Accepted Manuscript

The effect of quantitative easing on the variance and covariance of the UK and US equity markets

Abiodun Shogbuyi, James M. Steeley

PII: S1057-5219(17)30082-0
DOI: doi: 10.1016/j.irfa.2017.07.009
Reference: FINANA 1122

To appear in: *International Review of Financial Analysis*

Received date: 10 July 2016
Revised date: 8 June 2017
Accepted date: 7 July 2017

Please cite this article as: Abiodun Shogbuyi, James M. Steeley , The effect of quantitative easing on the variance and covariance of the UK and US equity markets, *International Review of Financial Analysis* (2016), doi: 10.1016/j.irfa.2017.07.009

THE EFFECT OF QUANTITATIVE EASING ON THE VARIANCE AND COVARIANCE OF THE UK AND US EQUITY MARKETS

by

Abiodun Shogbuyi[1] and James M. Steeley[2*]

ABSTRACT

We examine the impact on the variance-covariance structure of UK and US equity markets of the Quantitative Easing (QE) operations implemented by the Bank of England (BoE) and the Federal Reserve (Fed). While the theory of portfolio balance suggests that QE operations could affect markets other than those in which the operations occur, prior analysis of these other markets is scarce. We find that while QE operations in general reduced equity volatility, day to day operations generated spikes in volatility in UK equities. We also find that BoE operations increased the covariance between the UK and US equity markets.

Keywords: Quantitative Easing; Equity market; variance; co-variance; UK; US

We are grateful to participants at the 2015 Midlands Regional Doctoral Colloquium, Birmingham, the 2015 PhD conference in Monetary and Financial Economics at UWE, Bristol, our discussant, Klaus Grobys, and participants at the 2016 INFINITI conference at Trinity College, Dublin, and especially two anonymous *IRFA* reviewers for helpful suggestions and comments on earlier drafts. 1: Aston Business School, Aston University, Birmingham, B4 7ET. Email: shogbuya@aston.ac.uk . 2: Keele Management School, Keele University, Keele, ST5 5BG. Email: j.steeley@keele.ac.uk. *: Corresponding author.

THE EFFECT OF QUANTITATIVE EASING ON THE VARIANCE AND COVARIANCE OF THE UK AND US EQUITY MARKETS

1. Introduction

The financial crisis was characterized by increased instability across financial markets and the contagion of its effects across markets and countries. The contagion of asset return volatility across countries during times of stressed market conditions was first highlighted by the experience of the world-wide downturn in equity prices in October 1987. For example, King and Wadhwani (1990) found that the correlation between equity market movements in different countries and general levels of volatility were positively related. Understanding the evolution of the correlations between financial assets is central to establishing the limits of diversification, to security pricing, and to successful asset allocation. Moreover, the instability associated with contagion across countries may deter investors, may reduce liquidity, may increase firms' costs of raising finance, and ultimately stall economic growth. This study aims to determine whether the actions of QE, by both the Bank of England and the Federal Reserve improved stability in the US and UK equity markets, whether these benefits crossed national boundaries, and how the correlation between these markets evolved during and after the financial crisis.

The existing literature on the effects of QE, explored in more detail in the next section, has either concentrated directly on the immediate impact on the bond market especially on bond yields or more generally on the impact on the macroeconomic aggregates of output (GDP) and CPI inflation. However, changes in the supply of one asset class – as happens under QE asset purchase programmes - can influence the price of other assets, if the assets are imperfect substitutes.[1] This portfolio balance mechanism is one of the transmission mechanisms through which QE can influence both asset prices more generally and potentially beyond the boundaries of domestic financial markets. This opens up the possibility for transnational effects of QE. Bernanke (2015) argues that QE can affect other countries if increased domestic demand brings forward a rise in overseas output to meet it, and also by lowering the global risk free rate and global risk premia. By anchoring interest rate expectations near the zero lower bound, QE was actively promoted as a means to reduce economic uncertainty. Theoretical work by Veronesi (1999) and Ross (1989) shows how uncertainty resolution can impact upon asset return volatility. Taken together these theoretical frameworks motivate our study of the potential for there to exist trans-national effects of QE on equity market volatility.

In this study, we use a multivariate GARCH modelling framework to examine the variance and covariance structure of the UK and US equity markets, before, during and after the recent financial crisis. In particular, a multivariate framework is employed that permits a dynamic covariance structure between the two markets. Included in this dynamic structure are indicator variables for the different phases of the financial crisis and QE, and variables representing the intensity each QE action. In addition, we consider spill-over effects into the volatility of the French, German and Japanese stock markets. Looking first at each market in isolation, we find significant reductions of the equity market returns in the US on specific days of US QE1 operations that is greater than the general rise in returns that is experienced during the entire QE1 phase. We also find a positive return response to the resumption of QE in Japan that by contrast to US and UK QE activity was much less anticipated. Otherwise, the impacts of the phases of QE and specific days of QE actions appear to have been anticipated in the returns. We also find that the variance of the US equity markets were also unaffected

1. See Tobin (1958, 1961, 1963) for the development of the portfolio balance model.

by the US QE operations, but for the UK, we find that days of QE operations during both the QE1 and QE2 phases generated a significant increase in the variance of the UK equity market. This means that although volatility in these markets fell back in general after the commencement of 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. We also find spikes on the specific days of QE activity, during UK and US QE1, in the equity volatility in France and Germany, neither of which was experiencing QE at that time. In addition, the French and Japanese markets saw positive spikes in volatility during US QE3, with the latter being so after controlling for the contemporaneous resumption of QE activity in Japan. The German market appeared to experience a general increase in volatility during the US QE maturity extension programme, but this was reduced to below pre-crisis levels on days following US QE operations. For the variance-covariance structure of the US and UK equity market, our results reveal that the BoE but not the Fed QE daily operations increased both the volatility of equity returns in both markets and also the covariance between the two markets.

The remaining sections of the paper are as follows. Section 2 provides a brief overview of related literatures on the covariation between equity markets, the effects of macroeconomic policy on equity markets and the effects of quantitative easing on financial markets. These establish context and identify the ways in which our paper contributes to the literature. Section 3 describes the GARCH modelling framework that will be employed, and highlights the particular innovations in our modelling that enable us to examine the effects of QE. In Section 4, we describe the data used and provide some summary statistics. An analysis of the estimated coefficients of the GARCH models is reported in Section 5. Section 6 contains a summary and offers some conclusions and policy implications.

2. Literature Review

2.1 Equity Market Covariation

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. Berben and Jansen (2005) 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, while 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.[2] More recently, 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. Kasch and Caporin (2013) extend the model of Capiello et al (2006) to accommodate threshold changes in correlation that depend on changes in variance. Our model has threshold changes that depend on the transition through certain time periods corresponding to the crisis and the phases of quantitative easing.

2.2 Macroeconomic news and equity market volatility

In an efficient financial market, macroeconomic news should be fully and instantaneously reflected in market prices (and returns). Ross (1989) used a no-arbitrage martingale

2. Carrieri et al (2007) argue, however, that correlation is likely to be a conservative measure of international financial market integration. Diebold and Yilmaz (2009) have proposed an alternative method to the GARCH framework to capture spill-overs of volatility shocks from one country to another, using a VAR and aggregating volatility spill-overs from multiple other countries' equity markets into a single index. A recent application to spill-lovers between currency and equity markets is Grobys (2015). In our study, we are concerned with "spill-over" effects of QE activity rather than spill-overs of volatility.

theoretical asset pricing framework to establish that asset price volatility represents the rate of information flow into an efficient market. Higher volatility implies a higher rate of flow of information into prices and thus a more efficient market. The relationship between financial market volatility and macroeconomic news, in particular, is developed in the theoretical work of Veronesi (1999). In this model, if the uncertainty surrounding macroeconomic fundamentals is high, then news causes asset prices to move much more than when this uncertainty is lower.

The empirical literature on the effects of macroeconomic news announcements on stock prices has an extensive history, for example, Brealey (1970), Officer (1973), Rozeff (1974), Goodhart and Smith (1985), Campbell (1987), Cutler et al (1989), Schwert (1989a,b) and Wasserfallen (1989). More recent contributions to the literature relating conventional monetary policy surprises and other macroeconomic news on returns in stock markets and volatility in stock markets both within and across countries include, Becker (1995), Hamilton and Lin (1996), Bomfim (2003), Ederington and Lee (1993), Steeley (2004), Graham et al., (2003), Kearney and Lombra (2004), Nikkinen and Sahlström (2001, 2004a, 2004b, 2006), Brenner et al (2009) and Bekaert et al (2013).[3] Our paper adds to this literature by examining the impact of monetary policy actions during the recent crisis and QE phases on the volatility of and cross correlations between the UK and US equity markets.

2.3 Quantitative Easing and Financial Markets

In March 2009, the BoE monetary policy committee (MPC) announced the start of its asset purchase programme, financed by the electronic creation of money, at the same time as it reduced Bank Rate to 0.5%, its effective lower bound. The QE program in the UK was in three phases. The first phase, QE1 was between March 2009 and January 2010, when £200

3. This is a very small selection from a vast literature that to review would encompass an entire paper in itself. 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). Steeley and Matyushkin (2015) consider the effects of QE on bond market volatility.

billion was expended on purchase of assets, mostly gilts. The purchases of gilts were initially restricted to conventional gilts with a residual maturity between 5 and 25 years but at the August MPC meeting the maturity range of gilts to be purchased was brought forward to three years and over. Other assets such as commercial paper and corporate bonds were also purchased by the BoE but in significantly lesser quantities. In October 2011, the second phase of the quantitative easing (QE2) started and between October 2011 and May 2012 the BoE purchased an additional £125 billion of gilts. In July 2012, the MPC announced a further £50 billion of gilt purchases to run till November 2012 (QE3). Cumulatively, the £375 billion of asset purchases accounts for around 35 per cent of total amount of gilts in issue

The decision by the Federal Reserve to make large scale asset purchase (LSAP) came in two steps. The first, in November 2008, when the Fed announced purchases of housing agency debt and agency mortgage-back securities (MBS) of $600 billion. The second came in March 2009, when the Federal Open Market Committee (FOMC) decided to increase the purchases of agency-related securities by additional $850 billion and to also purchase longer-dated Treasury securities to the tune of $300 billion. In total, these purchases would comprise 22 per cent of the stock of longer-term agency debt, fixed-rate agency MBS, and Treasury securities outstanding. The operations (LSAP1), which were extended to March 2010, became known as QE1. However, as the financial crisis worsened, the Fed started a second round of LSAP (QE2) in November 2010, which brought about additional purchases of $600 billion in longer-term Treasury bonds until the middle of 2011. The Fed on September 21 2011, announced a new maturity extension programme (MEP). Under the programme, the Fed would buy an additional $400 billion in Treasury securities with remaining maturities of 6 to 30 years, while selling an equal amount of Treasuries with remaining maturities of 3 months to 3 years. The implementation of the Fed's LSAPs was carried out by the Federal Reserve Bank of New York under delegated authority from the FOMC.

Towards the end of our sample period, in April 2013, the Bank of Japan announced the start of a programme of qualitative and quantitative easing (QQE). The operational target of monetary policy was changed from the overnight call rate to the monetary base, with the latter to increase at an annual pace of 60-70 trillion yen. Purchases of government bonds would increase by 50 Trillion Yen annually. The qualitative aspect refers to an extension of the maturities of government bonds purchased as well as the extension to other asset classes including exchange traded funds and real estate investment trusts. [4]

Existing research on the effects of the QE operations has mostly focussed on the immediate impact in the bond market or on the impact on output (GDP) and CPI inflation. Studies by Meier (2009), Joyce.et.al. (2011), Meaning and Zhu (2011) and Breedon et.al. (2012), find significant reductions in bond yields in the UK resulting from asset purchases during the first phase of QE. By contrast, Joyce et.al. (2012), Martin and Milas (2012) and Goodhart and Ashworth (2012), which considered the QE2 and QE3 periods in the UK, and Meaning and Warren (2015) suggest that these later QE operations did not reduce government bond yields by as much or at all. For the US bond market, D'Amico and King (2010), Gagnon et.al. (2011), Glick and Leduc (2012) and Hamilton and Wu (2012), Bauer and Rudebusch (2014) and Neely (2015) found evidence of yield reductions of up to 100 basis points from the first phase of US QE. Like in the UK, later phases of QE have had more modest effects, see for example, Swanson (2011, 2015). Studies and surveys of the wider economic impacts of the QE operations in the US and UK include Baumeister and Benati (2010), Lenza et.al. (2010), Kapetanios et.al. (2012), Chen et.al (2012), Bridges and Thomas (2012), and Lyonnet and Werner (2012), Churm et al (2015), Bhattarai and Neely (2016), Weale and Wieladek (2016) and Haldane et al (2016), with the latter two studies indicating that the positive effects on GDP and CPI may be larger than reported in the earlier studies.

4. Timeline summaries of QE announcements and key events for the UK, the US and Japan can be found in Borio and Zabai (2016, Table 3).

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 balance mechanism is one of the transmission mechanisms through which QE can influence both asset prices (generally) and the wider economy, and provides theoretical grounding and motivation for our study of the effect of QE on equity market volatility and covariation.[5] 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 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 process may continue until all asset prices have been bid upwards to rebalance asset portfolios to accommodate the increased cash balances. The increase in asset prices, which leads to both wealth effects and lower costs of capital, in turn boosts the economy through increased investment and consumption. A recent study by Haldane et al (2016) suggests that the effects of QE on equity returns in the UK are mixed, sometimes positive and sometimes negative and are small in magnitude. Evidence in Villanueva (2015) draws a similar conclusion for the effects of QE on US stocks. By contrast, Ballati et al (2016) suggest that the effects on equity prices are stronger and the pass-through to the economy insignificant. Barbon and Gianinazzi (2017) report a significant increase in Japanese equity prices in response to the purchase of ETFs by the Bank of Japan after 2013.

As a general policy tool, QE was designed to reduce uncertainty and improve liquidity, and the models of Ross (1989) and Veronesi (1999) provide a theoretical channel through which the trans-national effects of QE can influence asset return volatility. It is, therefore, upon volatility rather than returns (where for example Haldane et al (2016) find a limited response) that we focus our study.

5. QE may also influence the economy through liquidity and expectations based transmission channels. These are described in, for example, Benford et al (2009).

Our study will add to a small number of studies that have examined the effects of QE on equity market volatility, although these have all been confined to studying the effects within a single country. Tan and Kohli (2011) examine the volatility of the US stock market over the period 2008 to 2011, encompassing the US QE1 and QE2 phases. They examine three models of volatility, 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, and the conditional volatility from a GARCH(1,1) model applied to the returns to the S&P500 index. They find that the onset of QE led to a significant drop in stock index volatility that then reverted to previous levels following the ending of a phase of QE. Joyce et al (2011) examine the behaviour of the option-implied volatility of the FTSE100 index between January 2009 and June 2010, a period encompassing the UK QE1 phase. They found that the twelve-month implied volatility fell by around 40% during 2009. They also constructed an option-implied probability distribution for the FTSE100 returns and found that it narrowed between February 2009 and February 2010, with the (lower) tail risk falling considerably. Examinations of the tail risk of US stocks by Wang et al (2015) and Hattori et al (2016) also suggest that QE dampened stock return volatility.

Joyce et al (2011) also consider the possibility of time variation in the correlation structure between asset classes. They use a diagonal VECH form of the multivariate GARCH and offer some preliminary evidence, using monthly data until the end of 2009, of increases in the volatility of the correlation between UK equities and bonds around the commencement of QE. However, the estimated conditional covariances appear to display some instability with the onset of the crisis, and the lack of statistical significance of some of the coefficient estimates, particularly in the unconditional variance-covariance matrix suggests that their model may be poorly specified. Steeley (2015) develops this analysis further by including all the phases of QE in the UK, isolating their separate effects, using daily data, measuring the intensity of QE activity on a particular day and including additional macroeconomic controls. 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. He is unable to reject the hypothesis that the correlations among UK asset classes did not change during the period 2004 to 2014.

In this study, we will extend and refine this earlier work in a number of important dimensions. First, we will broaden the analysis to more than a single country. This will enable us to see if QE activity effects not only the equity market volatility of the country within which the QE activity took place (the UK or the US) but also had an effect on volatility in another country that was not experiencing QE, specifically France and Germany and Japan. Japan actually resumed quantitative easing towards the end of our sample period, and so we also examine whether this had any incremental impact. The existing research on QE spill-over effects has focused on the effects of US QE on supporting asset prices (rather than volatility) and the economy, for example Fratzscher et al (2013), Rogers et al (2014), Neely (2015), Haldane et al (2016) and Chen et al (2017),[6] and so our study provides an insight into possible spill-overs into volatility.

Second, by combining the UK and US into a multivariate GARCH system, we examine whether the volatility of equity returns in these two countries and the correlation between them is affected by the QE operations of both countries, or whether one of them appears to dominate. Given the closely related nature and timing of the QE operations by both the Fed and the BoE, it is interesting to disentangle their effects on volatility within and between the two countries. Third, we include the more recent maturity extension programme of QE2 and the QE3 phase in the US, which have been much less studied than QE1 and QE2,

6. There are also emerging literatures examining the spill-overs from the very recent introduction of QE by the ECB into other European economies, which happened after the end of our sample period, for example, de Santis (2016), and for spill-overs into emerging economies, for example, Burns et al (2014).

to see whether their effects were different to the prior QE2 phase. Fourth, we refine the measure of QE intensity and calculate it for both countries. Overall, our paper offers substantial contributions to specific several existing literatures, as well as adding to the overall body of research that has examined the effects of QE.

3. 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 two markets.[7] Specifically, the basic model is

$$R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_{i,t} + \theta_{i,2}\text{D2}_{i,t} + \theta_{i,3}\text{D3}_{i,t} + \theta_{i,4}\text{D4}_{i,t} \quad (1)$$

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

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

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \alpha_{i,3}\text{Lehman}_{i,t} + \gamma_{i,i,1}D1_{i,t} + \gamma_{i,i,2}\text{D2}_{i,t} + \gamma_{i,i,3}\text{D3}_{i,t} \quad (2)$$

$$+ \gamma_{i,i,4}\text{D4}_{i,t} + \varphi_{i,i,1}\text{QE1}_{i,t} + \varphi_{i,i,2}\text{QE2}_{i,t} + \varphi_{i,i,3}\text{QE3}_{i,t} + \varphi_{i,i,4}\text{MEP}_{i,t}$$

where $R_{i,t}$ is daily the return from market i in week t, $i \in$ US,UK, France, Germany, Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} + \sum_{j=1}^{4}\gamma_{i,i,j} + \sum_{j=1}^{4}\varphi_{i,i,j} < 1$. 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 and so we include an autoregressive correction for those markets for which it is required. 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 and ending the day before the start of QE in each country, March 10, 2009 (UK) and March 24, 2009 (US).

The variables $D1_t$, $D2_t$ and $D3_t$ are also indicator variables capturing the effects of entire phases of QE activity. Thus, for the UK, the variables take the value of one during the

7. 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.

following periods, and are zero otherwise: $D1_{i,t}$ 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. For the Japanese market, we additionally add an indicator variable that takes the value 1 from the resumption of QE by the Bank of Japan on April 4th, 2013.

The intensity of QE activity on a particular day is measured by the variables $QE1_t$, $QE2_t, QE3_t$ and MEP_t (in the US QE equations only) and are similarly separated by the phases of QE. [8] The value of this variable on day *t* is the quantity of purchases on that day relative to the average daily quantity of purchases prior to that day. We examined a number of alternative measures of QE intensity, including the quantity of purchases on a day relative to the total (or average) across all QE periods and our key findings do not depend on the precise definition of the measure. [9]

The form of the variance equation in equation (2) is a standard GARCH(1,1) specification, where the conditional variance is a function of its immediate past values and past squared residuals only, with the addition of the same exogenous variables and indicators as appear also 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

8. As the Bank of Japan only publish QE activity data on an aggregated monthly basis, it is not possible to create a corresponding intensity variable, and so only a phase dummy variable is included to capture Japanese QE.

9. We acknowledge a referee of this journal for prompting us to consider a variety of measures. The advantage of using a measure relative to an average, rather than relative to a total, is that it takes the same order of magnitude as the phase dummy variables, which makes the interpretation of the estimated coefficients much more obvious. Although the bounds of forthcoming QE purchase exercises were announced at the start of each phase, the actual out-turn of purchases was not known in advance. So, to ensure the most conservative of testing frameworks, we measure intensity relative to the average of prior daily purchases, rather than the full sample average.

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.

In the first stage of the empirical analysis, each of the markets is modelled separately using equations (1) and (2). In order to capture the evolution of the correlations between the UK and US markets, and how this has been affected by their parallel QE activity in the post-crisis period, it is necessary to estimate the two markets together and to explicitly model the correlation processes. Within a multivariate setting it is possible, in principle, for each conditional variance or covariance term to depend on all the lagged variance and covariance terms, which quickly generates a large parameter space. We use the diagonal VECH restricted version of the multivariate GARCH model proposed by Bollerslev et al (1988), which reduces considerably the number of parameters to estimate.

Because the time periods of the phases of QE in the UK and the US sometimes overlap in full or in part, it is not possible to include all the QE phase variables used in the univariate specifications into the mean equations of the multivariate specification, due to the strong collinearity that is generated. However, we can include a sub-set that spans all of the separate phases. So, we include a single variable that encompasses the first QE phases for both the US and the UK. For the second phase, the original QE phase dummies can be used as they are unique time periods. For the third phase, like with the first, the variable covers the period from the start of the US maturity extension programme to the end of its third phase of QE, a period that encompasses the third phase of UK QE. A similar issue arises with the QE intensity variables, and we solve this by combining the individual QE intensity variables, on a per country basis, into a composite variable that captures daily QE intensity in that country throughout the entire sample period. So, we create two new variables, $\mathrm{QE}_{UK,t}$, and $\mathrm{QE}_{US,t}$ as

$$\mathrm{QE}_{i,t} = \mathrm{QE1}_{i,t} + \mathrm{QE2}_{i,t} + \mathrm{QE3}_{i,t} + \mathrm{MEP}_{i,t} \qquad i \in UK, US \tag{3}$$

and include both of them in the multivariate specifications of the means and of the variances and covariance.[10]

In this case, the variance processes are similar but simplified versions of the processes specified in equation (2), that is

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{i,t-1}^2 + c_{i,i}h_{i,t-1} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + e_{i,i,UK}\mathrm{QE}_{UK,t} + e_{i,i,US}\mathrm{QE}_{US,t-1} \tag{4}$$

while the companion covariance process is specified as

$$h_{i,m,t} = \omega_{i,m} + b_{i,m}\varepsilon_{i,t-1}\varepsilon_{m,t-1} + c_{i,m}h_{i,m,t-1} + \alpha_{i,3}\mathrm{Lehman}_{i,t} + e_{i,m,UK}\mathrm{QE}_{UK,t} + e_{i,m,US}\mathrm{QE}_{US,t-1} \tag{5}$$

As we find in the univariate model that of the dummy variables representing the Lehman collapse and the QE phases, only the Lehman dummy variable is significant in the variance specifications, we only include the former in the multivariate variance and covariance specifications. This aids the estimation of the multivariate model by reducing the parameters to be estimated and avoiding collinearity issues.

A potential pitfall with the diagonal VECH specification is that the matrices of parameters, for example, the 2×2 matrix $\underline{B}$ that has general element $b_{i,m}$, $i = 1,2,$ and $m = 1,2,$ might not be positive semi-definite. The solution that we adopt is to restrict the parameter matrices to have full rank, which guarantees positive semi-definiteness. Parameters of all of the models will be estimated by maximum likelihood using the Levenberg-Marquardt algorithm, which combines the Gauss-Newton method with a gradient descent method, Levenberg (1944) and Marquardt (1963).

4. Data and Summary Statistics

10. Since the UK and US trading days partially overlap rather than fully coincide, it is possible that the effects of US QE operations into the UK equity market may not be captured fully using a contemporaneous variable. So, we examine the model with the US QE intensity variable lagged by one day. Our conclusions are not changed whether using lagged or contemporaneous intensity variables. We make a similar substitution in the univariate models when examining the effects of US QE in Europe, and of both US and UK QE in Japan. We thank a participant at the 2016 INFINITI conference for suggesting this additional check.

Daily closing observations, adjusted for dividends, of the FTSE100, S&P500, CAC40, DAX30 and Nikkei225 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 operations commenced in March 2009, the choice of the sample starting period, is to enable a comparison of the variance both before and during QE for the two equity markets being examined.

The summary statistics for the returns series, in Table 1, show that the daily mean returns for the equity markets for the sample period range from 0.005 (France) to 0.030 (Germany) percent per trading day or about 1.24 and 12.6 percent per year, respectively, with the UK, Japan and the USA experiencing an annual returns of between 3.34 percent and 5.04 percent on average. While the US and UK markets both had negative skewness over the sample period, the level of skewness is small. The Japanese market displays a greater negative skewness, while the returns in the two European markets appear to have slight positive skewness. All the return series are leptokurtic, reflecting the fat-tailed nature of distributions of asset returns.

In addition to the summary statistics computed for the daily returns, we also computed the correlation coefficient between the daily equity market returns for the US and UK, dividing the sample to provide comparative statistics for periods before and during quantitative easing. The significance of the correlation coefficients were verified 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. A Chow test was also performed on the full sample estimation output with the March 11th 2009 commencement date of the first phase of the BoE QE operations as the breakpoint, with a null hypothesis of no break on the specified date. The null hypothesis was also strongly rejected (p=0.0001). A similar result is also obtained using March 25th 2009, the commencement date of the Fed's first purchases of Treasury bonds. The correlation between the markets increased from 54 percent prior to the start of QE to 67 percent afterwards.

QE asset purchase 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 since the start of QE, on March 11th 2009 for the UK and 25th 2009 for the US, was divided by the average daily market value of bond purchases through the QE activity across all QE activity days prior to the given day, for the respective country. This is taken as the measure of QE activity intensity on a given day. Figures 1 and 2 show frequency distributions of the sizes of the daily asset purchase quantities (relative to the prior daily average) during the individual phases of the QE operations, for both the UK and the US. It can be seen that the activity during QE1 in the UK spans a much wider range of relative sizes than during the latter two phases of QE. Moreover, only QE1 saw purchase activity that was regularly consistently larger than it had been to that point. By contrast, during QE2, the size of QE purchase activity was more moderate, concentrated around 85 percent of the prior average daily value, while during QE3, the activity reduced to as little as 47 percent of the prior daily average purchase values. For the USA, the distribution of relative sizes of QE purchase activity covers a broader range, from as little as 3 percent of the prior average to more than twice that average on two occasions. Moreover, there is less distinction between the phases than for the UK, except for a slight tendency for relative larger scale activity during QE2 and somewhat smaller scale activity during QE3, which itself saw the most actions with it being the most long lasting phase.

5. Empirical Results

Tables 2 and 3 present the estimates of the parameters of the models in equations (1) and (2). Table 2 contains the estimated parameters of the mean equation, equation (1), while Table 3 contains the estimated parameters for the variance equation, equation (2). Each table has an upper and a lower panel. The upper panel relates to QE activity in the UK, while the lower panel relates to QE activity in the US. Each panel features the country undertaking QE (the UK or the US) and then the three other countries France, Germany and Japan.

Given that UK and US QE activity was heavily anticipated, our prior expectation is that the impacts will be concentrated in the variance rather than in the mean. This is broadly what we see in the mean equations, although there are some interesting exceptions. Although not significant, the indicator variable capturing the impact of the Lehman Brothers collapse is associated with a reduction in returns in all countries examined. The phases of UK QE have no significant effect on equity returns, which is consistent with recent findings in Haldane et al (2016), and the variables measuring the intensity of QE activity have only a spill-over effect into the returns in the German equity market. During QE1, UK QE activity is associated with a significant rise in the returns in German equities (p=0.09), while during QE3, UK QE purchases appear to be reducing returns in German equities (p=0.05). During QE1 in the US, the entire phase of QE is associated with a rise in US equity returns (p=0.06), but this is more than offset by a reduction in returns on the days of actual QE activity (p=0.04). The observations of negative reactions to QE activity are in conflict with the portfolio rebalancing transmission channel of QE, in that investors that have sold bonds into the QE process are then seeking alternatives to replenish their portfolios, which puts upward (rather than downward) pressure on prices.[11] Therefore, we considered the possibility that the reaction on the day of QE purchases could be a correction to an overreaction the previous day, in response to anticipatory purchases of equity. We added an indicator variable that took

11. These results are robust to the alternative measures of QE activity that we examined and to other minor specification alterations for both the mean and variance equations and to alternative distributional assumptions and optimisation algorithms.

the value one the day before a QE operation, but found no significant effect and also no change to the negative and significant response on the day itself. However, this negative reaction is consistent with findings for UK QE reported in Joyce, Liu and Tonks (2014) that investors in gilts who were selling into the QE purchase programme were also selling off equities, replacing both with corporate bonds. It is possible, therefore, that US investors were replacing both government bonds and equity with corporate bonds during QE1. Later phases of US QE do not seem to influence US stock returns, which is consistent with findings in Villanueva (2015). In the case of Japan, we find a positive and significant effect on returns of the third phase of US QE, (p=0.03). However, as this phase fully encompasses the re-starting of QE in Japan, it is most likely that this is a positive reaction to its own renewed QE activity that, by contrast to the UK and US's responses to the financial crisis, was much less anticipated.[12] This is consistent with the portfolio rebalancing channel of QE, and the recent study by Barbon and Gianinazzi (2017).

Turning to the variance equations, in Table 3, the coefficients of the lag squared return and the previous conditional variance terms are also highly significant and within the expected range for all of the equity markets, with the bulk of the effect coming from the previous conditional variance. Indicator variables for the Lehman Brothers collapse are significant in all variance equations and, as expected, positive implying that this event period was followed by an increase in volatility in these equity markets.

If the subsequent periods of the quantitative easing acted to reduce volatility back to its pre-crisis levels, we should expect that the indicator variables for the phases of QE should be not significantly different from zero. With the exception of the second UK phase of QE where for the UK equity market the volatility was actually reduced significantly below pre-crisis levels (p=0.03), volatility in all four countries retreated to pre-crisis levels during the

12. Although, we also include a variable to capture the precise sub-period of Japanese QE, which turns out to be negative, the net effect (including the US QE3 variable) is still positive.

phases of UK QE. However, the QE intensity variables point to some disruption to the market on days of QE activity. Specifically, for the UK equity market, both during QE1 ($p=0.08$) and QE2 ($p=0.03$), there were significant increases in volatility in proportion to the size of the QE purchases being undertaken. In addition, we find spill-over effects of these daily UK QE purchases into the equity markets into both France ($p=0.06$) and Germany ($p=0.03$) during QE1 that, as described earlier, saw the highest frequency of relatively large QE purchase activity in the UK.

For the US phases of US QE, which in part overlap with those of the UK, we again find, as expected, a return of volatility to pre-crisis levels, in both the US and the other three countries. However, we find that the maturity extension programme in the US appears to have been accompanied by an increase in the volatility of German equities ($p=0.03$), although this is more than offset on days of actual QE purchases ($p=0.08$). We also see that days of US QE activity also spilled –over into the German equity market ($p=0.03$), as was also the case for days of UK QE activity. We also find that QE3 activity in the US spill-over to increasing volatility in both the French ($p=0.04$) and Japanese markets ($p<0.001$), the latter even after accounting for its own QE activity. By contrast to the experience of the UK, where QE purchase days were accompanied by increased equity market volatility, the same is not observed in the US, suggesting that the US equity market was more able to absorb QE related trading.

Figure 3 plots the estimated conditional volatility for the UK and US equity market returns over the sample period. Clearly the period depicted can be subdivided further into a pre-crisis and QE period. The pre-crisis period starting from 2004 sees relatively 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 at that time. It was not until September 2008, following the bankruptcy of Lehman Brothers that both equity markets simultaneously witnessed a surge in volatility, officially signalling the beginning of the financial crisis. The start of 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. Susbequent QE operations (QE2) again appeared to have calmed equity market volatility, although there were some noticeable spikes in the equity markets' volatility particularly for the US market around the last quarter of 2011. However barring this, equity market volatility had largely returned to pre-crisis levels in both markets by the end of our sample period. This is consistent with the significance levels of the QE related coefficients in conditional variance equations, although this might not be wholly attributable to the QE operations, given some of the other policy measures being implemented by the two countries over this period.

We turn now to a joint analysis of the US and the UK equity market to see how each market's return volatility and the correlation between them was responding to each other's QE activity. Revisiting the mean equations first, in the upper panel of Table 4, we again find that the first phase of US was associated with a boost to US equity returns (p=0.03), and that the UK now also appears to be responding to this first phase of QE (p=0.05). For the US, this significant rise in returns seems to continue beyond their first phase of QE into the period when the UK was undertaking its second phase of QE, indicating some potential spill-over effects, consistent with the portfolio rebalancing channel, from the UK to the US (p=0.02). In the univariate models, a puzzling result was the observation of significant negative responses of returns to daily QE1 activity in the US. Within the broader multivariate setting, the evidence of this is much weaker, (p=0.34) although now we are using composite intensity variables – which group the activity across all phases of QE.

The lower panel of Table 4, shows the estimation results of the variance-covariance specification from the DVEC model. The coefficients on the own past shocks and own past variance are significant and, for the conditional variances, consistent with the values obtained in the univariate cases ($p<0.0001$). The dummy variable capturing the impact of the financial crisis indicates that the crisis increased not only the conditional variances in the US and UK equity markets, as we found in the univariate modelling, but also significantly increased the covariance between the equity returns in the two countries ($p=0.01$). This is consistent with our summary statistics that suggested that the post-crisis correlation between the two markets was significantly increased. It is also consistent with the literature on financial market contagion; in times of crises financial markets are more likely to move together.

For the effects of daily QE activity, we find results that augment the findings of the univariate modelling in important ways. First, as with the univariate modelling, the daily QE activity in the US had no impact on US equity volatility. We now can also see that it had no effect on either the volatility of UK equities or the covariance between US and UK equities. In the univariate case, we found that UK QE activity impacted UK equity volatility in both the first and second phases of QE, and our composite variable picks this up again in the multivariate setting ($p=0.09$). But, what we also find in the multivariate setting is that daily QE activity in the UK is spilling over into both the volatility of US equities ($p=0.09$) and also the covariance between the two markets ($p=0.07$), increasing them all. The conditional correlation derived from the conditional variances and covariance from the multivariate model is shown in Figure 4. The rise in the conditional correlation that follows the financial crisis is clear, and consistent with the results for the unconditional correlation reported in Section 4. We can also see that this rise begins to decay during the phases of QE that follow.

6. Conclusion

Our study has examined the effects of US and UK QE operations, both in general and of the intensity of daily bond purchase activity by the monetary authorities, on the volatility of their equity market returns. This has been done both within each market and, by using a multivariate GARCH model, permitting QE effects to transfer from one market to another, and to also influence the cross market correlation in returns. We also consider the potential for QE effects to spill-over into other countries that were not experiencing QE activity as an immediate response to the financial crisis.

Our empirical results suggest that QE operations have had some significant impact on the equity markets examined. Consistent with recent studies that have examined the effects of QE on equity returns, our results from the univariate analysis indicate that QE operations mostly had relatively little impact on returns not only in the UK and US, but also in France and Germany that were not undertaking QE or in Japan that only resumed QE activity very recently. However, there was some indication that German equity returns were responding positively to UK QE daily activity during QE1 and QE3, while Japanese equities seemed to respond positively to the resumption of their own QQE programme in 2013.

Across all markets, the most dramatic result is the significant rise in the volatility of equity returns following the collapse of Lehman Brothers, from which many have dated the start of the financial crisis. Equally dramatic is the subsequent reversal of this rise once the UK and the US commence their QE operations. In all countries, volatility returned to pre-crisis levels during the phases of UK and US QE. For the UK, volatility actually decreased significantly below these levels during QE2. This suggests that QE operations not only calmed equity markets in the countries that were undertaking QE operations but also did so more widely, in Europe and in Japan. The intensity of daily QE activity in the UK was also found to cause increases (on those days) in the volatility of UK equity returns in the UK during QE1 and QE2, and the daily activity during QE1 also spilled over into daily volatility increases in France and Germany. This suggests that the additional financial market trading caused by the QE operations in the UK (through a portfolio rebalancing channel) was causing spikes in volatility in equity returns in these three countries, meaning that the success that QE had in dampening down the increase in volatility experienced during the financial crisis was intermittently disrupted by the effects of the QE operations themselves. US QE activity was observed to have little effect on equity market volatility, including in the US itself.

Our multivariate analysis supports the conclusions of our univariate analysis but allows us to consider the impacts of QE between the UK and US, who were both undertaking their QE operations in response to the financial crisis. As foreshadowed by the univariate analysis, we find effects coming from UK QE operations but not from US QE operations. In particular, we find that UK QE operations not only affected UK equity volatility, but also significantly increased US equity volatility and also the covariance between the two countries' equity returns. While these effects are for daily QE intensity, we also find that the correlation between the two countries returns increased in the aftermath of the financial crisis but that this correlation has fallen back somewhat over the course of QE.

We attribute the differences between the volatility responses to UK and US QE to the subtle differences in programme design. As the UK was the first to start government bond purchase operations, this may have had a disproportionate impact on financial markets compared to subsequent QE activity in either the US or the UK. Second, the layout of QE activity in the UK and the US were somewhat different. In the UK, the emphasis at the start of each phase of QE was on the size of the total purchases to be undertaken, whereas in the US, the announcements tended to mention monthly purchase targets rather than an overall total. The latter emphasis implies a smoother purchase sequence which may have resulted in less disruption to financial market volatility. The distribution of relative size of purchase activity was also much more concentrated within any given phase for the UK than for the US, again suggesting that US QE activity was being smoothed.

Our results have clear implications for portfolio selection and diversification in and across these equity markets for investors, since the correlation between the two markets was changing during the crisis and the subsequent phases of QE. This is also consistent with the observation in Joyce et al (2014) in the UK that investors were switching from both government bonds and equity into corporate bonds to access new diversification opportunities. In addition, our results provide policy makers with a greater perspective on the potential for day to day QE operations to temporarily affect other asset markets, both domestic and overseas.

References

Ballati, M., Brooks, C., Clements, M., Kappouy, K., (2016). Did Quantitative Easing only in ate stock prices? Macroeconomic evidence from the US and UK. Available at SSRN: http://ssrn.com/abstract=2838128.

Barbon, A., and Gianinazzi, V., (2017). Large-Scale ETF Purchases and the Cross-Section of Equity Prices: Evidence of the Portfolio-Balance Channel. Available at SSRN: https://ssrn.com/abstract=2925198.

Bauer, M D and Rudebusch, G D (2014): "The signaling channel for Federal Reserve bond purchases", *International Journal of Central Banking*, 10, 233-289.

Baumeister, C. and Benati, L. (2010). 'Unconventional monetary policy and the great recession – Estimating the impact of a compression in the yield spread at the zero lower bound', *Working Paper Series No. 1258, European Central Bank.*

Becker, G. Finnerty, J. and Friedman, J. (1995) Economic news and equity market linkages between the US and UK, *Journal of Banking and Finance*, ***19***, 1191-1210

Bekaert, G. and C. Harvey, 1995, Time varying world market integration, Journal of Finance 50, 403-444.

Bekaert, G. and G. Wu, 2000, Asymmetric volatility and risk in equity markets, Review of Financial Studies 13, 1-42.

Bekaert, G. Hoerova, M. and Lo Duca, M.(2013) Risk, uncertainty and monetary policy, *Journal of Monetary Economics, Vol.* 60, *No. 7,* 771-788

Benford, J., Berry, S., Nikolov, K. and Young, C.(2009) Quantitative easing. Bank of England Quarterly Bullentin 2009(2), 90-100.

Berben, R.P. and W.J. Jansen, 2005, Comovement in international equity markets: A sectoral view, *Journal of International Money and Finance* 24, 832-857.

Bhattaria, S., and Neely, C., (2016) A Survey of the Empirical Literature on U.S. Unconventional Monetary Policy. Federal Reserve Bank of St. Louis, Working Paper 2016-021A.

Bollerslev, T. (1986) Generalised autoregressive conditional heteroskedasticity, *Journal of Econometrics*, **31**, 307-27.

Bollerslev, T. (1987) A conditionally heteroskedastic time series model for speculative prices and rates of return, *Review of Economics and Statistics*, **69**, 542-547

Bollerslev, T., Engle, R.F. and Wooldridge, J.M., (1988). 'A Capital-Asset Pricing Model with time-varying covariances, *Journal of Political Economy **96**(1)*, 116-131

Bollerslev, T., Chou, R.Y. and K.F. Kroner, 1992, ARCH Modeling in Finance: A Review of the Theory and Empirical Evidence, *Journal of Econometrics* 52, 5-59.

Bomfim, A. (2003). Pre-announcement effects, news effects, and volatility: monetary policy and the stock market. *Journal of Banking and Finance*, ***27***, 133-151

Borio, C. and Zabai, A. (2016), "Unconventional monetary policies: a re-appraisal", BIS Working Papers No 570.

Brealey, R., 1970. The distribution and independence of successive rates of return from the British equity market, *Journal of Business Finance* 2, 29-40.

Breedon, F., Chadha, J. S., and Waters, A. (2012) 'The Financial Market Impact of UK Quantitative Easing', *Oxford Review of Economic Policy*, **28**(4), 702–28.

Brenner, M., Pasquariello, P., and M. Subrahmanyam, 2009, On the volatility and comovement of US financial markets around macroeconomic news announcements, *Journal of Financial and Quantitative Analysis* 44, 1265-1289.

Bridges, J. and Thomas, R. (2012). 'The Impact of QE on the UK Economy — Some Supportive Monetarist Arithmetic', *Bank of England Working Paper No. 442.*

Brunner, K. and Meltzer, A. (1973). 'Mr Hicks and the ''monetarists' 'E*conomica, vol. **40**(157),* 44–59.

Burns, A., Kida, M., Lim, J., Mohapatra, S., Stocker, M., (2014). Unconventional Monetary Policy Normalization in High-Income Countries : Implications for Emerging Market Capital Flows and Crisis Risks. Policy Research Working Paper;No. 6830. World Bank, Washington, DC.

Campbell, J.Y. (1987) Stock returns and the term structure. *Journal of Financial Economics*, **18**, 373-399

Capiello, L., Engle, R., and K. Sheppard, 2006. Asymmetric dynamics in the correlations of global equity and bond markets, *Journal of Financial Econometrics* 4, 537-572.

Carriero, F., V. Errunza, and K. Hogan, 2007. Characterizing world market integration through time. *Journal of Financial and Quantitative Analysis* 42, 915-940.

Chen, H., Curdia, V., and Ferrero, A. (2012) 'The Macroeconomic Effects of Large-Scale Asset Purchase Programmes'', *The Economic Journal vol.* ***122****(564),* F289–315.

Chen, Q., Lombardi M.J., Ross, A., and Zhu, F., (2017), Global impact of US and euro area unconventional monetary policies: a comparison. BIS Working Papers No 610.

Churm, R., Joyce, M., Kapetanios, G., and Theodoridis, K., (2015). Unconventional monetary policies and the macroeconomy: the impact of the United Kingdom's QE2 and Funding for Lending Scheme. Bank of England Staff Working Paper No. 542.

Cutler, D., Poterba, J., and L. Summers, 1989, What moves stock prices? *Journal of Portfolio Management* 15, 4-12.

D'Amico, S. and King, T.B. (2010). 'Flow and stock effects of large-scale treasury purchases', *Finance and Economics Discussion Series No. 2010-52.*

De Santis, R., (2016) Impact of the asset purchase programme on Euro area government bond yields using market news. ECB working paper no.1939.

Diebold, F.-X., Yilmaz, K., 2009. Measuring financial asset return and volatility spillovers, with application to global equity markets. *Economic Journal* 119, 158–171.

Ederington, L., and Lee, J. (1993). How markets process information: News releases and volatility. *Journal of Finance,* ***48***, 1161-1191

Engle, R.F. (1982) Autoregressive conditional heteroskedasticity with estimates of the variance of UK inflation, *Econometrica,* **50**, 987-1007.

Engle, R.F. (2002) Dynamic Conditional Correlation – A Simple Class of Multivariate GARCH models, *Journal of Business and Economic Statistics* 20, 339-350.

Fisher L., 1966, Some New Stock Market Indexes, *Journal of Business*, 39, 191-225.

Fratzscher, M., Lo Duca, M. and Straub, R. (2013). "On the spillovers of US quantitative easing", Working Paper No. 1557, European Central Bank.

French, K., W. Schwert, and Stambaugh R. (1987) Expected stock returns and volatility, *Journal of Financial Economics* **19**, 3-30.

Gagnon, J., Raskin, M., Remache, J. and Sack, B. (2011). 'The financial market effects of the Federal Reserve's large-scale asset purchases', *International Journal of Central Banking, vol.* ***7****(10),* 3–43.

Glick, R. and S. Leduc (2012). 'Central Bank Announcements of Asset Purchases and the Impact on Global Financial and Commodity Markets,' *Federal Reserve Bank of San Francisco Working Paper Series, 2012-31, August.*

Goodhart, C. and Ashworth, J (2012**)**, ' QE: A Successful Start May be Running into Diminishing Returns', *Oxford Review of Economic Policy,* **28**(4), 640-70

Goodhart, C., and R. Smith, 1985, The impact of news on financial markets in the United Kingsom, *Journal of Money Credit and Banking* 17, 507-511.

Graham, M., Nikkinen, J., and Sahlstrom, P. (2003) Relative importance of scheduled macroeconomic news for stock market investors. *Journal of Economics and Finance*, ***27***, 153-165

Grobys, K., (2015) Are volatility spillovers between currency and equity market driven by economic states? Evidence from the US economy. *Economics Letters* 127, 72-75.

Haldane, A., Roberts-Sklar, M., Wieladek, T., and C. Young (2016) QE: The story so far. *Bank of England Staff Working Paper* No. 624, October 2016.

Hamilton, J. and Lin, G. (1996). Stock market volatility and the business cycle, *Journal of Applied Econometrics, Vol.* ***11,*** 573-593

Hamilton, J. D. and Wu, J.C., (2012). The Effectiveness of Alternative Monetary Policy Tools in a Zero Lower Bound Environment, *Journal of Money, Credit and Banking*, 2012, 44, 3–46.

Hamao, Y., Masulis, R.W. and V.K. Ng, 1990, Correlations in Price Changes and Volatility across International Stock Markets, Review of Financial Studies 3, 281-307.

Hattori, Masazumi, Andreas Schrimpf, and Vladyslav Sushko. 2016. "The response of tail risk perceptions to unconventional monetary policy." American Economic Journal: Macroeconomics 8 (2): 111-136.

Johansson, A., 2010, Financial markets in East Asia and Europe during the global financial crisis, CERC working paper no.13. Stockholm School of Economics.

Joyce, M., Lasaosa, A., Stevens, I. and Tong, M. (2011). 'The financial market impact of quantitative easing', *International Journal of Central Banking, vol.* ***7****(3), 113–61*

Joyce, M., Liu, Z. and Tonks, I. (2014). "Institutional investor portfolio allocation, quantitative easing and the global financial crisis," *Bank of England working papers* 510, Bank of England.

Joyce, M.A.S., McLaren, N., and Young, C. (2012). ''Quantitative Easing in the United Kingdom: Evidence from Financial Markets on QE1 and QE2,'' *Oxford Review of Economic Policy,* ***28****(4)*, 671-701

Kapetanios, G., Mumtaz, H., Stevens, I. and Theodoridis, K. (2012). 'Assessing the economy-wide effects of quantitative easing', *Economic Journal, vol.* ***122****(564),* F316–47

Kasch, M., and M. Caporin, 2013. Volatility threshold dynamic conditional correlations: An international analysis. *Journal of Financial Econometrics* 11, 706-742.

Kearney, A., and Lombra, R. (2004). Stock market volatility, the news and monetary policy, *Journal of Economics and Finance*, ***28***, 252-259

King, M.A. and S. Wadhwani, 1990, Transmission of Volatility between Stock Markets, Review of Financial Studies 3, 5-33.

Koutmos, G. and G. Booth, 1995, Asymmetric volatility transmission in international stock markets, Journal of International Money and Finance 14, 747-62.

Lenza, M., Pill, H. and Reichlin, L. (2010). 'Monetary policy in exceptional times', *Economic Policy, vol.* ***62****, 295–339.*

Levenberg, K., 1944, A Method for the Solution of Certain Non-Linear Problems in Least Square, *Quarterly of Applied Mathematics* 2, 164–168.

Lyonnet, V. and Werner, R., (2012). 'Lessons from the Bank of England on Quantitative Easing and other Unconventional Monetary Policies'. *International Review of Financial Analysis, **25**, (2012), 94-105.*

Marquardt, D., 1963, An Algorithm for Least-Squares Estimation of Nonlinear Parameters, *SIAM Journal on Applied Mathematics* 11, 431–441.

Martin, C., and Milas, C., (2012). 'Quantitative easing: a sceptical survey', *Oxford Review of Economic Policy, vol. 28, No. **4***, 750-764.

Meaning, J. and Warren, J. (2015), "The transmission of unconventional monetary policy in UK government debt markets", *National Institute Economic Review* No. 234, November 2015

Meaning, J., and Zhu, F. (2011). 'The impact of recent central bank asset purchase programmes', *Bank of International Settlements Quarterly Review*, December, 73–83.

Meier, A. (2009). 'Panacea, curse, or non-event: unconventional monetary policy in the United Kingdom', *IMF Working Paper No. 09 / 163.*

Neely, C., (2015). "Unconventional monetary policy had large international effects", *Journal of Banking and Finance,* 52(C), 101-111.

Nikkinen, J., Omran, M., Sahlstrom, P., and Aijo, J. (2006). Global stock market reactions to scheduled U.S. macroeconomic news announcements. *Global Finance Journal*, *17*, 92-104.

Nikkinen, J., and Sahlstrom, P. (2001). Impact of scheduled U.S. macroeconomic news on stock market uncertainty: A multinational perspective. *Multinational Finance Journal*, *5*, 129-139.

Nikkinen, J., and Sahlstrom, P. (2004a). Impact of the federal open market committee's meetings and scheduled macroeconomic news on stock market uncertainty. *International Review of Financial Analysis*, **13**, 1-12.

Nikkinen, J., and Sahlstrom, P. (2004b). Scheduled domestic and US macroeconomics news and stock valuation in Europe. *Journal of Multinational Financial Management*, **14**, 201-215

Nikkinen, J., Omran, M., Sahlstrom, P., and Aijo, J., (2006). Global stock market reactions to scheduled U.S. macroeconomic news announcements, *Global Finance Journal* 17, 92–104.

Officer, R. (1973) The variability of the market factor of New York Stock Exchange, *Journal of Business*, **46**, 434-453.

Poon, S., and Granger, C.W.J. (2003) Forecasting volatility in financial markets: a review, *Journal of Economic Literature*, **41**, 478-539

Rogers, J., Scotti, C. and Wright, J. (2014). "Evaluating Asset-Market Effects of Unconventional Monetary Policy: A Cross-Country Comparison". International Finance Discussion Papers No. 1101, Board of Governors of the Federal Reserve System

Ross, S., (1989). Information and Volatility: The No-Arbitrage Martingale Approach to Timing and Resolution Irrelevancy, *The Journal of Finance* 44, 1-17.

Rozeff, M. (1974) Money and stock prices, market efficiency, and the lag in the effect of monetary policy, *Journal of Financial Economics **1***, 245-302

Schwert, G. W. (1989a). Why does stock market volatility change over time? *Journal of Finance*, **54**, 1115-51.

Schwert, G. W. (1989b) Business cycles, financial crises, and stock volatility, *Carnegie-Rochester Conference Series on Public Policy, 31, 83-126*

Shogbuyi, A.K, (2017) Quantitative Easing and Investing in Financial Asset Markets, PhD Thesis (Aston University, UK).

Steeley, J.M., (2004) Stock price distributions and news: Evidence from index options, *Review of Quantitative Finance and Accounting, 23,* 229-250.

Steeley, J.M., (2015) The effects of quantitative easing on the integration of UK capital markets", *European Journal of Finance,* in press.

Steeley, J.M. and Matyushkin, A. (2015). The effects of quantitative easing on the volatility of the gilt-edged market. *International Review of Financial Analysis*, ***37***, 113-128

Swanson, E., (2011): "Let's twist again: A high-frequency event-study analysis of operation twist and its implications for QE2", *Brookings Papers on Economic Activity*, 42, 151-207.

Swanson, E., (2015): "Measuring the effects of unconventional monetary policy on asset prices", *NBER Working Papers*, no 21816.

Tan, J. and Kohli, V. (2011). The Effect of Fed's Quantitative Easing on Stock Volatility, unpublished manuscript, University of California, Berkeley, available from SSRN.

Tobin, J. (1958) Liquidity preference as behaviour towards risk, *The Review of Economic Studies*, **25,** 65-86

Tobin, J. (1961). ‘Money, capital and other stores of value’, *American Economic Review, Papers and Proceedings, vol. **51**(2),* 26–37.

Tobin, J. (1963). A general equilibrium approach to monetary theory, *Journal of Money Credit, and Banking,* **142**, 171-204.

Veronesi, P., (1999). Stock market overreaction to bad news in good times: a rational expectations equilibrium model, *Review of Financial Studies* 12, 975 – 1007.

Villanueva, M., (2015) Quantitative Easing and US Stock Prices. Available at SSRN: https://ssrn.com/abstract=2656329 or http://dx.doi.org/10.2139/ssrn.2656329

Wang, Y-C., Wang C-W., and C-H. Huang (2015) The impact of unconventional monetary policy on the tail risks of stock markets between U.S. and Japan, *International Review of Financial Analysis* 41, 41–51.

Wasserfallen, W., 1989, Macroeconomic news and the stock market: Evidence from Europe, *Journal of Banking and Finance* 13, 613-626.

Table 1: Summary statistics of the daily equity returns Jan 2nd 2004-Oct 9th 2014.

	USA	UK	France	Germany	Japan
Mean%	0.020	0.013	0.005	0.030	0.013
Median%	0.070	0.024	0.042	0.090	0.000
Maximum%	10.957	9.384	10.595	10.798	13.235
Minimum%	-9.470	-9.265	-9.472	-7.434	-12.111
Std. Deviation%	1.230	1.166	1.411	1.361	1.530
Skewness	-0.313	-0.154	0.043	0.015	-0.649
Kurtosis	15.092	12.370	10.149	10.148	12.142
Jarque-Bera (P-value)	15042 (<0.0001)	10477 (<0.0001)	5778 (<0.0001)	5775 (<0.0001)	9639 (<0.0001)

Table 2: Estimated Parameters of the Mean Equation for the univariate GARCH models

This table contains the estimated coefficients for the conditional mean equations from the model $R_{i,t} = \alpha_{i,0}(j) + \alpha_{i,1}(j)\text{Lehman}_{j,t} + \theta_{i,1}(j)D1_{j,t} + \theta_{i,2}(j)\text{D2}_{j,t} + \theta_{i,M}\text{DM}_t + \theta_{i,3}(j)\text{D3}_{j,t} + \phi_{i,1}(j)\text{QE1}_{j,t} + \phi_{i,2}(j)\text{QE2}_{j,t} + \phi_{i,M}\text{MEP}_t + \phi_{i,3} + \alpha_{i,2}(j)\text{BoJQE}_t + d_1(j)R_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}(j)|\Omega_{t-1} \sim N(0, h_{i,t}(j))$, and $h_{i,t}(j) = \omega_{i,i}(j) + b_{i,i}(j)\varepsilon^2_{i,t-1}(j) + c_{i,i}(j)h_{i,t-1}(j) + \alpha_{i,3}(j)\text{Lehman}_{j,t} + \gamma_{i,i,1}(j)D1_{j,t} + \gamma_{i,i,2}(j)\text{D2}_{j,t} + \gamma_{i,i,3}\text{DM}_t + \gamma_{i,i,4}(j)\text{D3}_{j,t} + \varphi_{i,i,1}(j)\text{QE1}_{j,t} + \varphi_{i,i,2}(j)\text{QE2}_{j,t} + \varphi_{i,i,M}\text{MEP}_t + \varphi_{i,i,3}(j)\text{QE3}_{j,t}\alpha_{i,4}(j)\text{BoJQE}_t + \mu_i(j)R_{i,t-1}$, where $R_{i,t}$ is daily the return from market i in week t, $i \in$ US,UK,France,Germany,Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} + \alpha_{i,3} + \alpha_{i,4} + \sum \gamma_{i,i,k} + \sum \varphi_{i,i,k} + \mu_i < 1$. The variables $D1_{j,t}$, $D2_{j,t}$ $D3_{j,t}$ are QE phase's dummy variables for the US and the UK. DM_t is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise, $j \in$ US,UK. The variables $QE1_{j,t}, QE2_{j,t}$ and $QE3_{j,t}$ represents the individual QE operations over the entire QE period by the BoE or the Fed. The variable MEP_t represent the QE operation twist in the US. The variable BoJQE_t represents the period of quantitative and qualitative easing by the Bank of Japan. Below the estimated coefficients in parentheses are t-statistics.

Conditional Means (all estimated coefficients, except d_1, are $\times 10^2$)												
UK Quantitative Easing												
	Const.	Crisis	QE Phases				QE Operations				BoJ QE	AR(1)
	α_0	α_1	θ_1	θ_2	θ_3	θ_m	ϕ_1	ϕ_2	ϕ_3	ϕ_m	α_2	d_1
UK	0.0485	-0.2170	0.0780	0.1046	-0.0750		0.0424	-0.1959	-0.1353			
	(3.220)	(-1.240)	(0.774)	(0.706)	(-0.815)		(0.216)	(-0.800)	(-0.634)			(-2.206)
France	-0.0173	-0.2506	0.0041	-0.0185	0.1717		0.2547	0.1987	-0.3664			
	(-0.868)	(-1.127)	(0.035)	(-0.107)	(1.252)		(1.121)	(0.555)	(-1.261)			(-2.915)
Germany	0.0177	-0.2130	-0.0575	0.2453	0.2222		0.4670	-0.2162	-0.6161			
	(0.836)	(-0.934)	(-0.465)	(1.306)	(1.372)		(1.683)	(-0.643)	(-1.955)			
Japan	0.0226	-0.4830	0.0648	0.1006	-0.0868		-0.0820	0.0064	-0.0900		-0.0209	
	(0.842)	(-1.850)	(0.508)	(0.747)	(-0.715)		(-0.359)	(0.028)	(-0.319)		(-0.295)	
US Quantitative Easing												
US	0.0372	-0.3575	0.2460	0.0385	0.0796	0.1180	-0.4407	0.0179	-0.1073	-0.1376		-0.0661
	(1.874)	(-1.579)	(1.881)	(0.399)	(1.549)	(1.352)	(-2.061)	(0.186)	(-1.456)	(-1.010)		(-2.941)
France	-0.0171	-0.2910	0.0571	0.0122	-0.0296	0.1001	0.3865	-0.0008	0.0757	-0.2965		-0.0661
	(-0.752)	(-1.386)	(0.446)	(0.126)	(-0.437)	(0.617)	(1.155)	(-0.009)	(0.700)	(-1.20)4		(-2.972)
Germany	0.0229	-0.3066	0.0168	0.0762	-0.0186	-0.1387	0.3454	-0.0672	0.0325	0.2255		
	(0.904)	(-1.396)	(0.112)	(0.955)	(-0.255)	(-0.888)	(1.281)	(-0.900)	(0.339)	(0.995)		
Japan	-0.0004	-0.2919	0.0271	-0.0182	0.2919	0.0086	0.0358	0.0199	-0.2337	0.1213	-0.2194	
	(-0.015)	(-1.166)	(0.181)	(-0.140)	(2.236)	(0.093)	(0.142)	(0.206)	(-1.623)	(0.853)	(-1.790)	

Table 3: Estimated Parameters of the Conditional Variance Equation for the univariate GARCH models

This table contains the estimated coefficients for the conditional variance equations from the model $R_{i,t} = \alpha_{i,0}(j) + \alpha_{i,1}(j)\text{Lehman}_{j,t} + \theta_{i,1}(j)D1_{j,t} + \theta_{i,2}(j)\text{D2}_{j,t} + \theta_{i,M}\text{DM}_t + \theta_{i,3}(j)\text{D3}_{j,t} + \phi_{i,1}(j)\text{QE1}_{j,t} + \phi_{i,2}(j)\text{QE2}_{j,t} + \phi_{i,M}\text{MEP}_t + \phi_{i,3} + \alpha_{i,2}(j)\text{BoJQE}_t + d_1(j)R_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}(j)|\Omega_{t-1} \sim N(0, h_{i,t}(j))$, and $h_{i,t}(j) = \omega_{i,i}(j) + b_{i,i}(j)\varepsilon^2_{i,t-1}(j) + c_{i,i}(j)h_{i,t-1}(j) + \alpha_{i,3}(j)\text{Lehman}_{j,t} + \gamma_{i,i,1}(j)D1_{j,t} + \gamma_{i,i,2}(j)\text{D2}_{j,t} + \gamma_{i,i,3}\text{DM}_t + \gamma_{i,i,4}(j)\text{D3}_{j,t} + \varphi_{i,i,1}(j)\text{QE1}_{j,t} + \varphi_{i,i,2}(j)\text{QE2}_{j,t} + \varphi_{i,i,M}\text{MEP}_t + \varphi_{i,i,3}(j)\text{QE3}_{j,t}\alpha_{i,4}(j)\text{BoJQE}_t + \mu_i(j)R_{i,t-1}$, where $R_{i,t}$ is daily the return from market i in week t, $i \in$ US,UK,France,Germany,Japan. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} + \alpha_{i,3} + \alpha_{i,4} + \sum\gamma_{i,i,k} + \sum\varphi_{i,i,k} + \mu_i < 1$. The variables $D1_{j,t}$, $D2_{j,t}$ $D3_{j,t}$ are QE phase's dummy variables for the US and the UK. DM_t is the dummy variable for the US MEP. These dummy variables take the value of one during their respective periods and zero otherwise, $j \in$ US,UK. The variables $QE1_{j,t}$, $QE2_{j,t}$ and $QE3_{j,t}$ represents the individual QE operations over the entire QE period by the BoE or the Fed. The variable MEP_t represent the QE operation twist in the US. The variable BoJQE_t represents the period of quantitative and qualitative easing by the Bank of Japan. Below the estimated coefficients in parentheses are t-statistics.

Conditional Variance (all estimated coefficients, except b, c and μ are $\times 10^3$)														
	Const.	GARCH(1,1)		Crisis	QE Phases				QE Operations				BoJ QE	$R_{i,t-1}$
	ω	b	c	α_3	γ_1	γ_2	γ_m	γ_3	φ_1	φ_2	φ_m	φ_3	α_4	μ
UK Quantitative Easing														
UK	0.0018	0.0977	0.8811	0.0259	-0.0067	-0.0081		0.0009	0.0290	0.0224		-0.0003		
	(4.975)	(9.896)	(75.597)	(2.617)	(-1.463)	(-2.229)		(0.124)	(1.755)	(2.206)		(-0.013)		
France	0.0067	0.0407	0.9059	0.0329	-0.0020	0.0008		0.0206	0.0293	0.0176		-0.0420		-0.0025
	(10.343)	(5.428)	(84.308)	(3.599)	(-0.412)	(0.037)		(1.201)	(1.952)	(0.371)		(-0.838)		(-18.131)
Germany	0.0079	0.0487	0.8854	0.0373	0.0000	-0.0115		0.0118	0.0323	0.0512		-0.0236		-0.0019
	(9.543)	(5.787)	(70.529)	(3.349)	(-0.005)	(-0.693)		(1.012)	(2.215)	(1.225)		(-0.731)		(-14.456)
Japan	0.0088	0.0967	0.8524	0.0362	-0.0018	-0.0047		-0.0033	0.0247	0.0114		0.0043	0.0046	-0.0016
	(7.498)	(9.518)	(62.782)	(2.137)	(-0.287)	(-0.663)		(-0.336)	(1.144)	(0.581)		(0.143)	(2.793)	(-10.074)
US Quantitative Easing														
US	0.0025	0.0879	0.8795	0.0465	0.0045	-0.0003	0.0013	-0.0010	-0.0044	0.0007	-0.0029	0.0011		
	(6.384)	(10.132)	(72.430)	(2.788)	(0.933)	(-0.173)	(0.212)	(-1.219)	(-0.323)	(0.374)	(-0.225)	(0.627)		
France	0.0067	0.0428	0.9032	0.0309	0.0048	0.0016	0.0168	-0.0019	0.0176	-0.0015	-0.0201	0.0056		-0.0026
	(10.624)	(5.886)	(87.474)	(3.542)	(1.098)	(0.735)	(1.139)	(-1.443)	(1.159)	(-0.663)	(-0.624)	(2.064)		(-16.287)
Germany	0.0087	0.0472	0.8807	0.0395	0.0015	-0.0016	0.0418	0.0006	0.0417	0.0009	-0.0659	-0.0012		-0.0020
	(9.492)	(5.504)	(66.460)	(3.509)	(0.265)	(-0.659)	(2.223)	(0.354)	(2.218)	(0.322)	(-1.758)	(-0.338)		(-13.455)
Japan	0.0116	0.0967	0.8524	0.0511	0.0005	0.0094	0.0015	-0.0147	0.0241	-0.0115	-0.0016	0.0444	-0.0016	-0.0022
	(9.164)	(9.036)	(70.507)	(2.831)	(0.058)	(1.389)	(0.193)	(-3.180)	(1.037)	(-1.700)	(-0.249)	(5.859)	(0.857)	(-11.416)

Table 4: Estimated parameters for the multivariate DVECH GARCH model of the UK and US equity markets

This table contains the estimated coefficients from the model $R_{i,t} = \alpha_{i,0} + \alpha_{i,1}\text{Lehman}_{i,t} + \theta_{i,1}D1_t + \theta_{i,2,UK}\text{D2}_{UK,t} + \theta_{i,2,US}\text{D2}_{US,t} + \theta_{i,3}(j)\text{D3}_t + \phi_{i,1}\text{QE}_{UK,t} + \phi_{i,2}\text{QE}_{US,t} + d_{i,1}\text{R}_{i,t-1} + \varepsilon_{i,t}$, where $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon^2_{i,t-1} + c_{i,i}h_{i,t-1} + \delta_{i,i}\text{Lehman}_{i,t} + e_{i,i,UK}\text{QE}_{UK,t} + e_{i,i,US}\text{QE}_{US,t}$ and $h_{i,m,t} = \omega_{i,m} + b_{i,m}\varepsilon_{i,t-1}\varepsilon_{m,t-1} + c_{i,m}h_{i,m,t-1} + \delta_{i,m}\text{Lehman}_{i,t} + e_{i,m,UK}\text{QE}_{UK,t} + e_{i,m,US}\text{QE}_{US,t}$. The variables $\text{QE}_{UK,t}$ and $\text{QE}_{US,t}$ are composites of the QE operations variables across all QE phases for that country, while $D1_t$ and D3_t are composites of the first and third QE periods, respectively, across both countries. All other variables are as defined in tables 2 and 3.

Conditional Means (all estimated coefficients, except d_1, are $\times 10^2$)

	Const.	Crisis	QE Phases				QE Operations		$R_{i,t-1}$
	α_0	α_1	θ_1	$\theta_{2,UK}$	$\theta_{2,US}$	θ_3	ϕ_{UK}	ϕ_{US}	d_1
US	0.0237	-0.2315	0.1658	0.2190	0.1058	0.0781	-0.1704	-0.0376	-0.2400
	(1.439)	(-1.314)	(2.309)	(2.373)	(1.835)	(2.155)	(-1.669)	(-0.951)	(-12.681)
UK	0.0353	-0.1859	0.1594	0.1268	0.0223	0.0075	-0.1790	0.0001	-0.0929
	(1.922)	(-1.184)	(1.961)	(1.157)	(0.346)	(0.194)	(-1.577)	(0.003)	(-5.120)

Conditional Variances and Covariance (all estimated coefficients, except $b_{i,j}$ and $c_{i,j}$, are $\times 10^3$)

	Const.		Multivariate GARCH(1,1)				Crisis		UK QE Operations		US QE Operations	
	$\omega_{1,1}$	$\omega_{2,i}$	$b_{1,1}$	$b_{2,i}$	$c_{1,1}$	$c_{2,i}$	$\delta_{1,1}$	$\delta_{2,i}$	$e_{1,1,UK}$	$e_{2,i,UK}$	$e_{1,1,US}$	$e_{2,i,US}$
US	0.0023	0.0015	0.0819	0.0755	0.8885	0.8860	0.0444	0.0295	0.0031	0.0034	0.0004	0.0006
	(6.814)	(5.772)	(10.862)	(9.417)	(89.403)	(74.044)	(2.915)	(2.632)	(1.656)	(1.838)	(0.824)	(1.232)
UK		0.0021		0.0864		0.8851		0.0284		0.0037		0.0009
		(5.557)		(10.062)		(80.326)		(3.034)		(1.688)		(1.375)

Figure 1: Cross-Section Distribution of QE Purchase Activity: UK

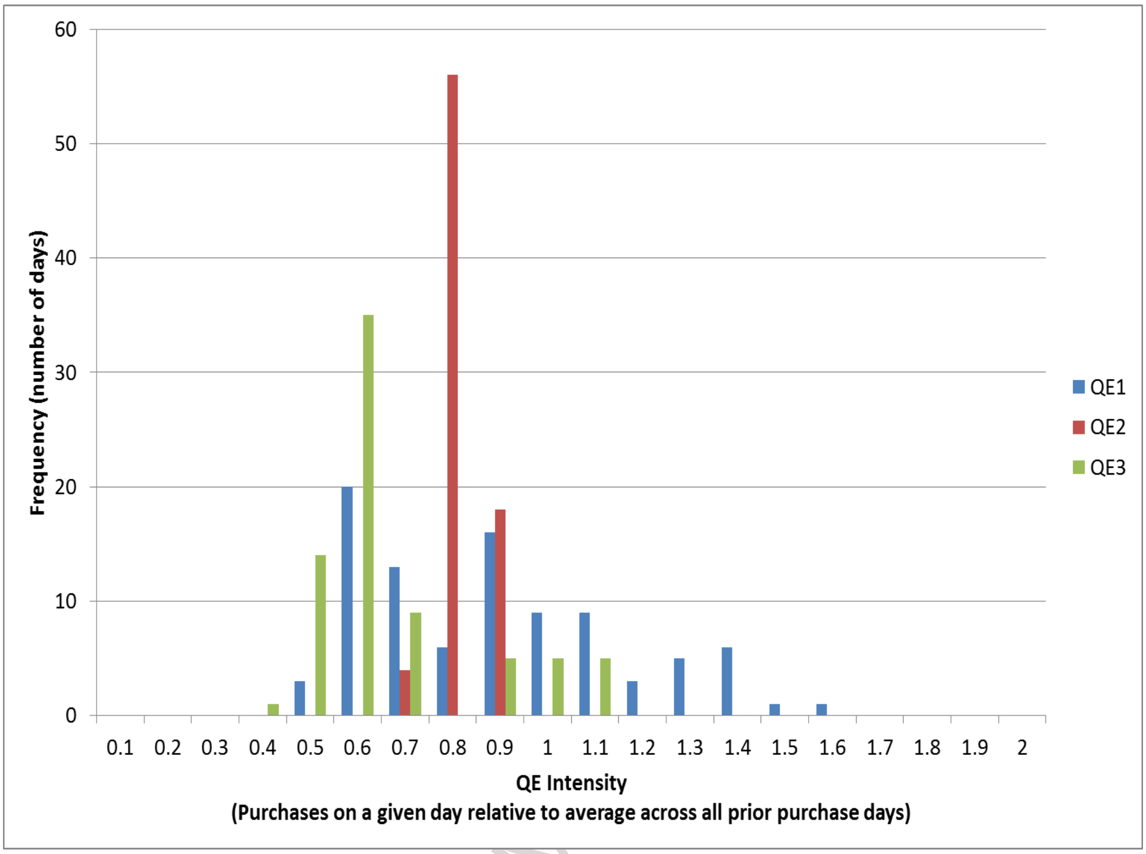


Figure 2: Cross-Section Distribution of QE Purchase Activity: US

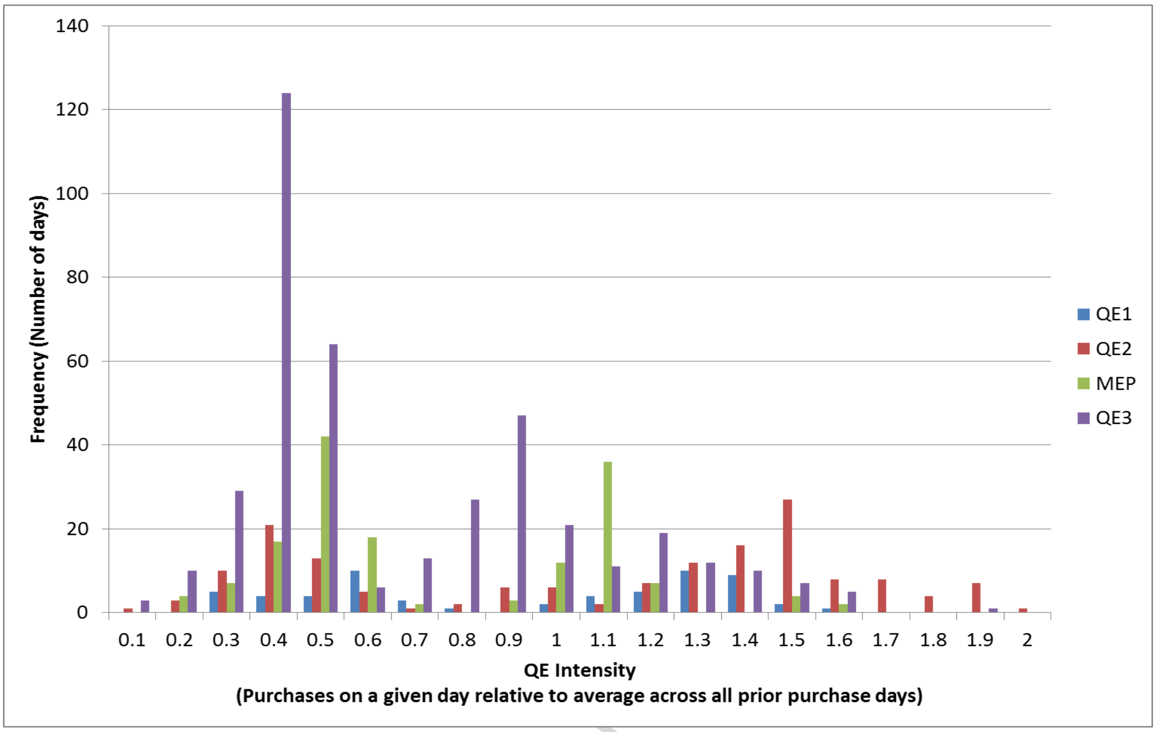


Fig 3: Estimated Conditional Volatility for UK and US Equity Returns Jan.04-Oct.14

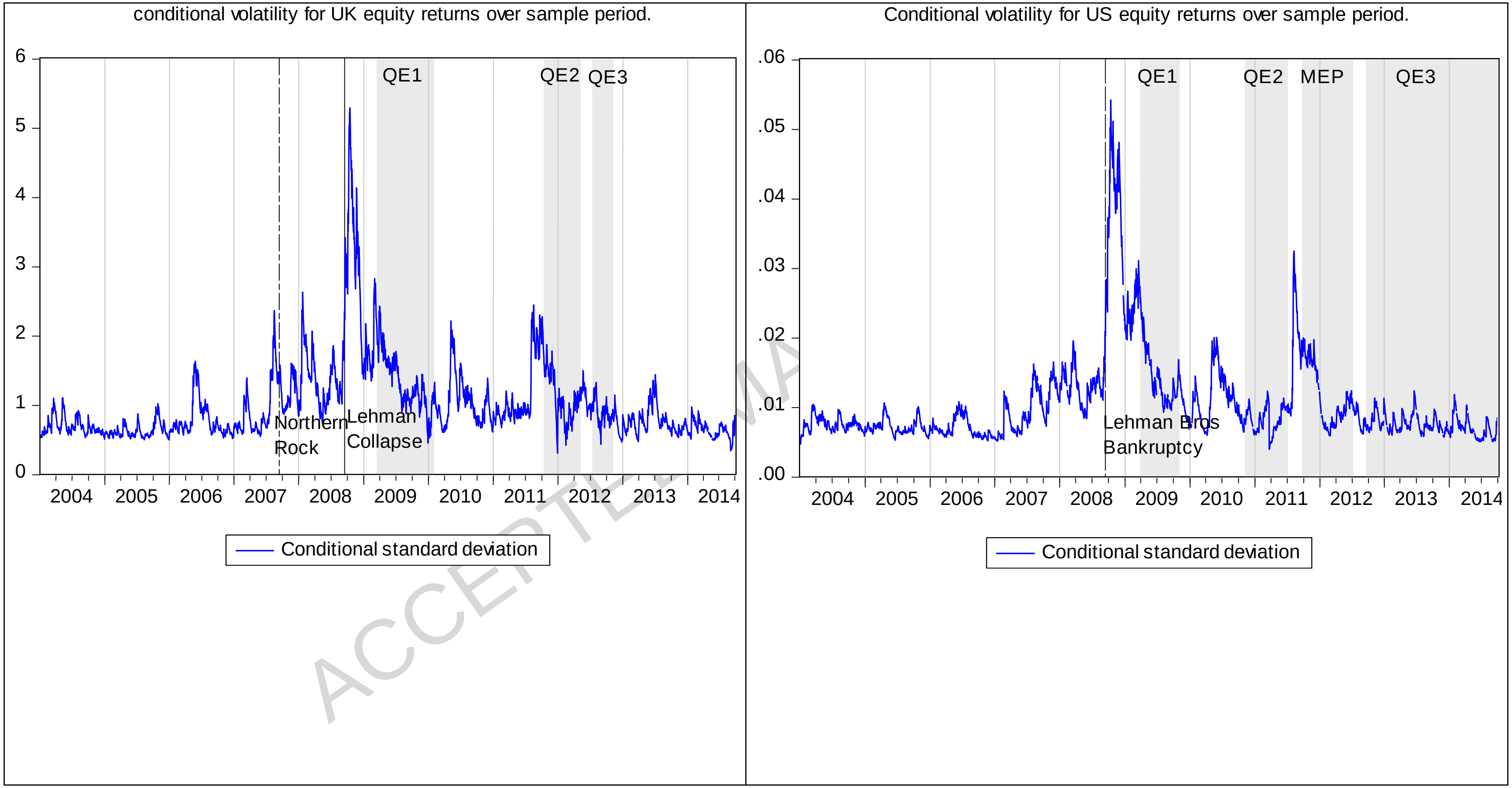
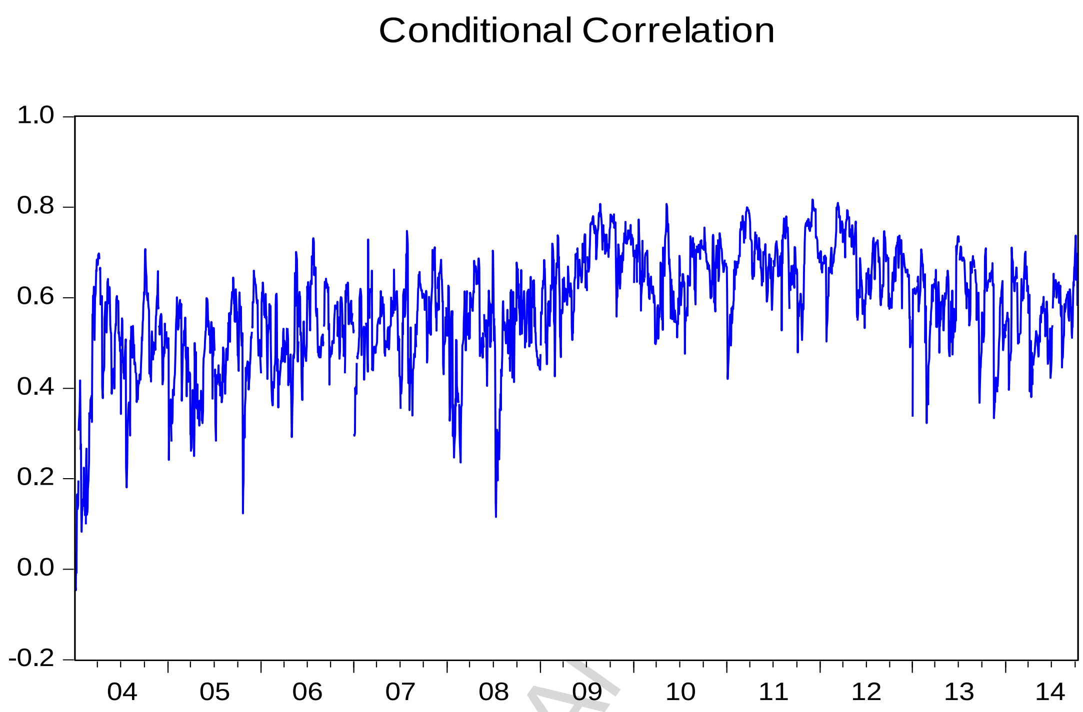


Fig 4: Conditional Correlation for UK and US Equity Returns Jan.04-Oct.14



Highlights

- We model the effects of US and UK QE on the variance – covariance of equity returns
- We examine these effects in the US and the UK and in Germany, France and Japan
- UK QE activity had more significant effects on volatility than US QE activity
- UK QE activity also affected the covariance between the US and UK equity markets
- We attribute these US/UK differences to the differences in the design of QE operations