	48
Q (24)	108.8195	0.1750	96

This table reports estimation results for the UK equity and bond yield covariation estimation using daily data from January 2004, to October 2014. Robust Bollerslev-Wooldridge standard errors are reported in parentheses. *** ** *, denote statistical significance at the 1%, 5% and 10% levels respectively. Multivariate Q-statistics is the Ljung and Box (1979) variant on multivariate Q-stats.

4.6 Chapter Conclusion

In this chapter an investigation of the time-varying conditional covariance between the stock markets in the UK and US; and the stock and bond markets within the UK and within the US against the backdrop of the quantitative easing operations implemented by their respective monetary authorities in the aftermath of the financial crisis, was carried out using the DVECH model. The results from the multivariate analysis of both the UK and US equity markets revealed that the QE operations had a positive impact on the variance-covariance structure of the UK and US equity markets, with the effect coming mainly from the UK QE operations.

The estimation results from both the symmetric and asymmetric DVECH models used to model the covariance between the stock and bond markets within the UK and within the US suggests that the QE operations both in the US and the UK brought about substantial changes in the conditional covariance between the stock and bond markets. Specifically, the conditional covariance between the bond and stock markets in the US and UK was negatively significant following the QE operations by the BoE and Fed. Similarly, it is found that both bond and equity market variance were elevated following the QE operations in the UK irrespective of whether a symmetric or asymmetric model is estimated.

In the US, the chapter finds that the asymmetric model provides no evidence of heighted variance for the equity market following the Fed QE operations even though a marginally significant positive variance effect was detected by the symmetric model. With respect to asymmetric effects, it was detected for the US, that not only variance (of the equity market), but also the covariance, between the stock and bond markets show significant asymmetric or leverage effects. No such significant asymmetric covariance effect between the UK stock and bond markets was found however.

While evidence of changing or heteroskedastic covariances across assets and financial markets have been reported over time, in the literature e.g. French et.al (1987), Bollerslev et.al (1988), Harvey (1989), Bodurtha and Mark (1991)] their sources are yet to be well identified. Moreover, none of the earlier or even later studies in the literature up until now, had given any consideration to financial markets covariation against the backdrop of a novel experience like the QE operations, thus not just focusing on the impact of an event such as a financial crisis or financial market crash. This study is thus distinguished from the other earlier studies in the literature in the aspect of investigating the covariation between the equity and bond market against a novel experience of the QE.

The major contribution of this chapter investigating the covariation between financial assets and across financial markets against the novel QE or LSAPs experience in the UK and US, is in fact that, LSAPs of the QE kind is a significant source of covariation or heteroskedastic (positive) covariance between the stock or equity markets and negative covariation between bond and stock markets. This has practical implication from for financial asset market investors.

From modern portfolio theory we know that investors should diversify between different financial assets and markets. The findings in the chapter would suggest that investors stand in good stead to benefit from tactical asset allocation between the bond and stock (intra-financial) markets, with QE operations in effect. The implication for inter-equity markets portfolio risk diversification however, is different when QE operations are in effect. This find becomes even more worthy of note especially if taken into consideration that the toolkit of monetary policy in aftermath of the financial crisis has been expanded to now include a hitherto unconventional tool in the mode of QE.

Chapter 5. QE and Long-run Equity Market Co-movements?

5.1: Introduction.

In the preceding chapter it was empirically established that the QE operations engendered a significant increase in covariance between the UK and US equity markets. Since investors might hold in their portfolios assets from more than one financial market at a time, to diversify portfolio risk, equity markets co-movement particularly if for a long-term should concern investors' vis-à-vis their portfolio risk diversification motive. Although the QE operations appeared to have impacted significantly on the covariance between the UK and US equity markets, it remains to be seen whether this QE induced significant increase in covariance has a long-run implication i.e. are the equity markets more converged or cointegrated as a result?

Partly informed by the global nature of the October 1987 stock market crash, a voluminous literature investigating various aspects of international equity markets interaction now exist albeit with conflicting conclusions. On the one hand are studies like French and Poterba (1991) which investigates within a mean-variance framework, the correlations between different national equity markets and the potential benefits of international portfolio diversification. On the other hand are studies such as Harvey (1991), Engel (1994), Bekaert and Harvey (1995) which investigate the extent to which equity returns can be explained by international asset pricing theories. There is also a large number of research including for example King and Wadhwani (1990) which focuses on the transmission of information and shocks between national stock markets.

Yet a strand of the literature starting with Taylor and Tonks (1989) and Kasa (1992) focus on long-horizon relationship by testing for cointegration across national stock market indices. Kasa (1992), using monthly and quarterly data from 1974 through August 1990 argued that the price (including dividends) indices for the equity markets of five major industrial countries including the US, Japan, UK, Germany and Canada were all cointegrated. Arshanapalli and Doukas (1993) examining the linkages and dynamic interactions among stock price indices in the major world stock exchanges for the period of January 1980 through May 1990, using the alternate Engle and Granger (1987) residual-based cointegration technique, reported evidence of significant international co-movements in stock price indices since the crash of October 1987. In their study, the three major European stock markets (i.e., France, Germany and the UK) were found to be cointegrated with the US stock market. Richards (1995) examined the statistical basis for the rejection by Kasa (1992) of the null hypothesis of no cointegration between different equity markets. He argued that the finding of a cointegrating relationship by Kasa was due to a failure to adjust asymptotic critical values to take account of the small number of degrees of freedom warranted by the small number (57) of observations.

Notwithstanding, that the benefits of international portfolio diversification which depends on the extent of heterogeneity among different equity markets diminishes in the presence of cointegration, since that would mean that in the long-run, correlations amongst market become stronger and the return and risk profile of different equity markets would move together. Studies continue to find evidence of increasing interdependence and co-movements between different markets, which have been attributed in some cases to increasing relaxation of exchange controls and increasing macroeconomic integration both regionally and globally. For instance in a study investigating the impact that the removal of exchange controls within major European economies had on the interdependence of European equity markets, Chelley-Steeley and Steeley (1996) found that the European equity markets (UK, Germany, Italy, Switzerland and France) have become substantially more integrated after the removal of exchange controls during the late 1970's and early 1980's, which heralded the creation in 1992 of the single market.

Providing additional evidence on cointegration for three major European stock markets (France, Germany and the UK), Rangvid (2001) found a decreasing number of common stochastic trend(s) influencing the stock markets i.e. the degree of convergence among European stock markets has increased during the recent two decades, corresponding to the very period after which capital restrictions have been lifted throughout the Euro area. However, Pascual (2003) argued that the Johansen cointegration test provides increasing values of the trace statistics, which a priori may be interpreted as an increasing support for cointegration but that if the cointegration test is fixed by keeping the sample size constant, no support or evidence for increasing cointegration or an increasing number of cointegrating vector is found.

Huang et.al. (2000) examined the causality and cointegration relationships among the stock markets of the US, Japan and the South China Growth Triangle (SCGT) region consisting of Hong Kong, Taiwan and the Southern part of the People's Republic of China (PRC) for the period starting October1992 to 1997. They found no cointegration relationship within the members of the SCGT, or between SCGT and the US, or between SCGT and Japan. But an examination of the lead, lag or feedback relations showed a significant Granger causality between the US and members of the SCGT, such that the US price changes could be used to predict subsequent day price changes in the Hong Kong and the Taiwan stock markets.

It is clear from the foregoing literature that conflicting or non-unanimous findings exist to the question of whether equity markets are cointegrated with each other. The financial crisis and its aftermath i.e. the turbulence or contagion effect (Roll, {1998}) witnessed across major financial markets, coupled with the monetary authorities response to the financial crisis in the form of the QE operations by the BoE, the Fed and lately the ECB, juxtaposed with the finding in the previous chapter of a significant increase in covariance between the UK and US equity markets' engendered by the QE actions and spill-over effects, particularly from the UK QE operations into the French and German equity markets, provides a compelling reason to revisit this debate. Thus, this chapter investigates or test for long-run equity market co-movement against the backdrop of the QE operations, amongst the equity markets in the UK, US and the Euro-area (France and Germany).

The remainder of this chapter is structured as follows: the next section explains the methodology- including unit root, vector auto-regressions (VARs), multivariate cointegration tests, Granger causality and impulse response functions as well as the data used for the empirical analyses. The results of the empirical analyses are presented in sections 5.3, 5.4, and 5.5. While section 5.6 concludes the chapter.

5.2: Methodology and Data

To achieve the aims of this chapter of the thesis, several econometric tests including tests for unit root/stationary, multivariate cointegration tests and Granger causality tests are used. The unit root analyses mainly derives from the Augmented Dickey-Fuller (ADF) test introduced by Dickey and Fuller (1979) in the following equation:

$$\Delta x_t = \alpha + \beta\tau + \delta x_{t-1} + \sum_{i=1}^{k-1} \theta_i \Delta x_{t-i} + \varepsilon_t \qquad (5.1)$$

where Δ = 1-L, x_t= stochastic variable at time t, τ =trend variable, and ε_t the white noise error term. The unit root null hypothesis tests $H_0: \delta = 1$ (i.e. contains a unit root) in the above equation against the one-sided alternative H_1 $\delta < 1$ (i.e. stationary). The power of the ADF statistic however is low when there is a structural break, since structural breaks can induce apparent unit roots in stationary autoregressive time series (Perron, 1989). The ADF test may fail to reject the H_0 in the presence of structural break(s). To circumvent this problem Perron and Vogelsang (1992) included a dummy variable in (5.1).

Zivot and Andrews (1992) pointed out that the Perron's approach is not without its own problem, arguing that 'a skeptic of Perron's approach would say that his choices of breakpoints are based on prior observation of the data and hence problems associated with 'pre-testing' are applicable to his methodology' (pp. 251). Subsequently, Zivot and Andrews (1992) modify the ADF specification to:

$$\Delta x_t = \alpha + \beta\tau + \gamma DU_t(\lambda) + \delta x_{t-1} + \sum_{i=1}^{k-1} \theta_i \Delta x_{t-i} + \varepsilon_t \qquad (5.2)$$

Where $\mathrm{DU_t}(\lambda)$ =1 if $t > T\lambda$, (otherwise zero); $\lambda \in (0,1) = T_B/\mathrm{T}$ depicts the location or relative timing of the change point or structural break; T is total number of observations; T_B is the time or date when the structural break occurred in the trend function, which is treated as unknown, priori. Zivot and Andrews (1992) simulate a set of critical values for different ρ, upon which the estimation results hinges.

In addition to the above specifications or tests for unit roots, the analysis in this chapter is further confirmed with the complimentary test of KPSS (1992) that assumes stationarity under the null hypothesis. The analysis shows that the null hypothesis could not be rejected under the three different test statistic used. This is to say that the stochastic variables or logarithmic stock price indices are all integrated i.e. I (1) and stationary in first differences.

Next an analysis of the logarithmic stock price indices in levels is run based on the following VAR model of order *p* specified as:

$$y_t = \alpha_0 + \sum_{i=1}^{p} \Phi_i y_{t-i} + \Psi z_t + u_t \tag{5.3}$$

With y_t an $n \times 1$ vector of jointly determined (endogenous) variables i.e. the logarithmic stock prices at time *t*, Φ_i is an $N \times N$ matrix, z_t is a $q \times 1$ vector of exogenous variables, and u_t is an $m \times 1$ vector of unobserved white noise disturbances. The choice of *p* is based on the Akaike Information Criteria (AIC). The components of the vector z_t are known as exogenous variables and they are the UK and US (QEUK and QEUS) variables determined outside of the VAR system i.e. there are no equations in the VAR with any components of z_t as dependent variables.

One potential concern regarding the analysis from the above restricted or reduced form VAR pertain to the endogeneity of the QE or LSAPs to the system. This potential weakness is mitigated by the fact that QE or the bond purchases were announced ex-ante by the BoE and Fed and thus are pre-determined or independent of the prevailing prices in the equity markets. Neither was there any indication that the BoE and Fed purchases were at any point adjusted to accommodate conditions in the equity markets. In other words it is the QE bond purchases that influence equity prices via a mechanism through which QE is theorised to operate and not the equity market prices or conditions determining the monetary authorities QE or bond purchases.

For the cointegration analysis, the Johansen (1988 and 1991) cointegration procedure is employed. The Johansen cointegration technique extends the Engle and Granger (1987) pioneering single-equation or residual based cointegration technique to a multivariate framework. Following Johansen (1988), this chapter consider a general vector error-correction (VECM) model of the following form:

$$\Delta y_t = \mu + \Gamma_1 \Delta y_{t-1} + \ldots + \Gamma_{k-1} \Delta y_{t-k+1} + \Pi y_{t-k} + \varepsilon_t \qquad (5.4)$$

Where $y_t = (p \times 1)$ vector of logarithmic stock prices at time t; $\Pi = (p \times p)$ parameter matrix; $\mu = (p \times 1)$ intercept term. The parameter matrix, Π, shows whether or not the $(p \times 1)$ vector of stock prices has a long-run or equilibrating relationship. Π is composed of $\alpha\beta'$, where both α and β have dimension $p \times r$. β contains the r cointegration vectors and α the loading coefficients. The rank (r) of Π equals the number of cointegrating vectors. If the rank of $\Pi = 0$, Eq. (5.4) collapses to a standard VAR model in first differences. If Π has full rank, all the stock price series in the system are stationary in levels. Cointegration exist if the rank of Π is between zero and the number of stock indices ($0 < r < N$).

The existence of a cointegrating vector is followed up with an evaluation of the sub-vector space to determine if any of the univariate series in the system do not belong in the cointegrating equation. This is done by specifying the restriction that their parameters are zero i.e. testing the hypothesis that a particular series do not appear in the cointegrating relationship. The test statistic follow a χ^2 (one) degree of freedom in each case for the univariate series.

The Granger representation theorem (Engle and Granger, 1987) states that if two or more time-series are cointegrated, then there must be Granger causality between them- either one-way or in both directions. The causality tests are based on the VECM, which shows the long-run dynamics of the adjustment process between the equity series or indices in the system. Impulse response functions are presented from the VECM. The VEC IRFs indicate the strength and magnitude with which shocks are transmitted within the system from one equity series to another.

It is noteworthy that while the analyses in the previous empirical chapters focused on returns, this chapter focus more strongly on the relationship among the stock prices that were used to calculate returns. Sample data included in this chapter comprise the daily price indices (adjusted for dividends) of the stock markets in the UK (FTSE100), the US (S&P500) and the Euro area i.e. Germany and France (DAX30 and the CAC40). These price indices are collected from DataStream and converted to natural logarithms and cover the period from January 2004 to October 2014.

5.3: Empirical Results

5.3.1: Unit root tests

The study implement regular unit root tests, that is, the ADF (1981) and the Phillips and Perron (1987); and the KPSS (1992) stationary test (Table 46). The ADF and PP tests confirm that the null hypothesis of a unit root in the levels of the stock price indices cannot be rejected at all conventional significance levels, while a unit root in the first differences of the stock prices is rejected at all significance levels. The results of the KPSS test, also show that the null hypothesis of stationarity is rejected for all four price indices, confirming the results from the ADF and PP tests.

To incorporate the possibility of a structural change in the series examined, this study, in addition to the regular unit root tests also uses the Z&A sequential test for a unit root against the alternative hypothesis of stationarity with a single structural change in the deterministic components (i.e. intercept and trend) at some unknown point. The Z&A unit root test results are presented in (Table 47). A visual inspection of this table reveals that with the exception of the S&P (significant at the 0.05), the test fail to reject the null hypothesis for all the price indices at all conventional significance levels. In other words, the logarithmic stock prices are all I (1), including the S&P (i.e. at the 0.01) significance level. Worthy of note also is that the break date that minimizes the one-sided t statistic for testing $\delta = 1$ for the S&P is significant and does actually correspond to the year and the month of the financial crisis. Precisely, after the collapse of Lehman Brothers around 2008:09. For the UK, France and Germany equity markets, the break points occurred for the FTSE and CAC on 2008:04 and much earlier for the DAX on 2007:12[19]

[19] The break date detected by the Z&A test for the UK, France and Germany stock price indices were all insignificant.

Generally, the regular unit root tests conform to test results produced from the Z&A unit root tests that incorporates a structural break. Thus all four stock price indices are found to be I (1) or generally stationary in first differences as depicted in the graphs below.

Figure 8: Graphical plot of the price indices in levels

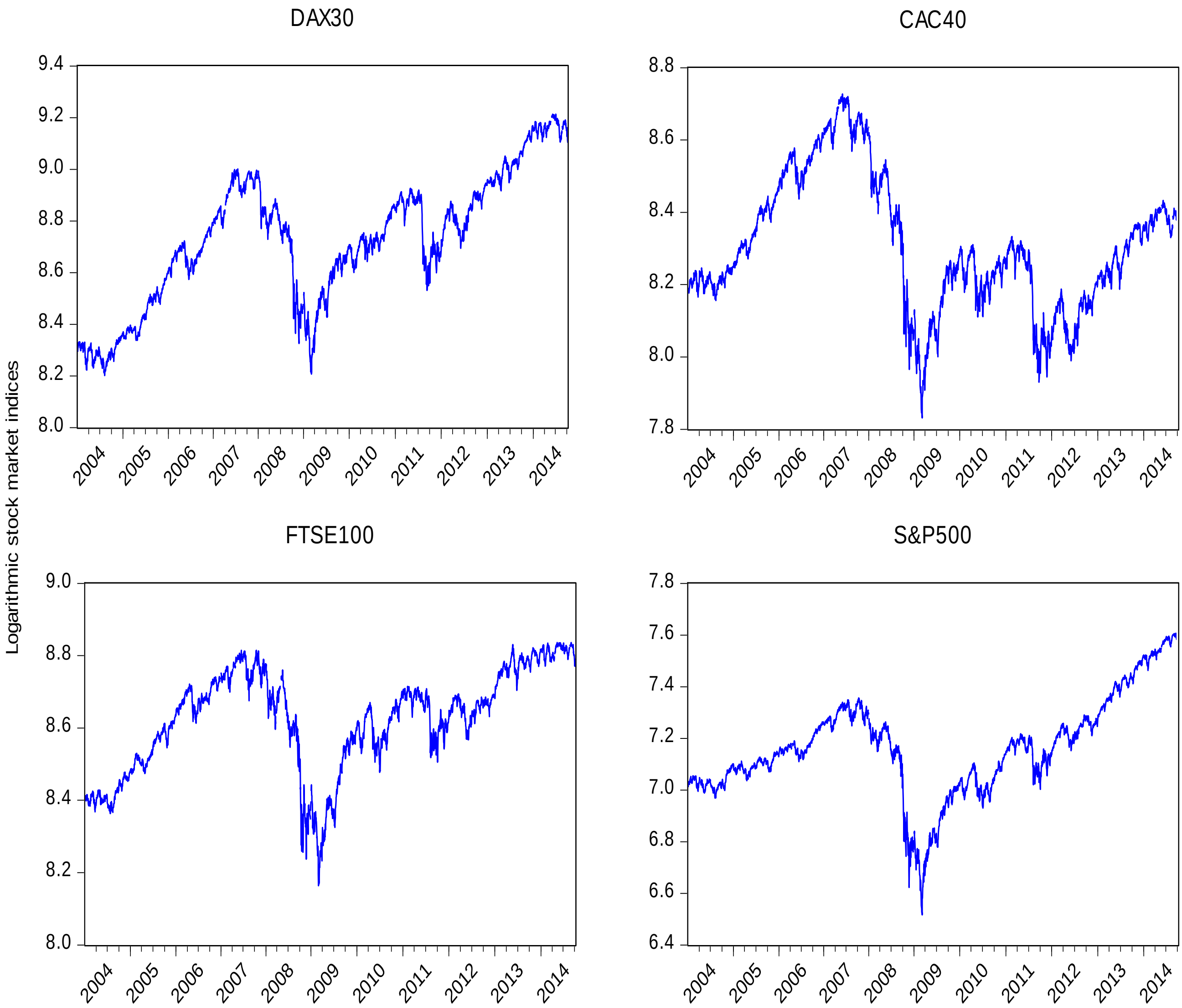


Figure 9: Graphical plot of the price indices in first differences

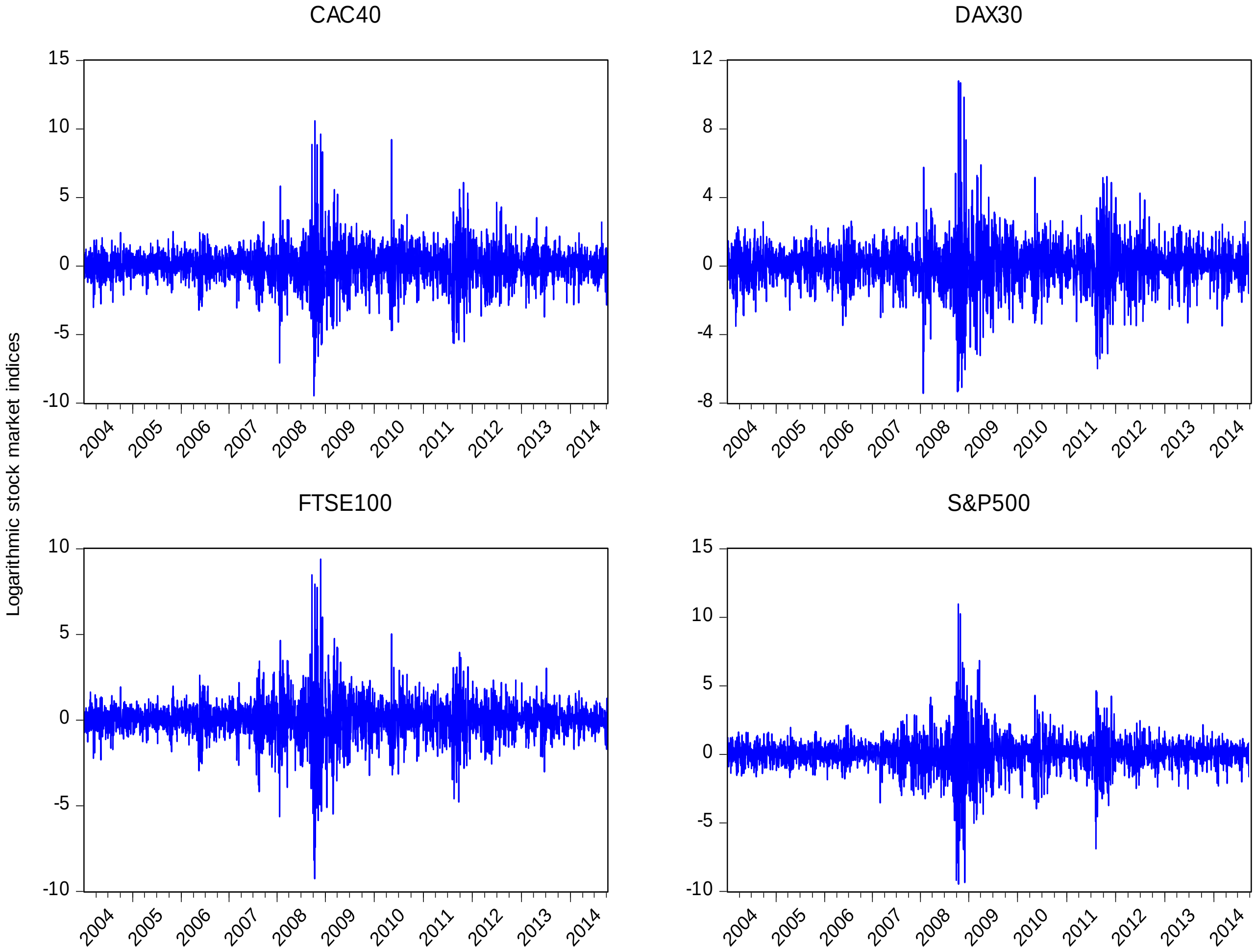


Table 46: Tests for a unit root (ADF, PP, and KPSS) with drift and trend

Series	ADF	PP	KPSS
LCAC	-1.9513	-2.073	0.543
ΔLCAC	-33.993***	-55.921***	0.095
LDAX	-2.220	-2.111	0.481
ΔLDAX	-52.733***	-52.836***	0.064
LFTSE	-2.361	-2.584	0.494
ΔLFTSE	-26.837***	-55.488***	0.052
LS&P	-1.335	-1.393	0.873
ΔLS&P	-41.858***	-58.804***	0.084

Note: This table shows the results of the Augmented Dickey and Fuller (1981; ADF), Phillips and Perron (1987; PP) unit root tests used to test for the nonstationarity of the series. A confirmatory analysis or test using the Kwiatkowski, Phillips, Schmidt, and Shin (1992; KPSS) that assumes stationarity under the null hypothesis was also conducted. Δ Stands for first difference of the respective price indices. *** denotes significance of the test of $\delta = 1$ at the 1% level.

Table 47: Tests for a unit root (Z&A) with drift and trend

Series	T	T_B	k	α	β	γ	δ	μ	S (e)
LCAC	2773	2008:04	7	.082	.000	-.006	-.009	-.000	.014
				(3.97)	(2.09)	(-3.66)	(-3.93)	(-.958)	
LDAX	2773	2007:12	7	.085	.000	-.006	-.010	-.000	.013
				(4.56)	(4.01)	(-4.56)	(-4.55)	(-2.60)	
LFTSE	2773	2008:04	7	.127	.000	-.006	-.010	0.00	.012
				(4.96)	(3.40)	(-4.43)	(-4.94)	(-.830)	
LS&P	2773	2008:09	7	.164	.000	-.013	-.023	.000	.013
				(5.24)	(2.6)	(-4.87)	(-5.21**)	(4.66)	

Note: This table shows the results for the Zivot and Andrews (1992) unit root test based on the equation $\Delta x_t = \alpha + \beta\tau + \gamma DU_t(\lambda) + \delta x_{t-1} + \sum_{i=1}^{k-1} \theta_i \Delta x_{t-i} + \varepsilon_t$. Where $DU_t(\lambda)$ =1 if $t > T\lambda$, (otherwise zero); $\lambda \in (0,1) = T_B/T$ depicts the location or relative timing of the change point or structural break; T is total number of observations; T_B is the time or date when the structural break occurred in the trend function. The t statistics are in parenthesis. The t statistic for δ is for testing $\delta = 1$. *K* is the lag. ** denotes significance of the test of $\delta = 1$ at the 5% level, using the critical values from Table 4A of Z&A (1992).

5.3.2: VAR

In order to capture the properties in the four univariate series, a VAR of the univariate series in log levels, including an intercept in each equation is estimated. A first step in the estimation of any VAR model, is to ascertain the appropriate lag length based on the relevant information criteria. An examination of the information criteria (see appendix) shows that while the Schwarz criterion (SC) suggests a maximum lag length of four, the Akaike (AIC) suggested nine as the maximum lag length for the VAR. Further specification test of the VAR model residuals using the LM test for serial correlation (see appendix), corroborates the AIC, suggesting also that the serial correlation is removed if the lag length is increased to nine. The VAR model estimated with 9 lags (see appendix) appear to have stable dynamics (see appendix).

5.3.3: Multivariate cointegration

Before proceeding with the cointegration test a decision need to be made on the appropriate specification for the cointegration test. This essentially boils down to whether an intercept, a trend or both are included in the potentially cointegrating relationship. A sensitivity analysis of the data to the type of specification (see appendix) shows the number of cointegrating vectors suggested by the trace and Max-Eigen statistics is one, given a linear or quadratic model with both an intercept and trend. The two lower panels (AIC and SIC) further provide information that could be used to select the appropriate model and lag length.

The AIC selected a linear model with an intercept and trend with one lag, the SIC suggested two different models of either no intercept no trend, or an intercept and no trend without any lag. A visual inspection of the graphical plots (see above) of the datasets i.e. the logarithmic levels of the stock indices however show a consistent trend or pattern particularly around the fall of 2008. Hence a linear cointegration model with an intercept and trend using one lag as suggested by the AIC is implemented for the cointegration test.

The results from the Johansen cointegration test for the full sample period from January 2004 to October 2014 is presented below in Table 48.The value of the trace test statistic under the null of $r = 0$ is 70.349 which is higher than the critical value of 63.876, the value of the λ_{max} test statistic under the null of $r = 0$ is 45.707, which is higher than the critical value of 32.118. However, for all other values of r, the trace and λ_{max} tests statistic are lower than the critical values allowing the rejection of the null hypothesis of more than one co integrating vector between the series in the system.

Table 48: Johansen cointegration test for the full sample period Jan. 2004 to Oct. 2014

Null Hypothesis	Alternative	Test statistic	p-value
Trace test			
r=0	r≤1	70.3497***	0.0129
r=1	r≤2	24.6424	0.8073
r=2	r≤3	11.7374	0.8298
Max.eigenvalue test			
r=0	r≤1	45.7072***	0.0006
r=1	r≤2	12.9050	0.8108
r=2	r≤3	7.6646	0.8504

Note: This table shows the Johansen maximal eigenvalue and trace tests. *** denotes rejection of the hypothesis at the 1% level, and r denotes the number of cointegrating relationships. P-values are from MacKinnon-Haug-Michelis (1999).

As only one cointegrating vector is found amongst the four series in the system, the study proceeded with an evaluation of the sub-vector space to determine if any of the univariate series in the system does not belong in the cointegrating equation. Interesting only in the case of the US equity market, the (S&P500) was the p-value insignificant (p-value >0.10) implying that the cointegrating relationship does not include the US equity market (see appendix). A similar result to this, with regards to the US equity market was found by Taylor and Tonks (1989) following the removal of exchange control in the UK.

In other to assess the impact of QE (if any) on the cointegration result, the full sample period is divided into a pre-QE and a QE period. An increasing number of cointegrating vectors for either of these sub-periods relative to the full sample could constitute evidence of the impact or non-impact of QE on the stock markets cointegration. Starting with the pre-crisis/QE sample (1/1/2004-31/8/2008), the Johansen cointegration test is re-estimated and the results are presented below (Table 49). Unlike in the full sample results, this indicates two cointegrating vector for both the trace test and the maximum eigenvalue (λmax). It is not implausible however, the increased cointegrating vector is due to decreased precision in parameter estimates as a result of the reduced sample size, rather than to any fundamental change in the underlying cointegrating relationship between the equity markets.

Table 49: Johansen cointegration test for the pre-crisis period (1/1/2004-29/8/2008)

Null Hypothesis	Alternative	Test statistic	p-value
Trace test			
r=0	r≤1	74.4099***	0.0051
r=1	r≤2	40.3763*	0.0878
r=2	r≤3	12.2226	0.7964
Max.eigenvalue test			
r=0	r≤1	34.0336**	0.0288
r=1	r≤2	28.1536**	0.0242
r=2	r≤3	6.9872	0.9016

Note: This table shows the Johansen maximal eigenvalue and trace tests. *** ** * denote rejection of the hypothesis at the 1%, 5% and 10% level respectively, and r denotes the number of cointegrating relationships. P-values are from MacKinnon-Haug-Michelis (1999)

The Johansen cointegration results for the QE sample period as shown in Table 50 indicates one cointegrating vector for the trace test and the maximum eigenvalue test, which is consistent with the result from the full sample cointegration analysis.

Table 50: Johansen cointegration test for the QE period (11/3/2009- 31/10/2014)

Null Hypothesis	Alternative	Test statistic	p-value
Trace test			
r=0	*r≤1*	75.0288***	0.0044
r=1	r≤2	32.1985	0.3778
r=2	r≤3	12.5641	0.7715
Max.eigenvalue test			
r=0	r≤1	42.8302***	0.0017
r=1	r≤2	19.6344	0.2647
r=2	r≤3	9.2424	0.6993

Note: This table shows the Johansen maximal eigenvalue and trace tests. *** denotes rejection of the hypothesis at the 1% level, and r denotes the number of cointegrating relationships. P-values are from MacKinnon-Haug-Michelis (1999)

5.3.4: VECM

The evidence of a cointegrating relationship between the series suggest the use of the error correction model (VECM) in testing for causality. The VECM is based on the error correction term (ECT) from the multivariate cointegrating equation and the variables in the system include the lagged values of the CAC, DAX, FTSE, and S&P.

The VECM result for the full sample period is presented first in Table 51. The lagged ECT from the cointegrating equation is found to be statistically significant only in the equation for the DAX (Germany) with its coefficient size of approximately -0.04 suggesting a 4% error correction or (daily) speed of adjustment to deviations from long-run equilibrium. The DAX can be predicted by its own lagged price change and by the lagged price changes of the other three equity indices i.e. the CAC, FTSE and S&P. For the remaining three equity indices, the error term is insignificant, but the lagged price changes of the CAC and the S&P are good predictors for the CAC or French stock prices. The lagged price changes of the CAC, the FTSE and the S&P are good predictors for the FTSE stock prices. While the lagged price change of the S&P appear to be good predictors for the other three equity stock indices, only the lagged price change of the S&P index is a good predictor for the S&P stocks.

Table 51: VECM Results for the entire sample period Jan. 2004 to Oct. 2014

Error Correction:	ΔLCAC	ΔLDAX	ΔLFTSE	ΔLS&P
ECT_{t-1}	-0.0034	-0.0434***	.-0.0011	-0.0042
	(0.0069)	(0.0066)	(0.0057)	(0.0065)
$\Delta LCAC_{t-1}$	-0.2965***	0.0692*	-0.1883***	-0.0440
	(0.0446)	(0.0425)	(0.0368)	(0.0416)
$\Delta LDAX_{t-1}$	0.0242	-0.1755***	-0.0073	-0.0079
	(0.0216)	(0.0206)	(0.0178)	(0.0202)
$\Delta LFTSE_{t-1}$	-0.0320	0.2107***	-0.1077***	0.0492
	(0.0504)	(0.0480)	(0.0416)	(0.0470)
$\Delta LS\&P_{t-1}$	0.4866***	0.1996***	0.4386***	-0.0947***
	(0.0253)	(0.0241)	(0.0209)	(0.0237)
C	-3.73×10^{-5}	0.0002	6.34×10^{-5}	0.0002
	(0.0002)	(0.0003)	(0.0002)	(0.0002)

Note: This table shows the VECM estimates for the entire sample period Jan. 2004 to Oct. 2014. Standard errors in parenthesis, *** ** * denotes significance at 1%, 5% and 10% level respectively. ECT is the error correction term from the cointegrating equation. Δ is the difference operator. C is the constant term

As it was earlier reported that an evaluation of the sub-vector space revealed that the cointegrating relationship found for the entire sample did in fact not include the US equity market, the study also estimated a VECM excluding the US equity market (S&P). The result of the re-estimated VECM is presented in Table 52. The ECT is still found to be significant only in the price change of the DAX equation of the ECM. However, the lagged price changes of the DAX index appear to now be good predictors for the CAC index, while none of the lagged price changes appear to be predictors for the FTSE index.

Table 52: VECM estimates excluding the US equity market.

Error Correction:	ΔLCAC	ΔLDAX	ΔLFTSE
ECT_{t-1}	-0.0034	-0.0435***	-0.0012
	(0.0073)	(0.0066)	(0.0062)
$\Delta LCAC_{t-1}$	-0.1293***	0.1376***	-0.0375
	(0.0466)	(0.0422)	(0.0389)
$\Delta LDAX_{t-1}$	0.0339*	-0.1715***	0.0013
	(0.0230)	(0.0209)	(0.0192)
$\Delta LFTSE_{t-1}$	0.0773	-0.2557***	-0.0091
	(0.0533)	(0.0483)	(0.0445)
C	-3.76×10^{-5}	0.0003	0.0001
	(0.0003)	(0.0002)	(0.0002)

Note: This table shows the VECM estimates excluding the S&P500, for the entire sample period Jan. 2004 to Oct. 2014. Standard errors in parenthesis, *** ** * denotes significance at 1%, 5% and 10% level respectively. ECT is the error correction term from the cointegrating equation. Δ is the difference operator. C is the constant term.

The VECM for the pre QE and QE periods are presented below, in Tables 53 and 54 respectively. For the pre-QE sample period, the ECT is found to be statistically significant in the price change equation of the DAX. However, for the QE sample period, the ECT is statistically significant in the price change equations of all four equity market indices. For the sub-periods, the lagged price changes of some of the other equity prices also appear to be fair predictors (with a 0.1 significance level) for the S&P.

Table 53: VECM Result for the Pre-QE period Jan. 2004 to Aug. 2008

Error Correction:	ΔLCAC	ΔLDAX	ΔLFTSE	ΔLS&P
ECT_{t-1}	-0.0094	-0.0712***	-0.0100	0.0169**
	(0.0086)	(0.0089)	(0.0079)	(0.0079)
$\Delta LCAC_{t-1}$	-0.2260***	0.2462***	-0.1411**	-0.0012
	(0.0610)	(0.0619)	(0.0550)	(0.0550)
$\Delta LDAX_{t-1}$	0.0767***	-0.0551**	0.0158	0.0341*
	(0.0266)	(0.0270)	(0.0240)	(0.0240)
$\Delta LFTSE_{t-1}$	-0.1200*	0.0147	-0.2024***	-0.0108
	(0.0671)	(0.0681)	(0.0604)	(0.0605)
$\Delta LS\&P_{t-1}$	0.4997***	-0.0556*	0.4455***	-0.0769**
	(0.0368)	(0.0374)	(0.0332)	(0.0333)
C	0.0001	0.0003	0.0001	0.0001
	(0.0003)	(0.0003)	(0.0003)	(0.0003)

Note: This table shows the VECM estimates for the pre-QE period. Standard errors in parenthesis, *** ** * denotes significance at 1%, 5% and 10% level respectively. ECT is the error correction term from the cointegrating equation. Δ is the difference operator. C is the constant term.

Table 54: VECM for the QE period (11/3/2009-9/10/2014).

Error Correction:	ΔLCAC	ΔLDAX	ΔLFTSE	ΔLS&P
ECT_{t-1}	-0.0051^{***}	-0.0034^{***}	-0.0047^{***}	-0.0042^{***}
	(0.0019)	(0.0018)	(0.0014)	(0.0015)
$\Delta LCAC_{t-1}$	-0.2005^{***}	-0.1507^{**}	-0.1178^{**}	-0.0334
	(0.0764)	(0.0731)	(0.0568)	(0.0605)
$\Delta LDAX_{t-1}$	0.0283	0.0346	0.0056	0.0540
	(0.0732)	(0.0700)	(0.0544)	(0.0579)
$\Delta LFTSE_{t-1}$	-0.0019	-0.0352	-0.0521	0.1118^{*}
	(0.0749)	(0.0716)	(0.0544)	(0.0593)
$\Delta LS\&P_{t-1}$	0.3119^{***}	0.3114^{***}	0.2695^{***}	-0.1566^{***}
	(0.0449)	(0.0430)	(0.0334)	(0.0356)
C	0.0001	0.0003	0.0002	0.0007^{***}
	(0.0004)	(0.0003)	(0.0003)	(0.0003)

Note: This table shows the VECM estimates for the QE period. Standard errors in parenthesis, *** ** * denotes significance at the 1%, 5% and 10% level respectively. ECT is the error correction term from the cointegrating equation. Δ is the difference operator. C is the constant term.

5.4: Causality tests

Next to be estimated is the Granger causality/block exogeneity test using chi-square (Wald) statistics for the joint significance of each of the other endogenous variable in levels. The reported estimates are asymptotic Wald statistics with the p-values in parentheses. The causality tests based on the error correction model are shown below for the full sample, the pre-QE and QE sample periods.

For the full sample period, results indicate a unidirectional causality from the S&P to the other three equity markets .Unidirectional causality is also reported from the FTSE to the DAX, and from the CAC to FTSE (see table 55). The results for the pre-QE and QE sample periods are presented in tables 56 and 57 respectively. For the Pre-QE sample, results show a unidirectional causality from the S&P to the CAC and FTSE. Also, a bidirectional causality between the FTSE and the CAC, as well as between the DAX and the CAC is detected. While for the QE sample period, unidirectional causality from the S&P to the CAC, DAX and FTSE; and from the CAC to the DAX and FTSE is detected.

Table 55: VEC Granger causality for the full sample period

	Excluded variables			
Dependent	LCAC	LDAX	LFTSE	LS&P
LCAC		1.2486 [0.2638]	0.4034 [0.5253]	367.5741*** [0.0000]
LDAX	2.6475 [0.1037]		19.2542*** [0.0000]	68.2224*** [0.0000]
LFTSE	26.0946*** [0.0000]	0.1696 [0.6804]		438.9829*** [0.0000]
LS&P	1.1155 [0.2953]	0.1533 [0.6954]	1.0952 [0.2953]	

Note: This table shows the Granger causality/Block exogeneity test results for the joint significance of the endogenous variables. *** ** and * represent significance at the 1%, 5% and 10% significance levels respectively. Significance implies that the column variable Granger causes the row variable.

Table 56: VEC Granger causality for the pre-QE sample period

		Excluded variables		
Dependent	LCAC	LDAX	LFTSE	LS&P
LCAC		8.3053***	3.1970*	183.5575***
		[0.0040]	[0.0738]	[0.0000]
LDAX	15.8074***		0.0467	2.2107
	[0.0001]		[0.8288]	[0.1371]
LFTSE	6.5827**	0.4339		179.6364***
	[0.0103]	[0.5101]		[0.0000]
LS&P	0.0005	2.0235	0.0319	
	[0.9816]	[0.1549]	[0.8581]	

Note: This table shows the Granger causality/Block exogeneity test results for the joint significance of the endogenous variables. *** ** and * represent significance at the 1%, 5% and 10% significance levels respectively. Significance implies that the column variable Granger causes the row variable.

Table 57: Granger causality for the QE sample period

		Excluded variables		
Dependent	LCAC	LDAX	LFTSE	LS&P
LCAC		0.3368	0.0382	53.5060***
		[0.5617]	[0.8449]	[0.0000]
LDAX	5.1988**		0.4730	57.6947***
	[0.0226]		[0.4916]	[0.0000]
LFTSE	5.3114**	0.0975		71.9275***
	[0.0212]	[0.7548]		[0.0000]
LS&P	1.0609	1.8362	2.3515	
	[0.3030]	[0.1754]	[0.1252]	

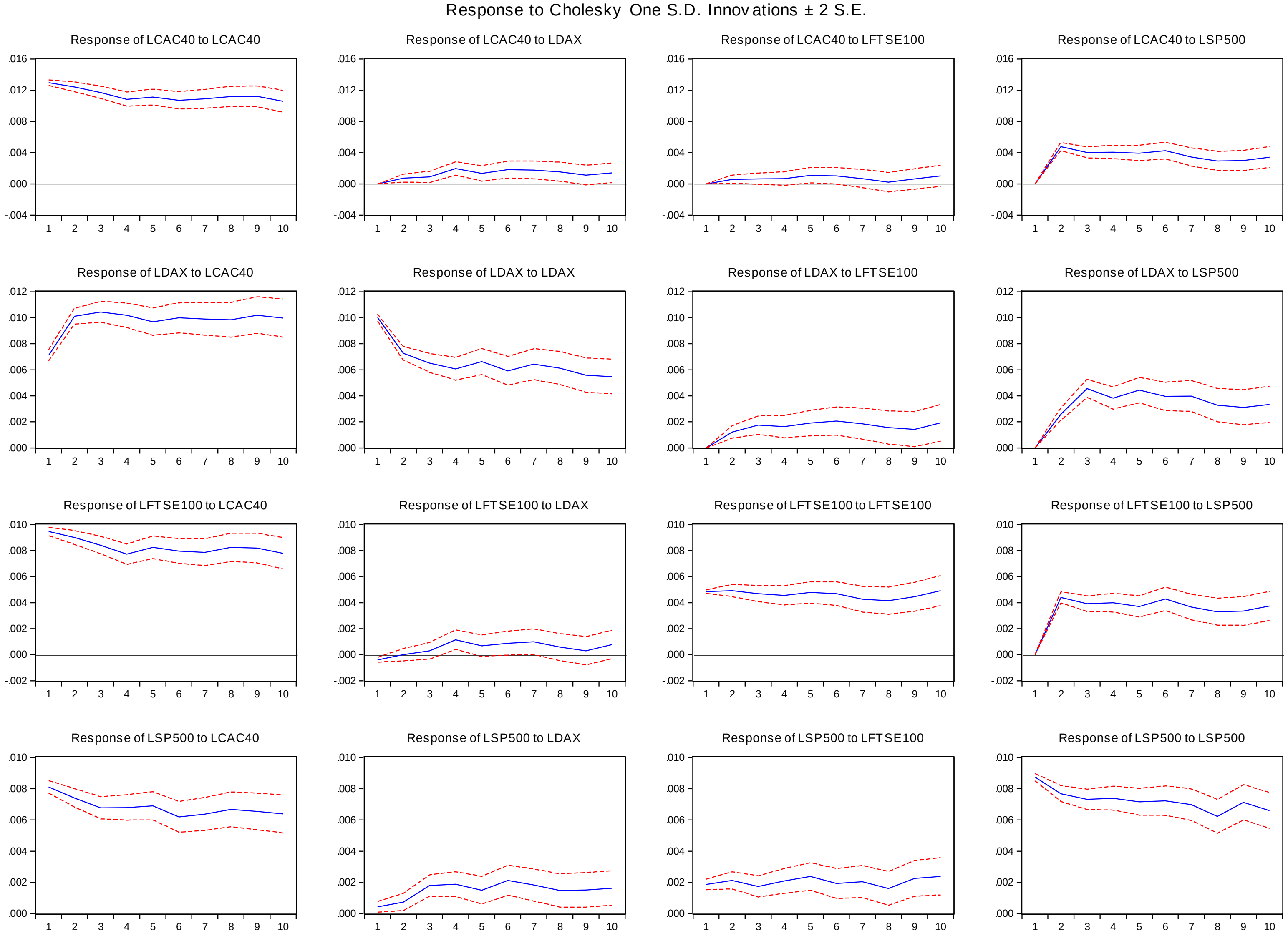
Note: This table shows the Granger causality/Block exogeneity test results for the joint significance of the endogenous variables. *** ** and * represent significance at the 1%, 5% and 10% significance levels respectively. Significance implies that the column variable Granger causes the row variable.

5.5: Impulse Response Functions

The Figure below shows orthogonalised impulse response functions (IRFs) from the VECM estimation. Each graph plots a 10 day impulse response function of the respective variable to an orthogonalised one standard deviation shock to the other variables in the system. Thus, for each variable from each equation individually, a unit shock is applied, and the effects upon the system are graphically depicted. The graphs show that a one standard deviation shock to the S&P generates a contemporaneous effect of around 0.04 percent in the CAC, DAX and FTSE series and the impacts remain significant up to the 10th lag. The observed impulse responses (ranging from 0.07-0.10) of the DAX, FTSE and the S&P to a one standard deviation shock to the CAC is more likely attributable to the ordering with the CAC index being first in the system. From the diagram, the CAC seems only responsive to its own shocks and then shocks to the S&P.

A one standard deviation shock to the FTSE generates a contemporaneous effect of about 0.02 percent in the S&P that remains significant to the 10th lag. The responses of the CAC to a one standard deviation shock to the FTSE although little is significantly different from zero, up to the 10th lag. The DAX appears a little responsive to shocks to the FTSE with the effect significant to the 10th lag as well. The individual stock indices or price series response to their own one standard deviation shock(s) are more profound and significant compared to the impulse response functions of the series to the others in the system.

Figure 10: VECM Impulse Réponse Functions



5.6: Chapter Conclusion

Against the background of the findings from the previous chapter to the effect that the period of the QE operations resulted in a significant increase in covariance between the UK and US equity markets, this chapter sought to unravel or ascertain if this QE induced increase in covariance means increasing cointegration between the equity markets. To this end, the daily logarithmic stock price indices of the US, UK, France and Germany equity markets were analysed. These price indices were all found to be integrated i.e. I (1).

The Johansen's multivariate cointegration test was conducted on the daily stock price indices of the aforementioned national equity markets. Only one cointegrating vector as indicated by both trace statistic and maximum Eigen value was found among the univariate price series in the full sample analysis. A further perusal of the sub-vector space of the cointegrating relationship for the period (full sample) indicates that while the three European national equity markets belong to the cointegrating vector, the US equity market did not.

The VECM estimated was used to disentangle two effects. First, to show the dynamic interactions between the series or price indices in the system, and more importantly, to ascertain if the QE operations have had any significant impact on the dynamic interaction between the equity markets. While the pre-QE sub sample analysis showed an increase in the number of cointegrating vectors relative to the full sample analysis, the QE sub-sample analysis show no increasing number of cointegrating vectors.

These results from the equity market analysis taken as a whole suggest no evidence of increasing long-run or cointegrating relationship against the backdrop of the QE operations especially between the US equity market and the other equity markets in the system. While this particular finding is in contrast with the findings of Arshanapalli and Doukas (1993), it is however more in line with the findings of Taylor and Tonks (1989). What is more unique to the current study however, is that the findings of no long-run comovements is against the backdrop of the novel LSAPs following the QE operations implemented by the monetary authorities in the UK and US. This appears to suggest that the estimated QE effects on the equity markets were generally short-lived or transient. Notwithstanding the similar and near simultaneous nature of these QE implementation by the BoE and the Fed.

Chapter 6: Conclusion

6.1: Introduction

This thesis examined the impacts of the QE operations as implemented by the BoE and the Fed in the aftermath of the 2008 financial crisis, on the broader financial market particularly the equity markets. As evident in the comprehensive literature review on the effects of the QE, carried out it the second chapter of this thesis, this aspect of the effects of the QE has not been given much consideration in the literature. The comprehensive analyses of the impacts of the QE or large-scale asset purchases on the broader financial market are necessary if monetary authorities are to depend on the QEP to achieve their objectives and also to prevent unintended consequences such as financial markets distortions. This thesis provide empirical investigations of the impacts or effects of QE on financial market stability including equity market volatility, equity-equity, and equity-bond markets covariance as well as equity market cointegration.

This concluding chapter summarises the main findings of the study with reference to the research objectives of the study set out at beginning, highlights the main contributions of this thesis to knowledge/the existing QE literature and then address the limitation of the study before suggesting an area for further research on the topic.

6.2: Summary of Findings

Quantitative easing (QE) is an unconventional monetary policy, and the probable impacts of this policy on the broader aspects of the financial markets were unknown. This thesis has examined these aspects of the possible impacts of QE on the returns and volatility of the equity markets, the covariance between equity markets, and the covariance between equity and bond markets, and the effect on equity market cointegration. Even though the bond markets were the main vehicles through which the Bank of England and the Federal Reserve as the monetary authorities in the UK and US respectively, conducted the QE operations, however, since the pioneering work by Tobin (1958, 1961, 1963), it has long been understood that changes in the supply of one asset class can influence the price of other assets, if the assets are imperfect substitutes. This portfolio balancing mechanism anchored on the doctrine of imperfect substitution between financial assets provides a nexus to the broader aspects of the financial market beyond the bond markets and hence the theoretical grounding and motivation for this research.

Modelling the conditional volatility of the individual equity market returns in the UK and the US, using a GARCH model augmented with the QE intensity, period, and the financial crisis indicator variables, the study finds that, the actual QE purchases brought about significant reduction in the returns of the US and UK following their respective QE3 operations. The insignificant decline in returns of the other actual QE phases both in the UK and US are attributed to the yields or returns have adjusted already to the earlier QE announcements that heralded the actual purchases as revealed in the event study analysis.

For the measure of the QE liquidity effects, the results show that both the QE operations by the Fed and the BoE QE improved liquidity as measured by the impact of the QE operations on the equity market trade volume trade in aftermath of the market strains or stress following the crisis.

Although volatility in the US and UK equity markets fell overall during the period of the QE, on specific days of actual QE activity in the UK, the volatility of equities increased in proportion to the amount of assets being purchased under the QE programmes. However, this impact on the UK equity market volatility was only observed during the early phase of the BoE QE operations, with the subsequent phases and duration of the QE actions leading to a reduction in the equity market volatility. This finding suggests that the equity market in the UK progressively adapted to the QE actions as the BoE interventions continued. The Fed and especially the BoE QE operations also appear to have had some modest impacts on the equity market in France and Germany. While the Australian equity market reacted marginally to the Fed QE1, as revealed by the empirical estimates of these equity markets against the backdrop of the UK and US LSAPs.

In the light of the simultaneous and almost similar nature of the QE operations in the UK and US, an investigation of whether the BoE and the Fed QE actions had an impact on the covariance structure between the equity markets in the UK and US, and the equity and bond markets within the US and UK was carried out. A DVECH specification was used to model the variance-covariance conditioning on threshold changes that depend on the transition through certain time periods corresponding to the financial crisis and the entirety of the quantitative easing operations. For the variance-covariance structure of the US and UK equity market, the results reveal that the BoE but not the Fed QE operations impacted on the variance-covariance structure of the US and the UK equity markets. Specifically, the covariance between the two markets increased significantly following the BoE QE operations. For the variance-covariance structure of the bond and equity markets within the UK and the US, the results from both the symmetric and asymmetric models used indicate that the QE operations had a significantly negative impact on the covariance structure of the bond and equity markets in both the UK and US.

Informed by the finding of the significantly increased covariance between the UK and US equity markets following the QE operations, the thesis, in order to establish if this increased covariance imply increasing cointegration for the equity markets, examined the long-run relationship in a framework incorporating cointegration tests, VECM and Granger causality tests. The results coming from the long-run evaluations of the effects of the BoE and Fed QE purchases on the equity markets examined, ultimately show that the effects appear to be without an increased long-run or equity market cointegration relationship.

6.3: Contributions of the Research

This research major contribution to the empirical literature is examining the impact of the unconventional monetary policy actions or the QE operations of the BoE and Fed on the returns, volatility, cross-correlations, covariance and cointegration of the broader financial markets particularly in the US and UK. Thereby avoiding a major pitfall of earlier studies in the literature just focusing on the impact of the QE operations on government bonds yields. To the best of the author's knowledge, this thesis represents the first thorough analyses of the effects from the signalling, portfolio rebalancing and liquidity channels of QE. Thus, a major contribution to the theoretical literature, of the thesis is providing a way of separating and testing the effects from the signalling and portfolio balance channels of QE.

Hitherto, the literature on central bank LSAPs has mostly used event studies focusing on the response of yields in the bond market to QE announcement to analyse these channels. In addition to carrying out an event study of the QE announcements, this thesis goes further by quantifying the actual QE purchases themselves in both the US and UK and capturing the effects of both on the equity and bond markets directly in the empirical modelling or methodology used. This way, the thesis is able to isolate the relative effects of the QE theoretical channels in addition to providing an international or cross country comparisons of the QE operations which is a major contribution to the literature, as prior studies have only focused on a single country. By broadening the analyses of the impacts of QE on the financial markets to more than a single country, an added contribution of this research to the literature is in providing a comparative study allowing us see if QE activity affects not only the equity market of the country within which the QE activity took place but if also they had any effect in another country that may not be engaging in QE at all or at the same time.

Most of the studies of the effects of QE hitherto had focused on a single country either the US or the UK and also on only the earlier phase of the QE operations, using monthly data. By incorporating all the phases of QE in the UK and US, this research provides an extension to the existing literature not just by including all the phases of QE in the UK and the US, but also by isolating their separate effects, using daily data, measuring the intensity of QE activity on a particular day and calibrating this into the data generating and modelling processes. The QE intensity measure captures the actual size of QE activity on a particular day, to determine whether this has an effect beyond a general effect of the markets being within a phase of QE.

From the academic standpoint, overall, this research offers substantial contributions to several parallel literatures on equity market volatility, equity-bond market covariation and equity market cointegration, as well as adding to the overall body of research that has examined the effects of QE generally. This thesis also has practical implications both from an investor's angle and the monetary authority perspective. From an investor angle, the contributions offered from the results of this thesis particularly on the covariation between the equity and bond markets, is that effective portfolio risk diversification or tactical asset allocations between the bond and stock markets are particularly beneficial when monetary authorities engage in QE actions or operations.

Furthermore, as the toolkit of monetary policy in aftermath of the recent financial crisis has been expanded to now include an hitherto unconventional tool in the mode of QE, an added contribution of this research from a policy maker's perspective would be to have a better appreciation of the financial market reaction function to a QE policy, thereby standing them in good stead to minimize unintended consequences or distortions to financial market or asset prices from the use of QE should the need arises in subsequent or future periods. The insight to be gleaned by the monetary authorities, from the empirical analyses from this thesis is that the effect of the QE on the financial asset market appear quite short-lived or transient to warrant any long-term financial market distortion.

6.4: Limitations of the Study and Suggested Area for Further Research

One potential limitation of the study is that it could not measure nor calibrate into the modelling process, the data on the ECB QE purchases. This was because the ECB QE only started much later and the ECB QE data were inaccessible at the time of writing up this research. Consequently and in the light of this limitation of the study, it would be insightful to empirically evaluate the effect of the ECB's on-going QE purchases on the financial markets of the countries directly or within the Euro-area or ECB's jurisdiction, for more generalizable results and possibly for a direct comparison with the results of this research on the BoE and Fed QE programs. Future work could be strengthened by including this apparent limitation of the current study.

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Appendices

Appendix 1

Univariate residual autocorrelation test (US equity)

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	-0.061	-0.061	10.222	0.001
		2	-0.015	-0.019	10.873	0.004
		3	-0.006	-0.008	10.979	0.012
		4	-0.009	-0.010	11.209	0.024
		5	-0.039	-0.041	15.446	0.009
		6	-0.016	-0.021	16.112	0.013
		7	0.006	0.002	16.216	0.023
		8	-0.008	-0.009	16.412	0.037
		9	-0.023	-0.026	17.871	0.037
		10	0.031	0.026	20.573	0.024
		11	-0.004	-0.003	20.611	0.038
		12	0.007	0.008	20.764	0.054
		13	-0.002	-0.002	20.775	0.077
		14	-0.027	-0.029	22.719	0.065
		15	-0.031	-0.034	25.412	0.045
		16	0.032	0.028	28.129	0.031
		17	0.001	0.003	28.132	0.043
		18	-0.022	-0.022	29.488	0.043
		19	0.004	-0.000	29.534	0.058
		20	-0.009	-0.013	29.739	0.074
		21	-0.005	-0.005	29.805	0.096
		22	-0.001	-0.002	29.806	0.123
		23	0.013	0.009	30.303	0.141
		24	-0.020	-0.020	31.435	0.142
		25	-0.036	-0.036	35.003	0.088
		26	-0.012	-0.020	35.375	0.104
		27	0.002	-0.003	35.381	0.129
		28	0.018	0.017	36.291	0.135
		29	-0.001	-0.004	36.295	0.165
		30	-0.032	-0.035	39.127	0.123
		31	0.010	0.006	39.403	0.143
		32	-0.038	-0.040	43.284	0.088
		33	0.007	-0.001	43.402	0.106
		34	-0.020	-0.021	44.458	0.108
		35	0.020	0.014	45.524	0.110
		36	-0.004	-0.003	45.564	0.132

Appendix 2

Univariate residual autocorrelation test (US equity) adjusted for 1 ARMA term

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	0.001	0.001	0.0017	
		2	-0.016	-0.016	0.6863	0.407
		3	-0.008	-0.008	0.8816	0.644
		4	-0.013	-0.013	1.3401	0.720
		5	-0.042	-0.042	6.1574	0.188
		6	-0.018	-0.019	7.0516	0.217
		7	0.004	0.002	7.0887	0.313
		8	-0.010	-0.011	7.3392	0.394
		9	-0.022	-0.023	8.6408	0.373
		10	0.031	0.028	11.225	0.261
		11	-0.002	-0.004	11.235	0.340
		12	0.008	0.008	11.389	0.411
		13	-0.004	-0.004	11.423	0.493
		14	-0.029	-0.030	13.706	0.395
		15	-0.032	-0.030	16.424	0.288
		16	0.030	0.030	18.852	0.221
		17	0.001	-0.000	18.857	0.276
		18	-0.022	-0.023	20.190	0.265
		19	0.002	0.000	20.200	0.322
		20	-0.009	-0.014	20.430	0.369
		21	-0.005	-0.004	20.509	0.427
		22	0.000	-0.001	20.509	0.489
		23	0.012	0.008	20.885	0.528
		24	-0.022	-0.023	22.217	0.507
		25	-0.038	-0.036	26.134	0.346
		26	-0.014	-0.018	26.676	0.372
		27	0.002	-0.001	26.683	0.426
		28	0.018	0.016	27.554	0.434
		29	-0.002	-0.007	27.562	0.488
		30	-0.032	-0.035	30.374	0.395
		31	0.006	0.006	30.477	0.441
		32	-0.037	-0.040	34.166	0.318
		33	0.003	0.000	34.191	0.363
		34	-0.018	-0.020	35.130	0.368
		35	0.019	0.015	36.076	0.372
		36	-0.001	-0.002	36.077	0.418

Appendix 3

Univariate residual autocorrelation test (UK equity)

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
| |	| |	1	-0.029	-0.029	2.3156	0.128
| |	| |	2	-0.008	-0.009	2.5022	0.286
| |	| |	3	-0.022	-0.023	3.8704	0.276
| |	| |	4	0.008	0.006	4.0393	0.401
| |	| |	5	-0.007	-0.007	4.1713	0.525
| |	| |	6	0.005	0.004	4.2347	0.645
| |	| |	7	0.001	0.001	4.2356	0.752
| |	| |	8	-0.025	-0.025	6.0103	0.646
| |	| |	9	0.001	-0.000	6.0124	0.739
| |	| |	10	0.004	0.004	6.0645	0.810
| |	| |	11	0.009	0.008	6.2762	0.854
| |	| |	12	-0.022	-0.021	7.6412	0.813
| |	| |	13	-0.001	-0.002	7.6420	0.866
| |	| |	14	-0.038	-0.038	11.648	0.635
| |	| |	15	-0.017	-0.020	12.431	0.646
| |	| |	16	0.007	0.005	12.587	0.703
| |	| |	17	0.009	0.007	12.818	0.748
| |	| |	18	-0.040	-0.039	17.226	0.508
| |	| |	19	-0.017	-0.018	18.003	0.522
| |	| |	20	0.004	0.001	18.040	0.585
| |	| |	21	-0.010	-0.012	18.319	0.629
| |	| |	22	-0.019	-0.021	19.292	0.627
| |	| |	23	-0.005	-0.007	19.352	0.681
| |	| |	24	-0.029	-0.030	21.684	0.598
| |	| |	25	0.016	0.014	22.381	0.614
| |	| |	26	0.000	-0.003	22.381	0.668
| |	| |	27	-0.015	-0.019	23.048	0.682
| |	| |	28	-0.006	-0.007	23.141	0.726
| |	| |	29	0.023	0.021	24.676	0.695
| |	| |	30	0.008	0.007	24.873	0.731
| |	| |	31	-0.044	-0.045	30.445	0.494
| |	| |	32	-0.003	-0.008	30.463	0.544
| |	| |	33	-0.004	-0.007	30.500	0.592
| |	| |	34	-0.029	-0.032	32.858	0.523
| |	| |	35	0.012	0.010	33.278	0.551
| |	| |	36	0.015	0.009	33.893	0.569

Appendix 4

Structural Break Tests.

US: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	1.01428	0.998	2006:03:23	0.1847	0.824
Returns	29.4002	0^{***}	2009:01:21	10.9282	0^{***}
All Coeffs.	29.4194	0^{***}	2009:01:21	10.9902	0^{***}

US: 2009:01:25-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	1.2913	0.954	2014:01:06	0.1847	0.824
Returns	1.0869	0.989	2013:07:25	0.1459	0.905
All Coeffs.	1.6125	1.000	2013:09:12	0.3322	0.980

UK: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	3.6045	0.439	2009:01:01	0.4333	0.498
Returns	57.2490	0^{***}	2008:08:13	21.6006	0^{***}
All Coeffs.	58.2387	0^{***}	2008:08:13	21.9560	0^{***}

UK: 2008:08:16-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	0.4582	1.000	2012:07:26	0.0315	1.000
Returns	1.3780	0.935	2012:10:11	0.1285	0.949
All Coeffs.	1.4811	1.000	2012:10:12	0.1646	1.000

France: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	0.5714	1.000	2009:01:01	0.0319	1.000
Returns	4.5678	0.297	2008:08:25	0.8701	0.239
All Coeffs.	4.5733	0.629	2008:08:12	0.8989	0.585

Germany: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	1.0696	0.992	2009:01:01	0.0598	1.000
Returns	1.4190	0.926	2008:08:27	0.1881	0.817
All Coeffs.	2.2062	0.977	2008:08:27	0.2492	1.000

Australia: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	5.4268	0.206	2009:01:01	0.4502	0.482
Returns	4.2289	0.341	2008:10:02	0.4373	0.494
All Coeffs.	6.8892	0.306	2008:10:02	0.9363	0.563

Hong-Kong: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	3.1244	0.529	2009:01:01	0.4491	0.483
Returns	5.6553	0.187	2008:08:14	0.3280	0.608
All Coeffs.	6.0182	0.410	2008:08:14	0.3852	0.946

Japan: 2004:01:01-2014:09:30

	Andrews-Quandt			Andrews-Ploberger	
	Test	P-Value	Date	Test	P-Value
Constant	1.8103	0.833	2008:12:23	0.1495	0.897
Returns	5.3859	0.210	2008:08:05	0.2994	0.644
All Coeffs.	8.7494	0.155	2008:08:05	0.4420	0.904

Appendix 5

VAR lag order selection criteria

Endogenous variables: LCAC40 LDAX LFTSE100 LSP500
Exogenous variables: C

Sample: 1/05/2004 10/09/2014
Included observations: 2770

Lag	LogL	LR	FPE	AIC	SC	HQ
0	8763.698	NA	2.11e-08	-6.324692	-6.316133	-6.321601
1	35977.25	54328.85	6.24e-17	-25.96191	-25.91912	-25.94646
2	36696.37	1433.567	3.75e-17	-26.46958	-26.39255	-26.44176
3	36839.94	285.7929	3.42e-17	-26.56169	-26.45043	-26.52151
4	36921.52	162.1680	3.27e-17	-26.60904	-26.46355*	-26.55649*
5	36940.98	38.61584	3.26e-17	-26.61154	-26.43181	-26.54663
6	36980.49	78.31001	3.20e-17	-26.62851	-26.41455	-26.55124
7	36990.58	19.97888	3.22e-17	-26.62425	-26.37606	-26.53461
8	37018.04	54.25157	3.19e-17	-26.63252	-26.35009	-26.53052
9	37037.10	37.61568	3.18e-17*	-26.63473*	-26.31807	-26.52036
10	37050.65	26.69413	3.19e-17	-26.63296	-26.28207	-26.50623
11	37066.00	30.21431*	3.19e-17	-26.63249	-26.24737	-26.49340

* indicates lag order selected by the criterion

VAR Residual Serial Correlation LM Tests

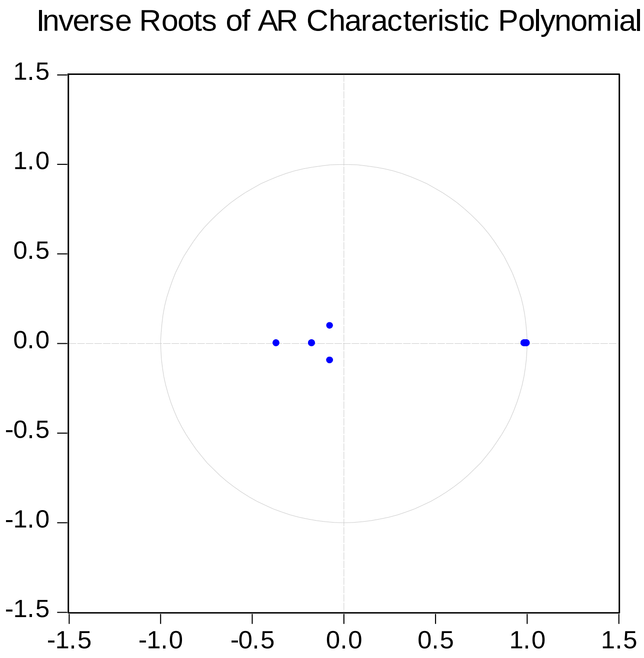
Null Hypothesis: no serial correlation at lag order h
Sample: 1/05/2004 10/09/2014
Included observations: 2779

Lags	LM-Stat	Prob
1	280.3524	0.0000
2	348.9331	0.0000
3	69.15253	0.0000
4	31.33014	0.0122
5	59.56019	0.0000
6	27.02775	0.0412
7	36.58120	0.0024
8	34.68341	0.0044
9	21.71788	0.1525

Probabilities from χ^2 with 16 df.

Appendix 6

Inverse Roots of AR Characteristic Polynomial



Appendix 7

VAR Estimation
Endogenous variables:CAC40 DAX30 FTSE100 SP500
Exogenous variables : C QE_{UK} QE_{US}

	LCAC	LDAX	LFTSE	LS&P
$LCAC_{t-1}$	0.6576*** (14.3238)	0.0996** (2.2853)	-0.2274*** (-6.0313)	0.0747* (1.7469)
$LCAC_{t-2}$	0.1962*** (3.2302)	-0.0681 (1.1821)	0.1363*** (2.7310)	0.0266 (0.4671)
$LCAC_{t-3}$	-0.0330 (0.5412)	0.0691 (1.1937)	-0.0319 (-0.6382)	-0.0612 (-1.0775)
$LCAC_{t-4}$	0.0920 (1.5106)	-0.1186** (-2.0517)	0.1041** (2.0818)	0.0640 (1.1284)
$LCAC_{t-5}$	0.0116 (0.1910)	0.0790 (1.3654)	-0.0204 (-0.4084)	-0.0024 (-0.0428)
$LCAC_{t-6}$	0.1119* (1.8386)	0.0041 (0.0709)	0.0763 (1.5265)	0.0237 (0.4178)
$LCAC_{t-7}$	0.1225** (2.0146)	0.0234 (0.4069)	0.0761 (1.5245)	0.1487*** (2.6246)
$LCAC_{t-8}$	-0.2144*** (-3.5217)	-0.0088 (-0.1533)	-0.1485*** (-2.9696)	-0.2497*** (-4.4014)
$LCAC_{t-9}$	-0.0099 (-0.1642)	-0.1021 (-1.771)	-0.0425 (-0.8533)	0.0944* (1.6696)
$LDAX_{t-1}$	0.0451* (1.814)	0.7180*** (30.4533)	0.0111 (0.5469)	0.0399* (1.7260)
$LDAX_{t-2}$	-0.0165 (-0.5480)	0.1003*** (3.5037)	0.0153 (0.6197)	0.0822*** (2.9264)
$LDAX_{t-3}$	0.0441 (1.4534)	0.0181 (0.6306)	0.0205 (0.8232)	-0.0569** (-2.0127)
$LDAX_{t-4}$	-0.0809*** (-2.6566)	0.0867*** (3.0014)	-0.0545** (-2.1806)	-0.0534* (-1.8837)
$LDAX_{t-5}$	0.6371**	-0.0174	0.0287	0.0684**

	(2.0739)	(-0.5998)	(1.1397)	(2.3925)
$LDAX_{t-6}$	-0.0434 (-1.4122)	0.0542* (1.8574)	-0.0128 (-0.5078)	-0.0677** (-2.3635)
$LDAX_{t-7}$	-0.0247 (-0.8081)	-0.0097 (-0.3353)	-0.0456* (-1.8141)	-0.02785 (-0.9767)
$LDAX_{t-8}$	0.0032 (0.1081)	-0.0233 (-0.8107)	0.0232 (0.9318)	0.0276 (0.9772)
$LDAX_{t-9}$	0.0233 (0.7871)	0.0396 (1.4071)	0.0460 (1.8885)	0.0104 (0.3771)
$LFTSE_{t-1}$	-0.0903* (-1.7296)	0.1372*** (2.7769)	0.8221*** (19.1516)	0.1008** (2.0715)
$LFTSE_{t-2}$	0.0262 (0.3764)	-0.0741 (-1.1189)	0.0482 (0.8409)	-0.1474** (-2.2663)
$LFTSE_{t-3}$	0.0653 (0.9343)	-0.0137 (-0.2067)	0.0784 (1.3660)	0.0928 (1.4259)
$LFTSE_{t-4}$	0.0339 (0.4872)	0.0196 (0.2964)	0.0458 (0.8001)	0.0175 (0.2705)
$LFTSE_{t-5}$	-0.0746 (-1.0721)	-0.0396 (-0.6004)	-0.0586 (-1.0251)	-0.1334** (-2.0565)
$LFTSE_{t-6}$	0.0119 (0.1723)	-0.0054 (-0.0831)	0.0044 (0.0782)	0.0792 (1.2214)
$LFTSE_{t-7}$	-0.0631 (0.9118)	-0.0240 (-0.3680)	0.01884 (0.3311)	-0.0682 (-1.0571)
$LFTSE_{t-8}$	0.1733** (2.4988)	0.0182 (0.2776)	0.0998 (1.7532)	0.1572** (2.4324)
$LFTSE_{t-9}$	-0.0357 (-0.5155)	0.0597 (0.9081)	0.0041 (0.0731)	-0.0483 (-0.7484)
$LS\&P_{t-1}$	0.5465*** (19.2503)	0.2968*** (11.0150)	0.5033*** (21.5861)	0.8792*** (33.2315)
$LS\&P_{t-2}$	-0.3466*** (-10.2590)	-0.0747** (-2.3311)	-0.2864* (-10.3205)	0.0422 (1.3415)

$LS\&P_{t-3}$	-0.0889** (-2.5194)	-0.1845* (-5.5090)	-0.08550*** (-2.9491)	-0.0760** (2.3105)
$LS\&P_{t-4}$	-0.0487 (-1.3670)	0.0349 (1.0321)	-0.0814*** (-2.7786)	-0.0419 (-1.2607)
$LS\&P_{t-5}$	-0.0090 (-0.2534)	-0.0561 (1.6569)	0.0257 (0.8778)	0.0220 (0.6622)
$LS\&P_{t-6}$	-0.0723*** (-2.0268)	-0.0327 (-0.9665)	-0.0698*** (-2.3803)	0.0151*** (-2.908)
$LS\&P_{t-7}$	-0.0900*** (-2.5143)	-0.0550 (-1.6177)	-0.0579** (-1.9693)	-0.0970*** (-2.9085)
$LS\&P_{t-8}$	0.0943*** (2.6624)	0.0392 (1.1682)	0.0446 (1.5338)	0.1502*** (4.5488)
$LS\&P_{t-9}$	-0.0006 (-0.0184)	0.02099 (0.6361)	0.0071 (0.2518)	0.0851*** (2.6285)
C	0.0214 (0.8964)	-0.0448** (-1.9768)	0.0427** (2.1780)	-0.0063 (-0.2864)
$LCAC_{t-10}$	0.0625 (1.3602)	0.0197 (0.4391)	0.0771** (2.0424)	0.0265 (0.6201)
$LDAX_{t-10}$	-0.0186 (-0.8195)	0.0257 (1.1906)	-0.0325* (-1.7406)	0.0261 (-1.2308)
$LFTSE_{t-10}$	-0.0449 (-0.8834)	-0.0597 (-1.2362)	-0.0691* (-1.6530)	-0.0416 (-0.8789)
$LS\&P_{t-10}$	0.0195 (0.6213)	0.0084 (0.2900)	0.0026 (0.1057)	0.0389 (1.3540)
QEF_{UK}	-0.0003 (-0.1973)	4.35E-05 (0.0229)	-0.0003 (-0.1829)	0.0010 (0.5416)
QEF_{US}	-0.0008 (0.2160)	0.0006 (0.1662)	-0.0027 (-0.8432)	-0.0007 (-0.2004)

Note: t-statistics in parenthesis. ***, **, and * represent significance at the 1%, 5% and 10% significance levels respectively.

Appendix 8

Cointegration Specification Sensitivity Analysis

Series: LCAC LDAX LFTSE LSP
Sample: 1/05/2004 10/09/2014
Included observations: 2778

Selected (0.05 level*) Number of Cointegrating Relations by Model

Data Trend:	None	None	Linear	Linear	Quadratic
Test type	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
Trace	0	0	0	1	1
Max-Eigen	0	0	0	1	1

* Critical values based on Mackinnon-Haug-Michelis (1999)

Information Criteria by Rank and Model

Data Trend:	None	None	Linear	Linear	Quadratic
Rank or No. of CE.s	No Intercept No Trend	Intercept No Trend	Intercept No Trend	Intercept Trend	Intercept Trend
	Akaike Information Criteria by Rank (rows) and Model (columns)				
0	-26.56969	-26.56969	-26.56812	-26.56812	-26.56649
1	-26.56767	-26.57078	-26.56986	-26.57834*	-26.57741
2	-26.56386	-26.56737	-26.56716	-26.57572	-26.57536
3	-26.55915	-26.56270	-26.56262	-26.57195	-26.57187
4	-26.55340	-26.557525	-26.55725	-26.56665	-26.56665
	Schwarz Information Criteria by Rank (rows) and Model (columns)				
0	-26.50139*	-26.50139*	-26.56812	-26.49128	-26.48111
1	-26.48229	-26.48327	-26.47594	-26.48229	-26.47496
2	-26.46141	-26.46065	-26.45617	-26.46046	-26.45583
3	-26.43962	-26.43667	-26.43455	-26.43748	-26.43527
4	-26.41679	-26.41211	-26.41211	-26.41297	-26.41297

Appendix 9: cointegration restriction test (LSP500)

Sample (adjusted): 1/08/2004 10/09/2014

Included observations: 2778 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LCAC40 LDAX LFTSE100 LSP500
Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	70.34972	63.87610	0.0129
At most 1	0.004635	24.64247	42.91525	0.8073
At most 2	0.002755	11.73745	25.87211	0.8298
At most 3	0.001465	4.072762	12.51798	0.7315

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	45.70725	32.11832	0.0006
At most 1	0.004635	12.90502	25.82321	0.8108
At most 2	0.002755	7.664683	19.38704	0.8504
At most 3	0.001465	4.072762	12.51798	0.7315

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Restrictions:

B(1,4)=0

Tests of cointegration restrictions:

Hypothesized No. of CE(s)	Restricted Log-likehood	LR Statistic	Degrees of Freedom	Probability
1	36959.46	0.219410	1	0.639490
2	36966.02	NA	NA	NA
3	36969.85	NA	NA	NA

Appendix 10: cointegration restriction test (LCAC)

Sample (adjusted): 1/08/2004 10/09/2014
Included observations: 2778 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LCAC40 LDAX LFTSE100 LSP500
Lags interval (in first differences): 1

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	70.34972	63.87610	0.0129
At most 1	0.004635	24.64247	42.91525	0.8073
At most 2	0.002755	11.73745	25.87211	0.8298
At most 3	0.001465	4.072762	12.51798	0.7315

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	45.70725	32.11832	0.0006
At most 1	0.004635	12.90502	25.82321	0.8108
At most 2	0.002755	7.664683	19.38704	0.8504
At most 3	0.001465	4.072762	12.51798	0.7315

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Restrictions:

B(1,1)=0

Tests of cointegration restrictions:

Hypothesized No. of CE(s)	Restricted Log-likehood	LR Statistic	Degrees of Freedom	Probability
1	36951.07	16.98773	1	0.000038
2	36966.02	NA	NA	NA
3	36969.85	NA	NA	NA

Appendix 11: cointegration restriction test
((LDAX)

Sample (adjusted): 1/08/2004 10/09/2014
Included observations: 2778 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LCAC40 LDAX LFTSE100 LSP500
Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	70.34972	63.87610	0.0129
At most 1	0.004635	24.64247	42.91525	0.8073
At most 2	0.002755	11.73745	25.87211	0.8298
At most 3	0.001465	4.072762	12.51798	0.7315

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	45.70725	32.11832	0.0006
At most 1	0.004635	12.90502	25.82321	0.8108
At most 2	0.002755	7.664683	19.38704	0.8504
At most 3	0.001465	4.072762	12.51798	0.7315

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Restrictions:

B(1,2)=0

Tests of cointegration restrictions:

Hypothesized No. of CE(s)	Restricted Log-likehood	LR Statistic	Degrees of Freedom	Probability	Probability	Restricted Log-likehood	LR Statistic
1	36944.33	30.46872	1	0.000000	0.000000	36944.33	30.46872
2	36966.02	NA	NA	NA	NA	36966.02	NA
3	36969.85	NA	NA	NA	NA	36969.85	NA

NA indicates restriction not binding.

Appendix 12: cointegration restriction test
(LFTSE)

Sample (adjusted): 1/08/2004 10/09/2014
Included observations: 2778 after adjustments
Trend assumption: Linear deterministic trend (restricted)
Series: LCAC40 LDAX LFTSE100 LSP500
Lags interval (in first differences): 1 to 2

Unrestricted Cointegration Rank Test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	70.34972	63.87610	0.0129
At most 1	0.004635	24.64247	42.91525	0.8073
At most 2	0.002755	11.73745	25.87211	0.8298
At most 3	0.001465	4.072762	12.51798	0.7315

Trace test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Unrestricted Cointegration Rank Test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
None [b]	0.016319	45.70725	32.11832	0.0006
At most 1	0.004635	12.90502	25.82321	0.8108
At most 2	0.002755	7.664683	19.38704	0.8504
At most 3	0.001465	4.072762	12.51798	0.7315

Max-eigenvalue test indicates 1 cointegrating eqn(s) at the 0.05 level
[b] denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values
Restrictions:

B(1,3)=0

Tests of cointegration restrictions:

Hypothesized No. of CE(s)	Restricted Log-likehood	LR Statistic	Degrees of Freedom	Probability
1	36956.33	6.476729	1	0.010930
2	36966.02	NA	NA	NA
3	36969.85	NA	NA	NA

NA indicates restriction not binding.

Appendix 13: GARCH Estimation UK QE1

Number of Observation: 230 Log-likelihood: 694.8208		
Panel A		
Variable	Coefficient	Std. Error
constant	-0.0015*	0.0008
QE1	0.2774	0.3489
Panel B		
(ω)	< -0.00001***	< 0.00001
(*b*)	0.0041	0.0044
(c)	1.0186***	0.0026
QE1	-4.53×10^{-5}***	-1.66×10^{-5}

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \phi_{i,1}\text{QE1}_{i,t} + \varepsilon_{i,t}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE1}_{i,t}$where $R_{i,t}$ is the daily return from market i in week t,. $i =$ UK. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE1_{i,t}$, represents the QE1 operations or actual purchases during the QE1 period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

GARCH Estimation UK QE2

Number of Observation: 148 Log-likelihood: 468.3168		
Panel A		
Variable	Coefficient	Std. Error
constant	-0.0012	0.0012
QE2	0.2814	0.4588
Panel B		
(ω)	0.00001	0.00001
(*b*)	0.06694	0.06944
(c)	0.67420***	0.21502
QE2	0.00757	0.00483

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \phi_{i,1}\text{QE2}_{i,t} + \varepsilon_{i,t}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE2}_{i,t}$where $R_{i,t}$ is the daily return from market i in week t,. $i =$ UK. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE2_{i,t}$, represents the QE2 operations or actual purchases during the QE2 period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

GARCH Estimation UK QE3

Number of Observation: 84 Log-likelihood: 288.4992		
Panel A		
Variable	Coefficient	Std. Error
constant	-0.00273**	0.00135
QE3	-1.13840*	0.65019
Panel B		
(ω)	0.00005***	0.00001
(*b*)	0.1515	0.1564
(c)	0.0980*	0.0026
QE3	-0.0029***	0.0005

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \phi_{i,1}\text{QE3}_{i,t} + \varepsilon_{i,t}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE3}_{i,t}$where $R_{i,t}$ is the daily return from market i in week t,. i = UK. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE3_{i,t}$, represents the QE3 operations or actual purchases during the QE3 period by the BoE. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

Appendix 14: GARCH Estimation US QE1

Number of Observation: 153 Log-likelihood: 447.1681		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00261**	0.00111
QE1	-1.42506	0.97343
$\varepsilon_{i,t-1}$	-0.04811	0.08970
Panel B		
(ω)	< 0.00001	< 0.00001
(*b*)	-0.0131***	0.0039
(c)	1.0076***	0.0004
QE1	-0.0037	0.0029

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \phi_{i,1}\text{QE1}_{i,t} + \varepsilon_{i,t} - d_1\, \varepsilon_{i,t-1}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE1}_{i,t}$, where $R_{i,t}$ is the daily return from market i in week t, i=US. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE1_{i,t}$, represents the individual QE operations or actual purchases during the QE1 period by the Fed. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

GARCH Estimation US QE2

Number of Observation: 166 Log-likelihood: 568.6869		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00060**	0.00117
QE2	0.00254	0.57085
$\varepsilon_{i,t-1}$	0.00592	0.08922
Panel B		
(ω)	< 0.00001	< 0.00001
(*b*)	0.0918	0.0759
(c)	0.8092***	0.1793
QE2	0.0036	0.0039

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \phi_{i,1}\text{QE2}_{i,t} + \varepsilon_{i,t} - d_1\, \varepsilon_{i,t-1}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE2}_{i,t}$, where $R_{i,t}$ is the daily return from market i in week t, i=US. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE2_{i,t}$, represents the individual QE operations or actual purchases during the QE2 period by the Fed. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

GARCH Estimation US QE3

Number of Observation: 521 Log-likelihood: 1858.334		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00103**	0.00043
QE3	-0.54235***	0.04518
$\varepsilon_{i,t-1}$	-0.04863	0.04956
Panel B		
(ω)	< 0.00001**	< 0.00001
(*b*)	0.1740***	0.0536
(c)	0.6328***	0.1094
QE3	0.0033	0.0028

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0}+\phi_{i,1}\text{QE3}_{i,t} + \varepsilon_{i,t} - d_1\,\varepsilon_{i,t-1}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{QE3}_{i,t}$, where $R_{i,t}$ is the daily return from market i in week t, i=US. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $QE3_{i,t}$,represents the individual QE operations or actual purchases during the QE3 period by the Fed. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.

GARCH Estimation US MEP

Number of Observation: 209 Log-likelihood: 642.0508		
Panel A		
Variable	Coefficient	Std. Error
constant	0.00144	0.00101
MEP	-0.74288	0.89167
$\varepsilon_{i,t-1}$	-0.01601	0.09382
Panel B		
(ω)	< 0.00001	< 0.00001
(*b*)	0.0934*	0.0507
(c)	0.8860***	0.0528
MEP	-0.0025	0.0087

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0}+\phi_{i,1}\text{MEP}_{i,t} + \varepsilon_{i,t} - d_1\,\varepsilon_{i,t-1}$ where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \phi_{i,1}\text{MEP}_{i,t}$, where $R_{i,t}$ is the daily return from market i in week t, i=US. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} < 1$. The variable $MEP_{i,t}$,represents the individual QE operations or actual purchases during the MEP period by the Fed. *** ** * indicate statistical significance at the 1%, 5% and 10% levels respectively.