The Effects of Quantitative Easing on the Integration of UK Capital Markets

by

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JEL: G12, E44, E52

Keywords: Quantitative Easing, Integration, Gilts, UK Bonds, UK stocks, Dynamic correlation

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We examine the effects of quantitative easing on the volatility of and correlation between stocks, short-term bonds and long-term bonds in the UK. Using a multivariate DCC GARCH model, we find that volatility in each of the markets experiences a significant increase during the financial crisis that is reversed during the first phase of quantitative easing. We find limited effects of the specific occurrence or intensity of QE activity on either the volatility or correlations for these asset classes, but some evidence that volatility persistence experienced temporary shifts during the sample period. We find short-term variability in the correlations between the markets during the crisis and quantitative easing periods, but cannot reject the hypothesis that correlations were constant throughout the sample period.

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1. Introduction

The contagion of asset return volatility across and within countries during times of stressed market conditions was first highlighted by the experience of the world-wide downturn in equity prices in October 1987. King and Wadhwani (1990) found that the correlation between market movements in different countries and general levels of volatility were positively related. Understanding the evolution of the correlations between financial assets is fundamental to establishing the limits of diversification, to security pricing, and to successful asset allocation. This study seeks to explore the effects of the recent financial crisis and the subsequent phases of quantitative easing on the correlations between the core asset classes in the UK financial markets.

In this study, we use a GARCH modelling framework to examine the interdependence between stock, short term bond and long term bond volatility. In particular, a multivariate framework is employed that permits a dynamic correlation structure between the three markets. Included in this dynamic structure are indicator variables for the different phases of the financial crisis and QE, variables representing monetary policy changes and activity and the intensity of QE activity in particular. We document significant increases in volatility in the markets starting from the Northern Rock bank rescue in September 2007 and that are further boosted following the collapse of Lehman Brothers in August 2008. We find that these changes are mostly reversed by the end of the first period of QE, except in the case of short term bonds. By contrast, we do not find such dramatic evidence that QE activity significantly altered the correlation structure between the three asset classes. Indeed, after controlling for the effects of QE on the conditional variances, the conditional correlations display a remarkable stability during the recent past. This is in contrast to the dramatic changes in these correlations observed during the aftermath of the Asian crisis and the dot.com boom and reported in an earlier study by Steeley (2006). Although, our time varying correlation structure does permit daily variation in the correlations between the asset classes during our sample period, this variation is not sufficient to reject a model of constant correlation. Therefore, we are unable to conclude that the variability in correlation that occurred during the crisis and QE phases was in excess of sampling variation around a constant long run correlation level between the asset classes. Therefore, the crisis and QE did not change the level of integration within UK capital markets.

The remaining sections of the paper are as follows. Section 2 provides a brief introduction to related literatures on the correlation between asset classes, the effects of monetary policy on different assets classes and the effects of quantitative easing on asset prices. These establish the context and provide some background for our study 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, summary statistics for the data are reported, along with an analysis of the estimated coefficients of the GARCH models. Section 5 contains a summary and offers some conclusions.

2. Review of related literatures

2.1 Asset market correlations

Studies of the interdependence of asset markets were facilitated 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). 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 observed asymmetric volatility relations between the financial markets of the USA, the UK and Japan, where the influence of negative shocks was different in both scale and direction to positive shocks. Bekaert and Wu document volatility asymmetries in the equity markets of a wide range of countries. Berben and Jansen (2005a) pioneered the use of time varying correlation structures within the MV-GARCH to study changes in the level of international integration of equity markets. Carrieri et al (2007) argue, however, that correlation is likely to be a conservative measure of international financial market integration.

Recently, the literature on equity market cross correlations has explored the economic mechanisms that might lie behind the observed empirical phenomena. Connolly et al (2007) relate high correlations to high levels of uncertainty, while Brunnermeier and Pedersen (2009) link correlations to sudden drops in market liquidity. Barberis et al (2005) suggest that investors' habitats can generate cross correlations as groups of investors trade similarly. Such herding behaviour can be driven by sentiment, for example, Kumar and Lee (2006). Chordia et al (2011) find that herding by retail investors during market downturns can cause higher stock correlations. Veldcamp (2006), Brockman et al (2010) and Höchstötter et al (2014) trace correlations to commonality of news releases and information collection. By contrast, Dungey and Martin (2007) and Dungey et al (2010) model contagion using a latent factor model approach.

While bond markets have been the setting for some of the key developments in GARCH methods, such as the ARCH-M model (Engle et al, 1987) and the Factor-ARCH model (Engle et al, 1990), the application of these methods to the study of inter bond market correlations has been more recent. Christiansen (2007) examined volatility spill-overs from a US and an aggregated European bond index to individual European bond markets, and documented increased spill-over effects arising from the adoption of the Euro. Skintzi and Refenes (2006) and Berben and Jansen (2005b) undertake similar studies and permit the correlation between the bond markets to be time-varying, using the smooth transition model introduced by Berben and Jansen (2005a). More recent papers, which exploit the properties of asset pricing models to model European bond market integration, include Abad et al (2010,2013), that latter of which documents an increase in segmentation of international bond markets between 2007 and 2009.

By contrast to the large literature examining the international transmision of equity market volatility, and the more recent literature examining the international transmission of bond market volatility, there are relatively few studies considering the correlation between asset classes. Anderson and Breedon (2000) documented significant volatility spillovers from equities to bonds in the UK, but not in the reverse direction. Dean et al (2010) present similar evidence for Australia, documenting stronger effects on bonds for negative shocks to equity and also evidence of spill-overs from the bond market to equities. Steeley (2006) found that past long-term bond volatility has a significant effect on current volatility of short-term bonds, long-term bonds and the current volatility of the FTSE 100 stock market. He also found that correlation between the stock market and the bond market changed sign from positive to negative following the post-Millenium stock market downturn. 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. More recently, Johansson (2010) examined asset markets in both the Asia-Pacific region and Europe, and found that 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 also uses the DCC framework but has threshold changes that depend on the transition through certain time periods corresponding to the crisis and the phases of quantitative easing.

2.2 Monetary policy announcements and asset markets

The literature on the effects of conventional monetary policy announcements on equity markets has a long history. Early contributions include Sprinkel (1964), Palmer (1970), Homa and Jaffee (1971) and Hamburger and Kochin (1972) for the USA and Saunders and Woodward (1976) for the UK. The early US studies found that money supply changes were not immediately transmitted to stock market prices, while the UK study found the opposite result. This literature then grew to encompass many forms of macroeconomic news announcements, for example, Brealey (1970), Goodhart and Smith (1985), Cutler et al (1989) and Wasserfallen (1989). Recent contributions to the literature relating conventional monetary policy surprises and other macroeconomic news on returns in stock and bond markets and volatility in stock markets both within and across countries include, Jones et al (1998), Balduzzi et al., 2001, Bomfim, 2003, Ederington and Lee, 1993, Graham et al., 2003, Kearney and Lombra, 2004, Nikkinen and Sahlström, 2001, 2004a, 2004b, 2006, De Goeij and Marquering (2006), Brenner et al (2009), Nowak (2011) and Abad and Chulia (2013).[1] This recent study, which focusses specifically on monetary surprises, finds that (conventional) monetary policy surprises increase bond market volatilities, but that the correlations between markets depend on the source and sign of the surprise. Brenner et al (2009) find that US macroeconomic surprises are reflected in changes in volatility and cross correlations among asset classes and document asymmetric responses. 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 key asset classes in the UK.

2.3 Quantitative Easing

The term "quantitative easing" (QE) is used to describe the Bank of England's programme of expansionary monetary policy through asset purchases funded by electronic money creation. The recent financial crisis that, in the UK, first came into sharp focus with the run on Northern Rock bank in September 2007, led ultimately to a lowering of the short term interest rate – the

1. This is a very small selection from a vast literature that to review would encompass an entire paper in itself.

instrument of (conventional) monetary policy – from 5 percent to 0.5 percent between October 2008 and March 2009. As early as January 2009, the Bank of England announced its attention to establish an asset purchase facility, and the asset purchases began two days after the reduction in the base rate from 1 percent to 0.5 percent in March 2009. The first phase of quantitative easing, QE1, lasted until January 2010 and saw £200 billion spent to purchase assets, mostly government bonds ("gilts"). By the end of QE1 40% of the stock outstanding of 3-10 year maturity bonds were purchased, 50% of the 10-25 year maturity bonds, and 15% of the more than 25 years maturity bonds were purchased. Other assets such as commercial paper and corporate bonds were also purchased by the Bank but in significantly smaller quantities, and these were being sold back into the market by December 2009. At the meeting of the Monetary Policy Committee held on the 4th of February 2010, the members decided not to increase the limit for asset purchases further. In October 2011 the second round of quantitative easing began (QE2) after the members of the Monetary Policy Committee voted to increase the limit of asset purchases further by £75 billion. A further increase of £50 billion was announced in February 2012 and the purchases were accomplished by the 2nd of May 2012. After only a two-month gap the QE asset purchase facility was restarted again. On the 5th of July 2012, the MPC announced a further £50 billion of gilt purchases, to be completed by November 2012, this phases being identified as QE3.[2]

Determining the effects of quantitative easing on the correlation between asset classes is not only important for investors, but is also fundamental to understanding whether quantitative easing is operating successfully. Quantitative easing has three main channels through which it can affect the economy. The first is a signaling channel. The use of QE demonstrates a commitment to low interest rates and monetary easing more generally, and this is likely to boost investment and consumption. The second is a liquidity channel. In this case, the purchases of gilts from the banks, by the Bank of England, enhance their reserve levels, that should then facilitate greater lending to commercial activity. The third channel is a portfolio balance channel, whereby the purchases of gilts may lead to an increase in asset prices, which leads to both wealth effects and lower costs of capital, that in turn boosts the economy through increased investment and consumption. As well as the direct upward pressure on gilt prices that may arise from the Bank's purchases, there can arise an additional "ripple effect" to increase the prices of other assets if the sellers of the gilts do not regard the cash received as a perfect substitute for the gilts sold, and use the cash to purchase other assets. This process may continue until all asset prices have been bid

1. Although the QE2 and QE3 phases have been separately distinguished in some recent survey papers, Joyce et al (2012) and Martin and Milas (2012), the short gap between them may mean that this distinction is not preserved in the future.

upwards to rebalance asset portfolios to accommodate the increased cash balances.[3] The success or otherwise of the ripple effect of quantitative easing must, therefore, depend on the correlation between the returns among different asset classes, which will reflect their degree of substitutability.

While there have a been a number of studies of the effects of QE on the prices and yields of various UK asset classes, for example, Meier (2009), Joyce et al (2011), Glick and Leduc (2011), Meaning and Zhu (2011), Joyce and Tong (2012), Breedon et al (2012) and Martin and Milas (2012), these in common with studies of the effects of US quantitative easing have focused mainly on the effects on prices and returns. An exception is Tan and Kohli (2011) who examine the volatility of the US stock market over the period 2008 to 2011, which encompasses 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.

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. In this study, we will extend and refine this earlier work in a number of important dimensions. First, we will consider all three phases of QE as well as the periods before, between and afterwards. This will enable us to see if QE has common effects on asset correlations, or whether each phase had distinct effects. Second, we will use data observed at daily intervals, rather than

3. See Benford et al (2009) for more detail on how each of these QE transmission channels operates.

monthly frequency, to better identify the evolution of the correlations within each of the phases of QE, which typically last for only a small number of months. Third, we augment the conditional variance and conditional correlation specifications with variables that can isolate the effects of the transitions of the markets through the crisis period and the phases of QE. Fourth, we consider the impact of specific monetary actions in both the conditional variance and conditional mean specifications of our model. These include the announcement of the results of the monthly MPC meetings, the occurrence of QE activity and the intensity of that activity. Overall, our paper offers substantial contributions to several existing literatures.

3. Modelling Capital Market Integration

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 three markets.[4] Specifically, the basic model is

$$R_{i,t} = \alpha_{i,1} + \alpha_{i,2}\mathrm{MPC}_t + \alpha_{i,3}\mathrm{APFday}_t + \alpha_{i,4}\mathrm{QEInt}_t + \alpha_{i,5}\mathrm{IndexChg}_t + \sum_{k=1}^{5}\sum_{i=1}^{3}\beta_{i,k}R_{i,t-k} + \varepsilon_{i,t} \quad (1)$$

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

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1} + \sum_{j=0}^{3} g_{j,i,i}D_{j,t} + \gamma_{i,i,1}\mathrm{MPC}_t + \gamma_{i,i,2}\mathrm{APFday}_t + \gamma_{i,i,3}\mathrm{QEInt}_t \quad (2)$$

where $R_{i,t}$ is daily the return from market i in week t, and the $i = 1{,}2{,}3$ markets are the short term bond market, the long term bond market and the equity market. The information set, Ω_{t-1}, includes all information known at time $t-1$, and $\omega_{i,i} > 0$, $b_{i,i}, c_{i,i} > 0$, $b_{i,i} + c_{i,i} + \sum_{j=1}^{4} g_{j,i,i} + \sum_{j=1}^{2}\gamma_{i,i,j} < 1$. Autoregressive terms comprising up to five lags of past returns in each market are included to control for coefficient bias or inefficiencies arising from any autocorrelation or cross autocorrelation in the returns. As first observed by Fisher (1966), index returns will be characterized by autocorrelation where the component asset returns respond with different speed

4. See also the survey paper by Bollerslev et al. (1992).

to new information. The regularity of both conventional and unconventional monetary policy activity suggests that including dummy variables to account for this is also desirable. Specifically, announcements of changes to UK monetary policy are made at the conclusion of the monthly meeting of the Monetary Policy committee, which is invariably on a Thursday. The reverse auctions that were used by the Bank of England for the purpose of buying bonds during the phases of QE were also clustered on particular weekdays. Figure 1 shows that these purchase auctions took place mostly during the first half of the week, with particular clusters on Mondays and Wednesdays. The variable MPC_t takes the value 1 on the days that the Monetary Policy Committee announced the outcomes of their monthly meetings, and takes a zero value on all other days. The variable APFday_t takes the value 1 on the days on which the Bank of England undertook the reverse auctions that comprised the mechanism for the Asset Purchase Facility (APF) established to conduct quantitative easing. This variable is zero on other days.

The variable $\mathrm{IndexChg}_t$ controls for the effects of changes to the constituents of the two bond indices. These are most acute for the short term bond index. As most UK bonds now reach their maturity date on one of four dates, March 7, June 7, September 7 and December 7, it is possible that on each of these dates a bond may have to leave the short term bond index. To accommodate this, and also additions when a medium term bond's maturity falls under 5 years, the index constituents are changed seven working days before the bond maturity dates. These changes generate a blip in the bond index data, most noticeable for the short term index, as can be seen clearly in Figure 2. This effect can be controlled by placing a dummy variable into equation (18) that takes the value 1 on the days that the index constituents are changed, and zero otherwise.

The form of the variance equation in equation (19) 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 four exogenous dummy variables. 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 sum, $b+c$, measures the degree of persistence in the conditional variance process.

The variance equation (19) includes four dummy variables designed to capture the financial crisis period in the UK ahead of the start of QE, and each of the three phases of QE. Thus, $D_{0,t}$ takes the value 1 from the day of the Northern Rock rescue on September 14th, 2007 until the day before the start of the QE1 asset purchases, March 10th 2009, and is zero otherwise. $D_{1,t}$ takes the value 1 during QE1, from 11th March 2009 until 26th January 2010, and is zero otherwise. $D_{2,t}$ takes the value 1 during QE2, from 10th October 2011 until 2nd May 2012, and is zero otherwise. $D_{3,t}$ takes the value 1 during QE3 from 5th July 2012 until 31st October 2012, and is zero otherwise.

While these dummy variables account for the effects of the broad phases of QE and the pre-QE crisis period, they do not directly measure the local impact on variability of QE activity. To accomplish this, we introduce a variable to measure the intensity of QE activity on a particular day. Almost all of the assets purchased by the Bank of England were gilts, UK government bonds. Although some forms of commercial paper were purchased, on a very small scale, these were being sold back into the market by December 2009. So, to measure QE intensity, we focus on the purchase of gilts by the Bank of England. Figure 3 shows the accumulated purchase activity in gilts, measured at the end of each month, and relative to the QE upper boundary. This shows that there was little room for other purchase activity given how close the accumulated gilt purchases came to the upper limits established for QE activity. The details of gilt purchases are available from the Bank of England's public data archives and we use these to construct our measure of QE intensity. In particular, for a given day, on which several different gilts may have been purchased, we identify the amount of each gilt that was purchased. To measure intensity, we take the ratio of the purchased amount for the bond to its outstanding issue size (both in terms of face value). The issuance data was collected from the public data archives of the UK Debt Management Office. We then average this ratio across all bonds that underwent a reverse auction on that day to create the intensity measure for that day. The variable QEInt_t is this measure of intensity and is included in both the variance specification (equation 2) and, as an additional control measure, in the mean equation (equation 1).[5] By the end of QE1, the median ownership share of gilts by the Bank of England was just under 30 percent of the outstanding issue, with some gilts having more than 60 percent of their outstanding issue owned by the Bank of England. These statistics increased slightly by the end of QE3. The cross section variation in ownership

5. Although the intensity measure is correlated with the APFday_t variable, approx. 76%, the statistical significance of the intensity measure is not qualitatively changed by the inclusion of both variables in the model.

shares of gilts by the Bank of England is depicted in Figure 4 for each of the QE1, post QE1 and QE2/3 periods.

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 markets however, and how this has been affected by QE, it is necessary to estimate the three 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 would generate around 50 parameters within even the most basic GARCH(1,1) specification. We use the dynamic conditional correlation (DCC) model proposed by Engle (2002), which reduces considerably the number of parameters to estimate, yet permits time varying correlations.[6] In this case, the conditional variance processes remain as specified in equation (2) while the covariance processes are specified as

$$h_{i,m,t} = q_{i,m,t} \sqrt{h_{i,t} h_{m,t}} / \sqrt{q_{i,t} q_{m,t}} \tag{3}$$

where, $q_{i,t}$ and $q_{i,m,t}$ are, respectively, the diagonal and off-diagonal elements of a quasi-correlation matrix, Q, that as a whole follows a "GARCH(1,1)" process, depending on just two parameters a and b, such that the diagonal elements are given by

$$q_{i,t} = (1 - a - b) q_{0,i} + a \varepsilon_{i,t-1}^2 + b q_{i,t-1} \tag{4}$$

and the off-diagonal elements are given by

$$q_{i,m,t} = (1 - a - b) q_{0,i,m} + a \varepsilon_{i,t-1} \varepsilon_{m,t-1} + b q_{i,m,t-1} \tag{5}$$

While this models permits the correlation between the markets to change through the sample period, and so through the phases of QE, it does not directly model the impacts of QE on the correlation since these effects are operating only through the variance processes, equation (2). An advantage of the DCC model is that it is possible to identify the effects of QE on the dynamic

6. In an earlier draft of the paper, we used a diagonal VECH (rank 1) model, which directly models the covariances rather than the correlations. The results regarding impacts of QE events and activities obtained from the VECH model were similar to those reported here for the DCC model. Caporin and McAleer (2013) have argued that the diagonal VECH (rank 1) model is indistinguishable empirically from the DCC model in small systems. We see this in our application also.

correlation process by including the variables for the phases of QE, monetary policy changes, specific QE activity and QE intensity, directly into the correlation process, equation (5). That is, we augment equation (5), as

$$q_{i,m,t} = (1-a-b)q_{0,i,m} + a\varepsilon_{i,t-1}\varepsilon_{m,t-1} + bq_{i,m,t-1} + \sum\nolimits_{j=0}^{3} g_{j,i,m}D_{j,t} + \gamma_{i,m,1}\text{MPC}_t + \gamma_{i,m,2}\text{APFday}_t + \gamma_{i,m,3}\text{QEInt}_t\,, \qquad i \neq m \tag{6}$$

To ensure that the additional variables in equation (6) are able to detect effects on correlation, without these effects being gathered up by the QE variables in the variance equation, equation (2), we also examine the model in (6) using the variance specification in (2) that has had the QE variables excluded.

While the motivation of the paper is to determine how the correlation, representing integration, between the markets has changed through the experience of QE, it is also possible that it has remained unaltered. To determine whether this is the case, we compare the results from the DCC model to the constant conditional correlation model proposed by Bollerslev (1987). In this model, the conditional covariances are restricted by a constant correlation coefficient to be of the form

$$h_{i,m,t} = \rho_{i,m}\sqrt{h_{i,t}h_{m,t}} \tag{7}$$

where $\rho_{i,m}$ is the constant correlation coefficient between the returns in markets i and m. To test which model is preferred, and so establish whether the time-variation in correlation is significantly different from sampling variation around a constant long run correlation, we use the Vuong Closeness Test, Vuong (1989). This is a likelihood ratio based test using the Kullback-Leibler information criterion.

The sum of the coefficients $b+c$ in the variance equation measures the persistence of the shocks to the variance process. It is possible that this persistence has changed through the sample period and may have altered, albeit temporarily, during the phases of QE or the pre-QE crisis period. We draw on the test of parameter constancy in GARCH models of Chu (1995)[7] and augment the variance model in (2) as follows,

6. Diebold (1986) and Lamoureux and Lastrapes (1990) had earlier recognized the importance of the possibility of changing persistence in GARCH models.

$$h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1} + \sum_{j=0}^{3} g_{j,i,i}D_{j,t} + \sum_{j=0}^{3} \varphi_{j,i,i}D_{j,t}\varepsilon_{t-1}^2 + \gamma_{i,i,1}\text{MPC}_t + \gamma_{i,i,2}\text{APFday}_t + \gamma_{i,i,3}\text{QEInt}_t \quad (8)$$

where now the sum of the coefficients measuring the persistence, $b + c + \varphi$, can change as the variance process passes through the crisis period and the three phases of QE. For completion, we also apply this same extension to our model of the time varying correlation process.

4. Data and Results

Daily closing observations on the FTSE-100 share price index (FT100), to represent stock returns, the index of prices of long term (more than 15 years to maturity) Government Stocks (FTLG), representing the return on long term bonds, and the index of prices of short term (less than 5 years to maturity) government stocks (FTSG), to represent short-term yields, were obtained for the period January, 5 2004 – June, 9 2014, providing some 2635 trading day observations for each series. Returns series are calculated as log differences in the respective price index.[8]

Table 1 contains summary statistics for the returns series in each of the markets. The average growth in the long term gilt-edged market over the sample period was positive and represents an annualised rate of about 1.78 percent, while the short term gilt index showed an average annualised growth rate of -0.80 percent.[9] The average growth rate on the FTSE 100 share index over the sample is an annualised rate of 4.11 percent. The equity return series has the greatest standard deviation, and the estimates reflect the well understood differences in risk between the three markets. The distribution of the long term gilt returns series is more symmetric and less leptokurtic than the equity returns series, while the short term gilt series also displays high kurtosis. These higher moment findings echo those found in the earlier study by Steeley (2006) for the period 1984 to 2004 indicating a long term stability in the relative magnitudes of higher moments of the returns to stocks and bonds in the UK.

In the short term bond series, there is little evidence of significant autocorrelation. By contrast in both the long term bond series and the equity market series, there is significant

8. The data are obtained from Datastream, codes FTSE100, FTBGSHT, FTBGLNG.
9. This negative annualized return for the short bong index is being driven by the index change distortions, see Figure 2. Without these days, the mean return to the index is positive and the kurtosis reduces to around 6.

evidence of autocorrelation in returns at all lags out to 4, and some beyond. Although statistically significant, the magnitude of the autocorrelations are small and vary in sign. The cross serial correlations indicate that past movements in short term interest rates affect the long term gilt-edged market, but do so in the opposite manner to what might be expected given well understood theories regarding the forward-looking behaviour of long term bond yields. The autocorrelation coefficient is, however, small and the sign may reflect a possible segmentation in the market caused by the anchoring of short term yields to the near zero lower bound from the beginning of QE1. It could also be being affected by the index change days.

A returns series that has either a changing conditional or unconditional variance will exhibit high levels of autocorrelation among its squared and absolute returns. Autocorrelation of this type suggests that large absolute returns are more likely to be followed by large absolute returns than by small absolute returns. This variance clustering, first identified in US equity returns by Fama (1965), also generates excess kurtosis in returns as seen in both the short bond and equity indices. There is evidence of significant autocorrelation in the squared returns both of the equity and long bond indices. Together, with the excess kurtosis statistics, there is strong reason to suspect that all three series may exhibit changing variances.

Maximum likelihood estimates of the parameters in equations (1) and (2) were obtained using the Levenberg-Marquardt algorithm, which combines the Gauss-Newton method with a gradient descent method, Levenberg (1944) and Marquardt (1963). The coefficient estimates are reported in Table 2. The coefficients that capture autocorrelations and cross serial correlations in the returns series present stronger evidence of relationships between the three markets than was apparent from the autocorrelation statistics in Table 1. Again these identify some short term negative relationships between the returns to short and long term bonds, now in the presence of a control for the changes in the bond index constituents. The dummy variable that captures the effect of bond maturity changes on the constituents of the bond indices is strongly significant for both of the bond index series.

There is no significant effect on either bond or stock index returns of the announcement of the results of the monthly MPC meetings. This is due to the likelihood that for most of the sample period, the monthly announcement has been one of no change and that this has been very well anticipated. Any anticipated effects of the bond auction days themselves on the bond indices are also found to be insignificant, again consistent with such effects being well anticipated. By contrast, the days of bond auction activity appear to have a significant effect on the stock market index returns. This interrelationship between the two markets is consistent with a portfolio balance effect operating across the two markets on these days. Intriguingly, the effect observed in the equity market is negative, possibly suggesting that funds were being withdrawn from the equity market to purchase other (non-equity based) substitutes for the gilts being sold into the reverse auctions It is also possible that the reverse auctions, as a direct manifestation of QE, were viewed as a signal of the continuing economic difficulties and caused drops in equity prices on these days. The variable measuring the intensity of QE activity on a particular day is also not significant for either of the bond index returns, but does show some weak significance for equity returns. The sign of this variable is positive, suggesting that the intensity of QE, has some offsetting effect for the otherwise observed negative impact on equity returns.

The estimated conditional variances of the returns for each of the three markets are shown in Figure 5, where changes during the financial crisis and then through the phases of QE can be seen clearly. It can also be seen that for both short term bonds and the FTSE 100 index that volatility had begun to rise in the three months ahead of the Northern Rock rescue, but until that point had not exceeded the peak levels observed over the preceding four years. For both short and long term bonds, the collapse of Lehman Brothers, at the time the fourth biggest investment house in the world, in August 2008 led to further increases in the volatility, particularly for the long term bond index. While long term bond volatility did not decline until the start of QE1 in March 2009, both equity volatility and short term bond volatility had begun to decrease earlier during the first quarter of 2009. By the end of QE1, each of the market's volatilities had fallen back to levels not much above those seen pre-crisis. Between QE1 and QE2, volatility in each of the markets experienced further instability and peaks, with both long term bonds and equities experiencing rises in volatility ahead of QE2. Since QE3, volatility in each market appears little different to the pre-crisis levels.

The parameters of the variance processes indicate that all the volatility series are highly persistent. The variable that captures differences during the period between the Northern Rock rescue on September 2007 and the start of QE1 in March 2009 is highly significant for all three markets volatility series. This indicates that the financial crisis coincided with a significant increase in the volatility in both the bond and stock market in the UK. However, the periods of QE do not show a significant increase in volatility above the pre-crisis level. This confirms the impression from the graphs in Figure 5, that the QE periods saw volatility in these markets return to pre-crisis levels. The announcement of the results of the MPC meetings does seem to have some impact upon the volatility of returns, for the short term bond index (weakly positive) and for the equity index returns (negative). In addition, the days of reverse auctions appear to cause a significant drop in the volatility of short term bonds. For the first 5 months of QE1, the gilts that could be purchased had to have a maturity in excess of 5 years. The drop in volatility on these days in the short term bond index is likely due to these bonds being marginalized by market participants on days when other (longer term) bonds were part of the reverse auction process. No additional effect relating the intensity of QE to volatility is found for any of the three return indices. Diagnostic statistics indicate some remaining autocorrelation in the squared residuals of just the long term bond index returns. Alternative specifications, with different lag specifications among either the past returns in equation (1) or the past squared residuals in equation (2), were unable to eliminate this remaining autocorrelation.

The correlations between the standardized residuals from each of the three models are reported at the base of Table 2. The correlation between the short and long term bonds is 0.725, indicating an expected positive long run relation between these two markets consistent with the expectations hypothesis of the term structure of interest rates. By contrast, bond indices are negatively correlated with the equity index, with the longer term bonds show a greater negative correlation coefficient. These indicate that there may have been some hedging possibilities between the two markets during the sample period. To determine whether this long run correlation exhibited significant short run variation, we now examine the results of the multivariate DCC GARCH model that can identify time variation in the correlations between the markets.

In Table 3, Panel A, the estimated coefficients are reported for the multivariate DCC version of the GARCH model that estimates the parameters of (1) and (2) for each market together and also specifies the covariance structure between the three markets, equations (3), (4) and (5).[10] Since, the parameter estimates for variables that are common to the models in Table 2 are very similar to those obtained there, and retain the same interpretations, this discussion will focus on the estimated covariance and correlation structures. The multivariate model does, however, suggest that the conditional variance of the short term bond index remained significantly above

10. The parameters of the DCC process in Table 3, and the event-augmented DCC processes reported in Tables 4 and 5, are obtained using the two-step estimation procedure developed in Engle (2002) and Capiello et al (2006).

its pre-crisis level throughout the phases of QE, a feature not detected by the corresponding univariate model.

The correlation processes are all highly persistent. The estimated dynamic conditional correlations, along with the conditional variances – which are very similar to those in Figure 5, are show in Figure 6. The dynamic correlations exhibit fairly limited fluctuations around the fixed levels calculated from the correlations between the standardized residuals from the univariate GARCH models, reported at the base of Table 2. The correlation between long term bond returns and both the short term bond returns and the stock index returns both appear to decline during the summer of 2007, but stabilize following the Northern Rock bailout. Only the correlation between the long term bonds and the stocks shows a reaction to the Lehman collapse. This effect is also present in the correlation between stocks and short term bonds, which also dips following the Lehman collapse. Overall, however, there is little evidence from the graphs that the conditional correlations were strongly affected by the crisis and QE phases.

The results in Table 4, which reports on the DCC model that has the correlation processes augmented by the variables capturing QE related events and phases, broadly support the impression obtained from the graphs.[11] When there are also QE variables present in the conditional variances, there are no significant effects of any of the QE variables on the dynamic correlations between the asset classes, suggesting that the crisis and QE did not change the correlation structure between these three asset classes. Only when QE variables are removed entirely from the conditional variance process is there any sign of the correlation processes detecting a significant effect. For the correlation between both the stock index and either of the bond indices, there is a significant negative effect (only weakly with the long bond index) of the financial crisis (pre-QE1) period. This is picking up the decline detected in the graphs that actually commenced prior to the Northern Rock bailout.

While there is clear evidence that the correlations between the three indices experienced temporary variations during the crisis and QE, they also appear to have returned to pre-crisis levels thereafter. It is possible that, while dramatic visually, these changing correlations are not significant departures from a long run constant correlation. To assess this possibility, the

11. In Tables 4 and 5, we report only the parameters that are new to the particular specification. This is to save space and because the other parameters are either very similar or the same (because of the two-step estimation process) as those in the Tables 2 and 3.

multivariate GARCH is re-specified with a constant correlation structure, equation (7), and the parameters re-estimated. The estimated parameters are given in Panel B of Table 3. The variance processes are again highly persistent, with a positive effect for the period of the financial crisis ahead of the start of QE. For this model, the continuing significant increase in volatility for short term bonds, seen also in the DCC model in Panel A of the table, is also present here. The estimated correlation coefficients are very similar to the estimates obtained from the univariate models in Table 2, with a significant positive correlation between the two bond indices, 0.729, and significant negative correlations between the equity and bond indices, -0.319 for the short term bond index, and -0.270 for the long term bond index. Using this specification, however, we do identify an effect of QE intensity. For the short bond index, the volatility increases on days of QE activity, the greater is the amount of QE undertaken on that day. The log-likelihood for this model is slightly better than for the DCC model, in Panel A, but the Schwartz Bayesian Information Criterion is less negative, suggesting that the DCC model is preferred. Since these differences are small, we formally test the difference between the two models using the Closeness Test of Vuong (1989). We obtain a test statistic value of 0.263 that indicates that there is no significant differences between the two models, ($p>0.38$). Therefore, we cannot conclude from this evidence that the financial crisis or the subsequent actions of QE significantly disrupted the correlation and, hence integration, of stocks and bonds in the UK.

We undertake, however, one further set of robustness checks of this conclusion, by examining whether the persistence of shocks to either the variance or correlation processes displays any instability relating to the phases of QE. To isolate the effects of QE on variance persistence, and because we cannot reject a constant correlation model in favour of a changing correlation model, we maintain a constant correlation while allowing the variance persistence to change. In Panel A of Table 5, we find that only the persistence of the volatility of the long bond return index displays any significant effect. Specifically, during the pre-QE1 phase, the persistence increases significantly ($p<0.01$). We can obtain a clearer picture of the impact on volatility persistence by calculating the half-life of a shock to the variance process, that is, the time it takes for half of the shock to have dissipated. The half-life may be calculated by $\ln(0.5)/\ln(b + c + \varphi)$. For the long bond index volatility, the half-life of a shock to volatility increases by 40 days during the period from the Northern Rock bailout to the commencement of QE. Once QE is activated, the persistence of volatility of long bonds returns to its pre-crisis level.

Augmenting the processes for the dynamic conditional correlations in a similar manner, we find significant effects in the persistence of shocks to the correlation between the FTSE index returns and the other two index returns. These results are reported in Panel B of Table 5. In both cases, the persistence of shocks to the correlation processes is reduced relative to the pre-crisis period. During the pre-QE1 phase, the half-life of shocks to the correlation between the FTSE index and the short bond index reduces by 19 days. During the QE phase, the half-life of shocks to the correlation between the FTSE index and the long bond index reduces by 25 days. The contrasting results regarding persistence in variance and persistence in correlation mirror the contrast between the relative stability of the correlation process through the crisis and phases of QE compared to the significant rise in variance seen during the crisis that is largely reversed during the operation of QE.

5. Conclusions

In this study, we examined empirically the links between the volatility of short term bond returns, long term bonds returns and stock returns in the UK between 2004 and 2014. The empirical analysis used a multivariate GARCH framework that permitted rich and flexible dynamic structures. In particular, the model featured time-varying correlations among the returns processes and variables to capture the effects on both volatility and correlation of the financial crisis, the phases of QE, the intensity of QE activity and specific changes in monetary conditions.

It was found that the volatility of all three assets increased significantly in the period from the start of the financial crisis that, for the UK, was around the time of the Northern Rock bank rescue until the start (or just before the start) of QE1 in March 2009. This volatility was seen to be further boosted during the crisis by the collapse of Lehman Brothers in August 2008. Volatility was seen to reduce to pre-crisis levels by the end of QE1 for all three assets classes. By the end of QE3, only short term bond return volatility had not reduced to levels equivalent to those experienced in the pre-crisis years. In addition, the days of reverse auctions appear to cause a significant drop in the volatility of short term bonds. By contrast, the intensity of QE activity, which we measured by taking the ratio of the amount of a bond purchased to its outstanding issue size, was found to raise the volatility of short term bonds, but not by enough to offset the fall observed on the reverse auction days. The intensity of QE activity did not significantly affect the volatility of either long term bonds or stocks.

The correlations between the three asset classes were seen to fluctuate around fairly stable long run values. Taking all three assets together, we were unable to reject the hypothesis that the correlation levels between them were constant throughout the sample period. When dummy variables for the crisis, the phases of QE and QE activity and intensity are introduced directly into the dynamic correlation processes, we find no significant evidence of any effects not already explained by effects on the volatility of the returns on the three separate asset classes. Again, this points to considerable stability in the correlations between the asset classes in recent years. On investigating the possibility that the persistence of shocks to either volatility or correlation may have experienced changes during the recent financial market turmoil, we find that the persistence of shocks to the volatility of long bonds did significantly increase during the pre-QE1 period, but reverted to a pre-crisis level once QE activated. The persistence of shocks to the correlation between stocks and short term bonds was also changed during this period, but was reduced. The persistence of shocks to the correlation between stocks and long term bonds was found to reduce during QE1. The persistence of shocks to the correlation between short term and long term bonds was not affected by the crisis or the phases of QE.

During the phases of QE, the correlation between short and long term bonds was remarkably stable, showing no significant influence of QE related events and activity. One of the channels through which QE is anticipated to operate on the economy is through a portfolio balance mechanism that relies on market segmentation. Any increase in correlation would have indicated that markets are more integrated than segmented and so the behaviour of the bond market during QE could have been making the operation of QE more difficult. There is no indication that this was the case.

The variation in correlation observed in this study provides an interesting contrast to, but is consistent with, that observed for the period between 1984 and 2004, in Steeley (2006). In that earlier study, the correlation between bonds and stocks was also found to be around 70 percent and, within the constraints of the less sophisticated framework than is examined in this paper, appeared to be relatively stable. By contrast, the correlation between equity and both short term and long term bonds changed sign from positive (around 30 percent) to negative (around -15 percent), between 1984 and 2004. The legacy of that change in correlation, which appeared to follow the Asian crisis and dot.com booms of the late 1990s, has been observed in this study. The perceived safe-haven status of UK bonds during that time appears, from the additional evidence in this study, to have led to a long term change in the relationship between the returns on stocks and bonds in the UK, as the negative correlation has continued through to the current time. While the evidence of changing short run correlations found in this study reinforces the importance of permitting correlation structures to evolve within empirical specifications, the overall conclusion is that the financial crisis and QE has not changed the correlation structure, and hence the integration of UK financial markets, which has been fairly stable since the beginning of the 21st century.

6. References

Abad, P., and Chulia, H., 2013, European Government Bond Markets and Monetary Policy Surprises: Returns, Volatility and Integration, unpublished working paper, University Rey Juan Carlos, Madrid, Spain.

Abad, P., Chuliá, H., and M. Gómez-Puig, 2010, EMU and European government bond market integration, *Journal of Banking and Finance* 34, 2851–2860.

Abad, P., Chuliá, H., and M. Gómez-Puig, 2013, Time-varying integration in European Government Bond Markets, *European Financial Management* 20, 270-290.

Arnold, I., and Vrugt, E., 2010, Treasury Bond Volatility and Uncertainty about Monetary Policy, *The Financial Review* 45, 707-728.

Anderson, N., and Breedon, F., 2000, Fifty Years of UK Asset Price Volatility, *Journal of Risk* 2, 63-77

Balduzzi, P., Elton, E.J., Green, T.C., 2001. Economic news and bond prices: evidence from the U.S. treasury market. *Journal of Financial and Quantitative Analysis* 36, 523 – 543.

Barberis, N., Schleifer, A., and Wurgler, 2005. Comovement. Journal of Financial Economics 75, 283-317.

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.

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

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

Berben, R.P. and W.J. Jansen, 2005b, Bond market and stock market integration in Europe, working paper De Nederlandsche Bank.

Bollerslev, T., 1986, Generalized Autoregressive Conditional Heteroscedasticity, *Journal of Econometrics* 31, 307-327.

Bollerslev, T., 1987, On the correlation structure for the generalised autoregressive conditional heteroscedasticity process, *Journal of Time Series Analysis* 9, 121-131.

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 Finance* 27, 133–151.

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), 702-728.

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.

Brockman, P., I. Liebenberg, and M. Schutte, 2010, Comovement, information production, and the business cycle, *Journal of Financial Economics* 97,107-29.

Brunnermeier, M., and L. Pedersen, 2009, Market liquidity and funding liquidity, *Review of Financial Studies* 22, 2201-2238.

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.

Caporin, M., and M. McAleer, 2013, Ten things you should know about DCC, unpublished working paper, University of Padova and Erasmus University.

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

Chordia, T., Goyal, A., and Q. Tong, 2011, Pairwise correlations. Unpublished working paper, Emory University, University of Lausanne, Singapore Management University.

Christiansen, C., 2007, Volatility-spillover effects in European bond markets, *European Financial Management* 13, 923-948.

Connolly, R., C. Stivers, and L. Sun, 2007. Commonality in the time-variation of stock-stock and stock-bond return comovements. *Journal of Financial Markets* 10, 192-218.

Chu, C.J., 1995, Detecting parameter shift in GARCH models, *Econometric Reviews* 14, 241-266.

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

Dean, W., Faff, R., and Loudon, G., 2010, Asymmetry in Return and Volatility Spillover between Equity and Bond Markets in Australia, *Pacific-Basin Finance Journal* 18, 272-289.

De Goeij, P. and Marquering, W., 2006, Macroeconomic Announcements and Asymmetric Volatility in Bond Returns, *Journal of Banking and Finance* 30, 2659-2680.

Diebold, F.X., 1986, Modelling the persistence of conditional variances: comment, *Econometric Reviews* 5, 51-56.

Dungey, M., and V. Martin, 2007. Unravelling financial market linkages during crises. *Journal of Applied Econometrics* 22, 89-119.

Dungey, M., Milunovich, G., and S. Thorp, 2010. Unobservable shocks as carriers of contagion. *Journal of Banking and Finance* 34,1008-1021.

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 Heteroscedasticity with Estimates of the Variance of U.K. 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.

Engle, R.F., Lilien, D. and R. Robins, 1987, Estimating Time Varying Risk Premia in the Term Structure: the ARCH-M Model, *Econometrica* 55, 391-407.

Engle, R.F., Ng, V.K. and M. Rothschild, 1990, Asset pricing with a FACTOR-ARCH covariance structure: Empirical estimates for Treasury bills, *Journal of Econometrics* 45, 213-37.

Fama, E., 1965, The Behaviour of Stock Market Prices, *Journal of Business* 38, 34-105.

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

Glick, R., and Leduc, S., 2012, Central Bank Announcements of Asset Purchases and the Impact on Global Financial and Commodity Markets, *Journal of International Money and Finance* 31, 2078-2102.

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 Sahlström, P. (2003). Relative importance of scheduled macroeconomic news for stock market investors, *Journal of Economics and Finance* 27, 153–165

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.

Hambuger, M., and L. Kochin, 1972, Money and stock prices: The channels of influence. *Journal of Finance* 27, 231-250.

Höchstötter, M., S. Meyer, R. Riordan and A. Storkenmaier, 2014, International stock market comovement and news, *Journal of Financial Research* 37, 519-543.

Homa, K., and D. Jaffee, 1971, The supply of money and common stock prices, *Journal of Finance* 26, 1045-1066.

Huang, J., and Lu, L., 2008, Macro factors and volatility of Treasury bond returns, unpublished working paper, Penn State University.

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

Jones, C., Lamont, O., and Lumsdaine, R., 1998, Macroeconomic news and bond market volatility, *Journal of Financial Economics* 47, 315–337.

Joyce, M., Lasaosa, A., Stevens, I., and Tong, M., 2011, The Financial Market Impact of Quantitative Easing in the United Kingdom, *International Journal of Central Banking*, **7**, 113–61.

Joyce, M., 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, 671–701.

Joyce, M., and Tong, M., 2012, QE and the Gilt Market: A Disaggregated Analysis, *Economic Journal* 122, F348–84.

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, pp. 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.

Kumar, A., and K. Lee, 2006, Retail investor sentiment and return comovements. *Journal of Finance* 61, 2451-2486.

Lamoureux, C.G., and W.D. Lastrapes, 1990, Persistence in variance, structural change and the GARCH model, *Journal of Business and Economic Statistics* 8, 225-234.

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

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 skeptical survey, *Oxford Review of Economic Policy* 28, 750–764.

Meier, A., 2009, Panacea, Curse, or Nonevent: Unconventional Monetary Policy in the United Kingdom, IMF Working Paper No. 09/163.

Meaning, J., and Zhu, F., 2011, The Impact of Recent Central Bank Asset Purchase Programmes, *Bank of International Settlements Quarterly Review*, December, 73–83.

Nikkinen, J., and Sahlström, P. (2001). Impact of Scheduled U.S. Macroeconomic News on Stock Market Uncertainty: A Multinational Perspecive. *Multinational Finance Journal* 5, 129-139.

Nikkinen, J., and Sahlström, 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 Sahlström, P., (2004b). Scheduled domestic and US macroeconomic 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.

Nowak, S., Andritzky, J., Jobst, A. and Tamirisa, N., (2011). Macroeconomic fundamentals, price discovery, and volatility dynamics in emerging bond markets. *Journal of Banking & Finance* 35, 2584-2597.

Palmer, M., 1970, Money supply, portfolio adjustments and stock prices, *Financial Analysts Journal*, July/August.

Saunders, A., and R. Woodward, 1976, Money supply and share prices: the evidence for the UK in the post-CCC period, *The Investment Analyst* 46, 24-27.

Skintzi, V. and A-P. Refenes, 2006, Volatility spillovers and dynamic correlation in european bond markets, *Journal of International Financial Markets, Institutions and Money* 16, 23-40.

Sprinkel, B., 1964. Money and Stock prices, (Homewood, IL: Richard D. Irwin).

Steeley, J., 2006, Volatility transmission between stock and bond markets, *Journal of International Financial Markets Institutions and Money* 16, 71-86.

Veldcamp, L., 2006, Information markets and the comovement of asset prices, *Review of Economic Studies* 73, 823-45.

Vuong, Q., 1989, Likelihood Ratio Tests for Model Selection and non-nested Hypotheses, *Econometrica* 57, 307–333.

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 returns

Returns are calculated from daily observations on the FTA Government Stocks (<5 years) index (FTSG), the FTA Government Stocks (>15 years) index (FTLG) and the FTSE 100 share index (FTSE), between January 5th, 2004 and June 9th, 2014. Mean, Std. Dev., Skew., and Kurt., are the sample mean $\times 10^3$, standard deviation $\times 10^3$, skewness and kurtosis of the returns series. Min., Max., and Med., are the two extreme and central values of the returns distribution, and Q1 and Q3 are the lower and upper quartile values. The cross autocorrelation at lag τ is the correlation coefficient between the returns of the first named series in period t with the return on the second named series in period t-τ. For normally distributed returns, the 5 percent significance level for the autocorrelations coefficients is 0.038.

	Obs.	Mean	Std. Dev.	Skew.	Kurt.	Min.	Q1	Med.	Q3	Max.
FTSG	2635	-0.0315	1.694	-3.840	26.94	-0.017	-0.000	0.000	0.001	0.007
FTLG	2635	0.0699	6.797	0.101	3.858	-0.033	-0.004	0.000	0.004	0.057
FTSE	2635	0.1600	11.930	-0.157	8.921	-0.093	-0.005	0.001	0.006	0.094
	Autocorrelations of returns at lag									
	1	2	3	4	5	6	7	8	9	10
FTSG	-0.009	-0.027	-0.016	-0.007	-0.019	0.029	-0.029	0.009	0.016	-0.022
FTLG	0.051	-0.095	-0.076	0.041	0.003	-0.035	-0.054	-0.045	0.025	0.047
FTSE	-0.051	-0.046	-0.057	0.070	-0.052	-0.034	0.025	0.030	-0.024	0.016
	Autocorrelations of squared returns at lag									
	1	2	3	4	5	6	7	8	9	10
FTSG	-0.012	-0.005	-0.010	-0.011	-0.001	-0.009	0.005	-0.011	-0.008	0.005
FTLG	0.332	0.130	0.089	0.133	0.130	0.113	0.084	0.083	0.064	0.085
FTSE	0.241	0.289	0.325	0.300	0.369	0.219	0.219	0.177	0.272	0.286

		Cross serial correlations of returns at lag		
		-1	0	1
FTSG	FTLG	-0.001	0.568	-0.046
FTSG	FTSE	0.020	-0.239	0.011
FTLG	FTSE	0.028	-0.344	0.004

Table 2: Univariate GARCH models

This table contains the estimated coefficients from the model, $R_{i,t} = \alpha_{i,1} + \alpha_{i,2}\text{MPC}_t + \alpha_{i,3}\text{APFday}_t + \alpha_{i,4}\text{QEInt}_t + \alpha_{i,5}\text{IndexChg}_t + \sum_{k=1}^{5}\sum_{i=1}^{3}\beta_{i,k}R_{i,t-k} + \varepsilon_{i,t}$, $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1} + \sum_{j=0}^{3} g_{j,i,i}D_{j,t} + \gamma_{i,1}\text{MPC}_t + \gamma_{i,2}\text{APFday}_t + \gamma_{i,3}\text{QEInt}_t$, where $R_{i,t}$ is the return at time t on index i, $i \in$ {FTSG,FTLG,FTSE} as defined in Table 1. Estimated parameters are indicated by a caret, and ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The variable MPC_t is a dummy variable taking the value unity on days of MPC meetings and is zero otherwise, APFday_t is a dummy variable that takes the value unity on days that the Bank of England made asset purchases under the QE arrangements, QEInt_t is a measure of the intensity of QE activity on these purchase auction days, and IndexChg_t is a dummy variable that controls for the effects of quarterly changes to the bond index constituents. The dummy variables, $D_{j,t}$, $j = 0.1,2,3$ take the value one if time *t* is within, respectively, the crisis period pre-QE, QE1, QE2 and QE3, and are zero otherwise. Log-L is the maximized value of the log-likelihood function (assuming Normally distributed errors) using the Levenberg-Marquardt non-linear optimization algorithm. Q(10) [$Q^2(10)$] is the Box-Ljueng test for autocorrelation applied to the standardized [squared] residuals. SBIC is the Schwartz Bayesian information criterion.

Coefficient	FTSG	FTLG	FTSE
$\hat{\alpha}_1 \times 10^3$	0.072***	0.072	0.677***
$\hat{\alpha}_2 \times 10^3$	0.011	-0.053	-0.417
$\hat{\alpha}_3 \times 10^3$	-0.000	0.000	-2.207**
$\hat{\alpha}_4$	0.056	0.278	0.935*
$\hat{\alpha}_5$	-0.011***	-0.009***	-0.002
$\hat{\beta}_{1,1}$	0.021	-0.231***	-0.068
$\hat{\beta}_{1,2}$	0.013	0.090	0.310
$\hat{\beta}_{1,3}$	0.006	0.108	-0.270
$\hat{\beta}_{1,4}$	-0.001	0.131	-0.057
$\hat{\beta}_{1,5}$	-0.006	0.067	-0.150
$\hat{\beta}_{2,1}$	-0.011***	0.068***	0.004
$\hat{\beta}_{2,2}$	-0.010**	-0.078***	-0.013
$\hat{\beta}_{2,3}$	-0.009**	-0.081***	0.089
$\hat{\beta}_{2,4}$	0.003	0.008	0.013
$\hat{\beta}_{2,5}$	0.000	-0.015	0.049
$\hat{\beta}_{3,1}$	-0002	0.002	-0.060
$\hat{\beta}_{3,2}$	-0.001	-0.002	-0.015
$\hat{\beta}_{3,3}$	-0.000	-0.004	-0.009
$\hat{\beta}_{3,4}$	0.001	0.006	-0.006
$\hat{\beta}_{3,5}$	0.004*	0.032***	-0.012
$\hat{\omega} \times 10^6$	0.0098**	0.389**	2.560***
$\hat{b}$	0.0195***	0.046***	0.106***
$\hat{c}$	0.9637***	0.937***	0.866***
$\hat{g}_0 \times 10^6$	0.0394**	0.709**	8.860***
$\hat{g}_1 \times 10^6$	0.0183	-0.179	-3.500
$\hat{g}_2 \times 10^6$	0.0222	0.418	-2.930
$\hat{g}_3 \times 10^6$	0.0239	0.173	-1.550
$\hat{\gamma}_1 \times 10^6$	0.1240*	3.220	-10.90**
$\hat{\gamma}_2 \times 10^6$	-0.0678**	-0.007	0.293
$\hat{\gamma}_3 \times 10^3$	0.0163	0.260	0.005
Log-L	14303.98	9694.469	8574.311
SBIC	-10.788	-7.282	-6.431
Q(10)	10.374	5.665	2.304
$Q^2(10)$	4.908	23.946***	7.008
		Cross correlations of standardized residuals	
FTLG	0.725		
FTSE	-0.263	-0.312	

Table 3: Multivariate GARCH models

This table contains the estimated coefficients from the model, $R_{i,t} = \alpha_{i,1} + \alpha_{i,2}\text{MPC}_t + \alpha_{i,3}\text{APFday}_t + \alpha_{i,4}\text{QEInt}_t + \alpha_{i,5}\text{IndexChg}_t + \sum_{k=1}^{5}\sum_{i=1}^{3}\beta_{i,k}R_{i,t-k} + \varepsilon_{i,t}$, $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1} + \sum_{j=0}^{3} g_{j,i,i}D_{j,t} + \gamma_{i,i,1}\text{MPC}_t + \gamma_{i,i,2}\text{APFday}_t + \gamma_{i,i,3}\text{QEInt}_t$, and in Panel A $h_{i,m,t} = \rho_{i,m,t}\sqrt{h_{i,t}h_{m,t}}$, $\rho_{i,m,t} = q_{i,m,t}/\sqrt{q_{i,i,t}q_{m,m,t}}$, $q_{i,m,t} = q_{i,m}(1-a-b) + a\varepsilon_{i,t-1}\varepsilon_{m,t-1} + bh_{i,m,t-1}$, while in Panel B, $h_{i,m,t} = \rho_{i,m}\sqrt{h_{i,t}h_{m,t}}$, where $R_{i,t}$ is the return at time t on index i, $i \in \{\text{FTSG,FTLG,FTSE}\}$ as defined in Table 1. Estimated parameters are indicated by a caret, and ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The variable MPC_t is a dummy variable taking the value unity on days of MPC meetings and is zero otherwise, APFday_t is a dummy variable that takes the value unity on days that the Bank of England made asset purchases under the QE arrangements, QEInt_t is a measure of the intensity of QE activity on these purchase auction days, and IndexChg_t is a dummy variable that controls for the effects of quarterly changes to the bond index constituents. The dummy variables, $D_{j,t}, j = 0,1,2,3$ take the value one if time t is within, respectively, the crisis period pre-QE, QE1, QE2 and QE3, and are zero otherwise. Log-L is the maximized value of the (multivariate) log-likelihood function (assuming Normally distributed errors) using the Levenberg-Marquardt (CC) or BFGS (DCC) non-linear optimization algorithm. Q(10) [$Q^2(10)$] is the Box-Ljueng test for autocorrelation applied to the standardized [squared] residuals. SBIC is the Schwartz Bayesian information criterion.

	FTSG	FTLG	FTSE	FTSG	FTLG	FTSE
	Panel A: Dynamic Conditional Correlation (DCC)			Panel B: Constant correlation (CC)		
$\hat{\alpha}_1 \times 10^3$	-0.032	0.060	0.158	0.046**	-0.094	0.726***
$\hat{\alpha}_2 \times 10^3$	0.015	-0.066	-0.000	0.004	0.041	-0.362
$\hat{\alpha}_3 \times 10^3$	-0.095	0.000	-2.245**	-0.000	0.000	-0.002**
$\hat{\alpha}_4$	0.045	0.267	0.979**	0.062	0.289	0.861*
$\hat{\alpha}_5$	0.011***	-0.009***	-0.002	-0.011***	-0.008***	-0.002
$\hat{\beta}_{1,1}$	0.016	-0.240***	-0.061	0.018	-0.228***	-0.060
$\hat{\beta}_{1,2}$	0.012	0.256**	0.287***	0.000	0.053	0.284**
$\hat{\beta}_{1,3}$	0.001	0.113	-0.316***	0.005	0.115	-0.273**
$\hat{\beta}_{1,4}$	0.002	0.007*	-0.005	-0.003	0.113	-0.027
$\hat{\beta}_{1,5}$	-0.027	-0.066	-0.125	-0.007	0.054	-0.125
$\hat{\beta}_{2,1}$	-0.014***	0.095***	-0.011	-0.013***	0.044*	0.011
$\hat{\beta}_{2,2}$	-0.017**	-0.130***	-0.006	-0.009**	-0.072***	-0.005
$\hat{\beta}_{2,3}$	-0.008**	-0.083***	0.101**	-0.010***	-0.094***	0.090***
$\hat{\beta}_{2,4}$	-0.001	0.044	0.046	0.001	-0.007	0.017
$\hat{\beta}_{2,5}$	0.008	0.011	-0.052	-0.001	-0.024	0.041
$\hat{\beta}_{3,1}$	-0.000	0.014	-0.046**	-0.001	0.005	-0.061***
$\hat{\beta}_{3,2}$	-0.000	0.005	-0.033	0.003	-0.007	-0.010
$\hat{\beta}_{3,3}$	-0.001	0.005	-0.054	-0.000	-0.004	-0.013
$\hat{\beta}_{3,4}$	0.004	0.006	0.065**	0.002	0.010	-0.011
$\hat{\beta}_{3,5}$	0.007**	0.032**	-0.059**	0.003	0.028**	-0.012
$\hat{\omega}_{i,i,} \times 10^6$	0.010**	0.452***	2.660***	0.018***	0.478***	3.030***
$\hat{b}_{i,i}$	0.020***	0.046***	0.106***	0.027***	0.050***	0.097***
$\hat{c}_{i,i}$	0.962***	0.939***	0.865***	0.951***	0.935***	0.867***
$\hat{g}_{0,i,i} \times 10^6$	0.042***	0.725**	9.280***	0.047***	0.562**	8.760***
$\hat{g}_{1,i,i} \times 10^6$	0.022	-0.133	-2.320	0.028*	0.386	-2.440
$\hat{g}_{2,i,i} \times 10^6$	0.027**	0.521	-1.930	0.037**	1.110*	-2.780
$\hat{g}_{3,i,i} \times 10^6$	0.030**	0.270	-0.713	0.044***	0.636	-2.220
$\hat{\gamma}_{1,i,i} \times 10^6$	0.141*	2.640	-11.60**	0.066	1.050	-11.14**
$\hat{\gamma}_{2,i,i} \times 10^6$	-0.079***	-0.259	-0.530	-0.131***	-2.550**	-0.103
$\hat{\gamma}_{3,i,i} \times 10^3$	0.018	0.299	4.586	0.0385**	0.804	4.732
	Dynamic Conditional Correlation Parameters			Constant Conditional Correlations		
$\hat{a}$	0.014***			FTSG	0.729***	-0.319***
$\hat{b}$	0.966***			FTLG	-0.270***	
Log-L	33681.04			33704.93		
SBIC	-25.562			-25.352		
Q(10)	23.58***	11.82	21.82**	25.24***	7.35	2.34
$Q^2(10)$	5.17	23.43***	9.18	2.26	40.79***	8.33

Table 4: QE Effects in the Dynamic Conditional Correlation

This table, Panel A, contains the estimated coefficients from the DCC model, $h_{i,m,t} = \rho_{i,m,t}\sqrt{h_{i,t}h_{m,t}}$, $\rho_{i,m,t} = q_{i,m,t}/\sqrt{q_{i,i,t}q_{m,m,t}}$, $q_{i,m,t} = q_{i,m}(1-a-b) + a\varepsilon_{i,t-1}\varepsilon_{m,t-1} + bh_{i,m,t-1} + \sum_{j=0}^{3} g_{j,i,m}D_{j,t} + \gamma_{i,m,1}\text{MPC}_t + \gamma_{i,m,2}\text{APFday}_t + \gamma_{i,m,3}\text{QEInt}_t$, , where $\varepsilon_{i,t}$ is the residual at time t from the models in Table 2 applied to the returns on each index i, $i \in$ {FTSG,FTLG,FTSE} as defined in Table 1. In Panel B, the residuals are from a corresponding model that has had the QE effect variables removed from the conditional variance equation. Estimated parameters are indicated by a caret, and ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The variable MPC_t is a dummy variable taking the value unity on days of MPC meetings and is zero otherwise, APFday_t is a dummy variable that takes the value unity on days that the Bank of England made asset purchases under the QE arrangements, QEInt_t is a measure of the intensity of QE activity on these purchase auction days. The dummy variables, $D_{j,t}$, $j = 0.1,2,3$ take the value one if time t is within, respectively, the crisis period pre-QE, QE1, QE2 and QE3, and are zero otherwise. Log-L is the maximized value of the (multivariate) log-likelihood function (assuming Normally distributed errors) using the Levenberg-Marquardt non-linear optimization algorithm. Q(10) [Q^2(10)] is the Box-Ljueng test for autocorrelation applied to the standardized [squared] residuals. SBIC is the Schwartz Bayesian information criterion

	FTSG,FTLG	FTSG,FTSE	FTLG,FTSE
Panel A: Including variance effects			
$\hat{a}$		0.015***	
$\hat{b}$		0.966***	
$\hat{g}_{0,i,m}$	-0.000	-0.001	-0.001
$\hat{g}_{1,i,m}$	0.000	-0.002	-0.001
$\hat{g}_{2,i,m}$	0.001	0.001	0.001
$\hat{g}_{3,i,m}$	0.002	-0.000	-0.001
$\hat{\gamma}_{1,i,m}$	-0.005	0.002	0.001
$\hat{\gamma}_{2,i,m}$	-0.001	-0.004	-0.002
$\hat{\gamma}_{3,i,m}$	-0.912	1.618	1.430
LogL		21698.15	
SBIC		-16.39	
Q(10)	23.58***	11.82	21.82**
Q^2(10)	5.17	23.43***	9.18
Panel B: Excluding variance effects			
	FTSG,FTLG	FTSG,FTSE	FTLG,FTSE
$\hat{a}$		0.015***	
$\hat{b}$		0.965***	
$\hat{g}_{0,i,m}$	0.002	-0.002**	-0.002*
$\hat{g}_{1,i,m}$	0.001	-0.002	-0.001
$\hat{g}_{2,i,m}$	0.001	0.001	-0.001
$\hat{g}_{3,i,m}$	0.001	-0.000	-0.001
$\hat{\gamma}_{1,i,m}$	-0.005	0.002	0.001
$\hat{\gamma}_{2,i,m}$	-0.000	-0.003	-0.002
$\hat{\gamma}_{3,i,m}$	-0.982	1.676	1..489
LogL		21582.27	
SBIC		-16.31	
Q(10)	24.73***	12.59	21.04**
Q^2(10)	5.56	26.12***	10.07

Table 5: Time-varying Persistence in Volatility and Correlation

This table contains the estimated persistence coefficients $\varphi_{j,i,m}$,from the model, $R_{i,t} = \alpha_{i,1} + \alpha_{i,2}\text{MPC}_t + \alpha_{i,3}\text{APFday}_t + \alpha_{i,4}\text{QEInt}_t + \alpha_{i,5}\text{IndexChg}_t + \sum_{k=1}^{5}\sum_{i=1}^{3}\beta_{i,k}R_{i,t-k} + \varepsilon_{i,t}$, $\varepsilon_{i,t}|\Omega_{t-1} \sim N(0, h_{i,t})$, and in Panel A, $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1} + \sum_{j=0}^{3} g_{j,i,i}D_{j,t} + \gamma_{i,i,1}\text{MPC}_t + \gamma_{i,i,2}\text{APFday}_t + \gamma_{i,i,3}\text{QEInt}_t + \left(\sum_{j=0}^{3}\varphi_{j,i,i}D_{j,t}\right)\varepsilon_{t-1}^2$, and $h_{i,m,t} = \rho_{i,m}\sqrt{h_{i,t}h_{m,t}}$, and in Panel B, $h_{i,t} = \omega_{i,i} + b_{i,i}\varepsilon_{t-1}^2 + c_{i,i}h_{i,t-1}$,$h_{i,m,t} = \rho_{i,m,t}\sqrt{h_{i,t}h_{m,t}}$, $\rho_{i,m,t} = q_{i,m,t}/\sqrt{q_{i,i,t}q_{m,m,t}}$, $q_{i,m,t} = \omega_{i,m}(1-a-b) + a\varepsilon_{i,t-1}\varepsilon_{m,t-1} + bh_{i,m,t-1} + \sum_{j=0}^{3} g_{j,i,m}D_{j,t} + \gamma_{i,m,1}\text{MPC}_t + \gamma_{i,m,2}\text{APFday}_t + \gamma_{i,m,3}\text{QEInt}_t + \left(\sum_{j=0}^{3}\varphi_{j,i,m}D_{j,t}\right)\varepsilon_{i,t-1}\varepsilon_{m,t-1}$, where $R_{i,t}$ is the return at time t on index i, $i \in$ {FTSG,FTLG,FTSE} as defined in Table 1. Estimated parameters are indicated by a caret, and ***, **, * indicate statistical significance at the 1%, 5% and 10% levels, respectively. The variable MPC_t is a dummy variable taking the value unity on days of MPC meetings and is zero otherwise, APFday_t is a dummy variable that takes the value unity on days that the Bank of England made asset purchases under the QE arrangements, QEInt_t is a measure of the intensity of QE activity on these purchase auction days. The dummy variables, $D_{j,t}$, $j = 0.1,2,3$ take the value one if time t is within, respectively, the crisis period pre-QE, QE1, QE2 and QE3, and are zero otherwise. Log-L is the maximized value of the (multivariate) log-likelihood function (assuming Normally distributed errors) using the Levenberg-Marquardt non-linear optimization algorithm. Q(10) [Q^2(10)] is the Box-Ljueng test for autocorrelation applied to the standardized [squared] residuals. SBIC is the Schwartz Bayesian information criterion.

	Panel A: Constant Conditional Correlation				Panel B: Dynamic Conditional Correlation		
(CC)	FTSG	FTLG	FTSE	(DCC)	FTSG,FTLG	FTSG,FTSE	FTLG,FTSE
FTSG		0.728***	-0.267***	$\hat{a}$		0.015***	
FTLG			-0.319***	$\hat{b}$		0.965***	
$\hat{\varphi}_{0,i,i}$	0.001	0.007***	0.008	$\hat{\varphi}_{0,i,m}$	0.012	-0.003	-0.025***
$\hat{\varphi}_{1,i,i}$	-0.001	-0.003	-0.016	$\hat{\varphi}_{1,i,m}$	-0.005	-0.058**	-0.038
$\hat{\varphi}_{2,i,i}$	-0.001	-0.003	-0.008	$\hat{\varphi}_{2,i,m}$	-0.026	-0.029	-0.024
$\hat{\varphi}_{3,i,i}$	-0.000	-0.002	-0.015	$\hat{\varphi}_{3,i,m}$	-0.041	-0.074	-0.113
LogL		33714.30				21597.55	
SBIC		-25.61				-16.28	
Q(10)	25.24***	7.35	2.34		24.73***	12.59	21.04**
Q^2(10)	2.26	40.79***	8.33		5.56	26.12***	10.07

Figure 1

Gilt Purchase Auctions by day of the week

This figure shows the distribution of gilt purchase auctions across the days of the week for each of the sub-samples. The bars are ratio of the number of times that weekday was used for purchase auctions to the total number of that weekday in the sub-sample. For example, almost 80 percent of all Wednesdays during the QE1 phase experienced gilt purchase auctions. (Data source: Bank of England).

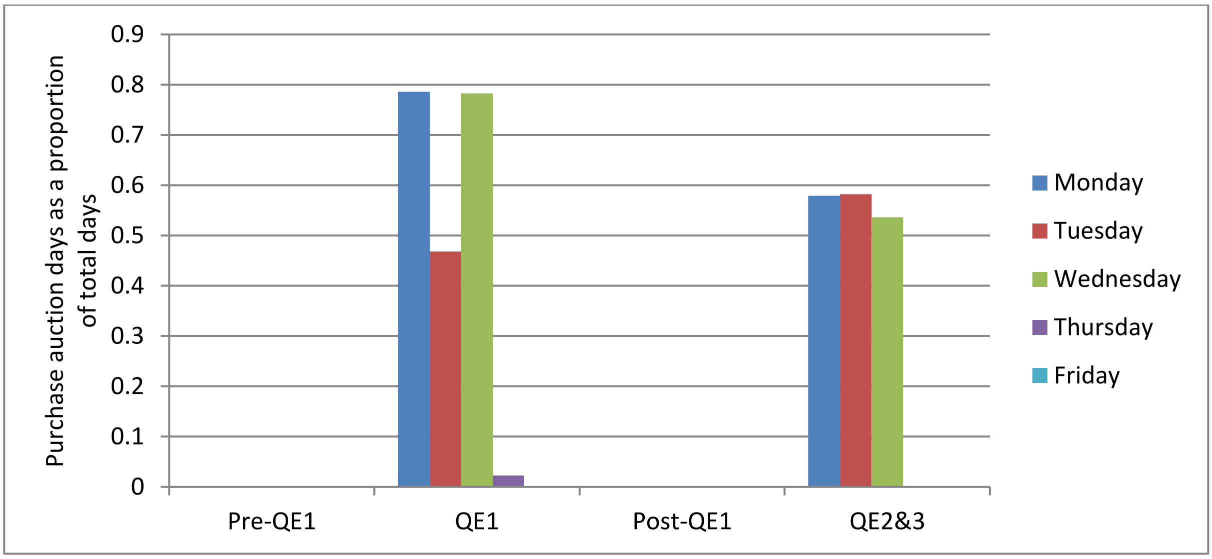

Figure 2: Returns (daily log price difference)

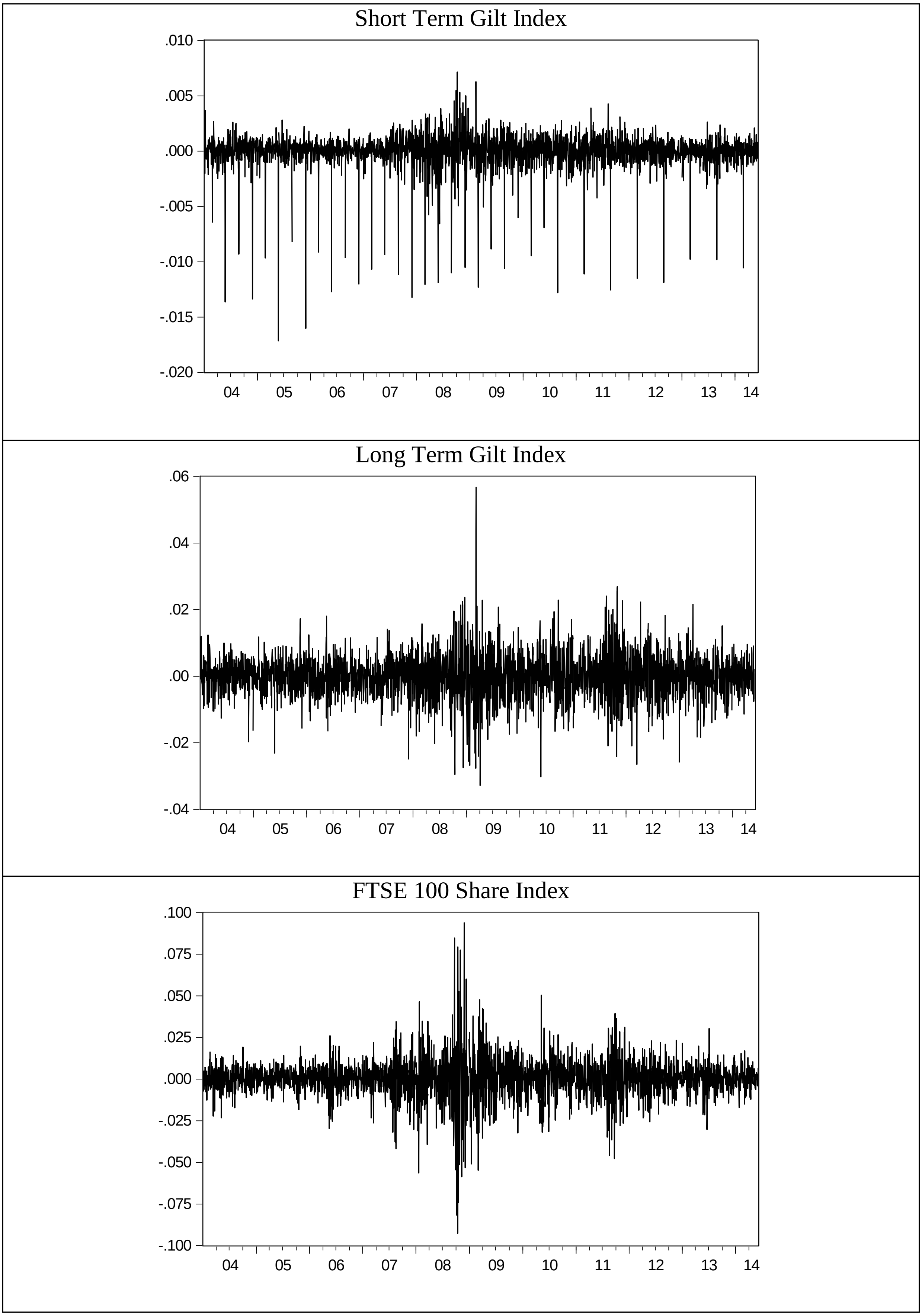

Figure 3

Accumulated Purchases of Gilts by the Bank of England

This figure shows the month end accumulated total of gilts purchased by the Bank of England since the beginning of the QE Asset Purchase Programme. The left hand end of each QE boundary marks the step change in the boundary, as further QE was announced by the Bank of England. (Data source: Bank of England).

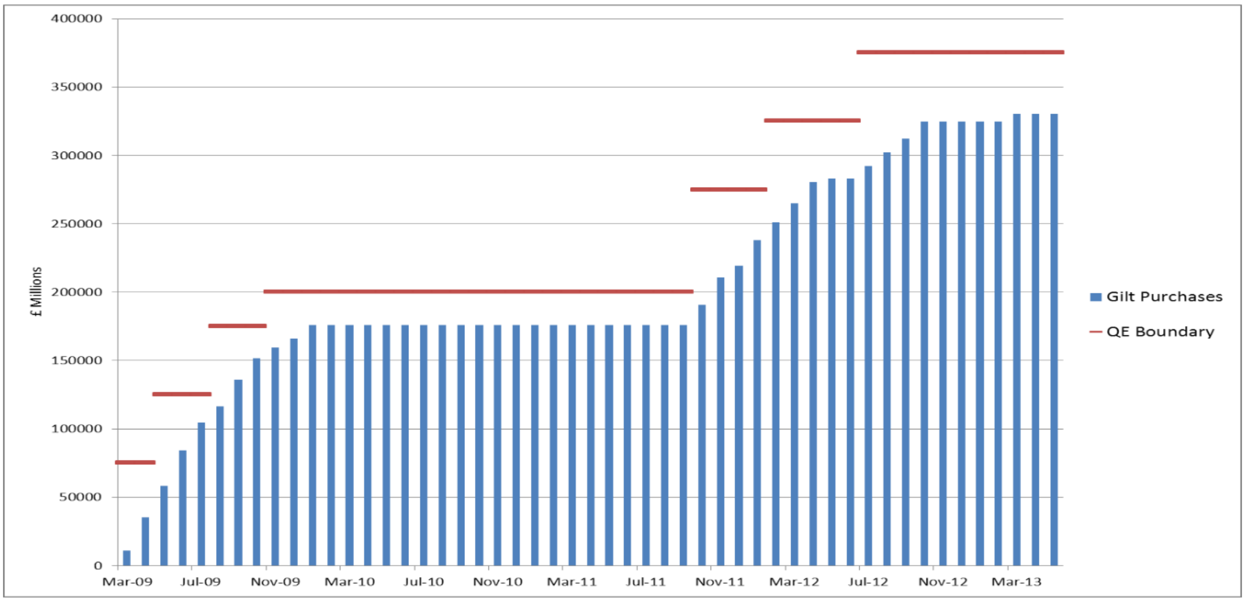

Figure 4

Holdings of Individual Gilts by the Bank of England

The box plots shows the distribution of ownership shares of individual gilts held by the Bank of England at the end of each of the sub-periods indicated. The boxes measure the median and inter-quartile range (IQR) of the distribution, while the whiskers measure the furthest data points within 1.5 IQR of the outer quartiles. (Data source: Bank of England and the UK DMO).

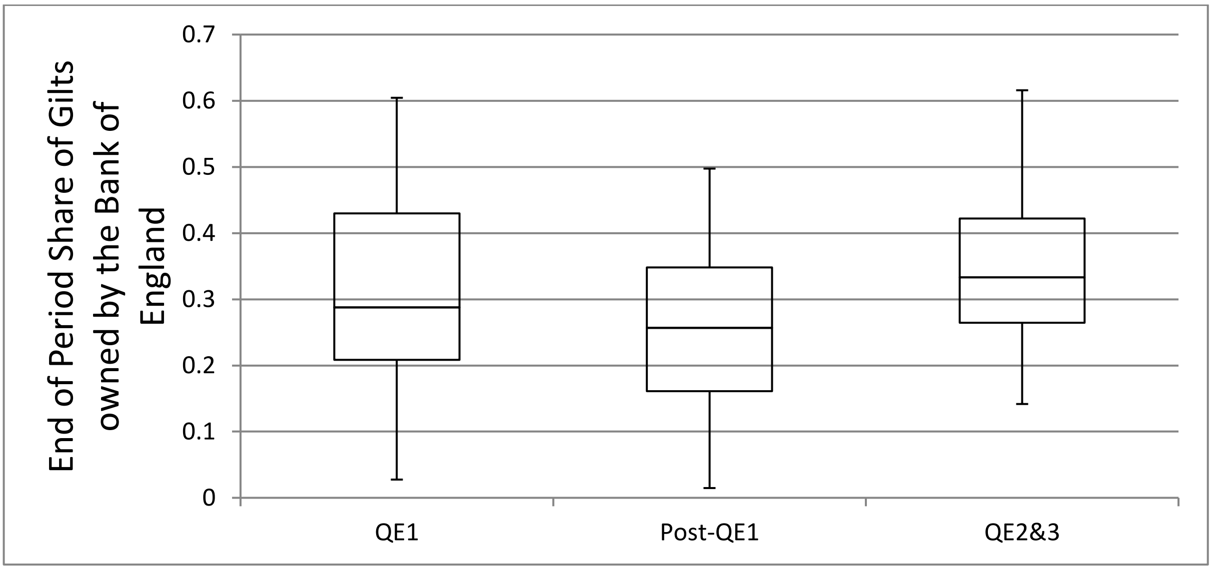

Figure 5: Estimated Conditional Variance Processes from univariate GARCH models

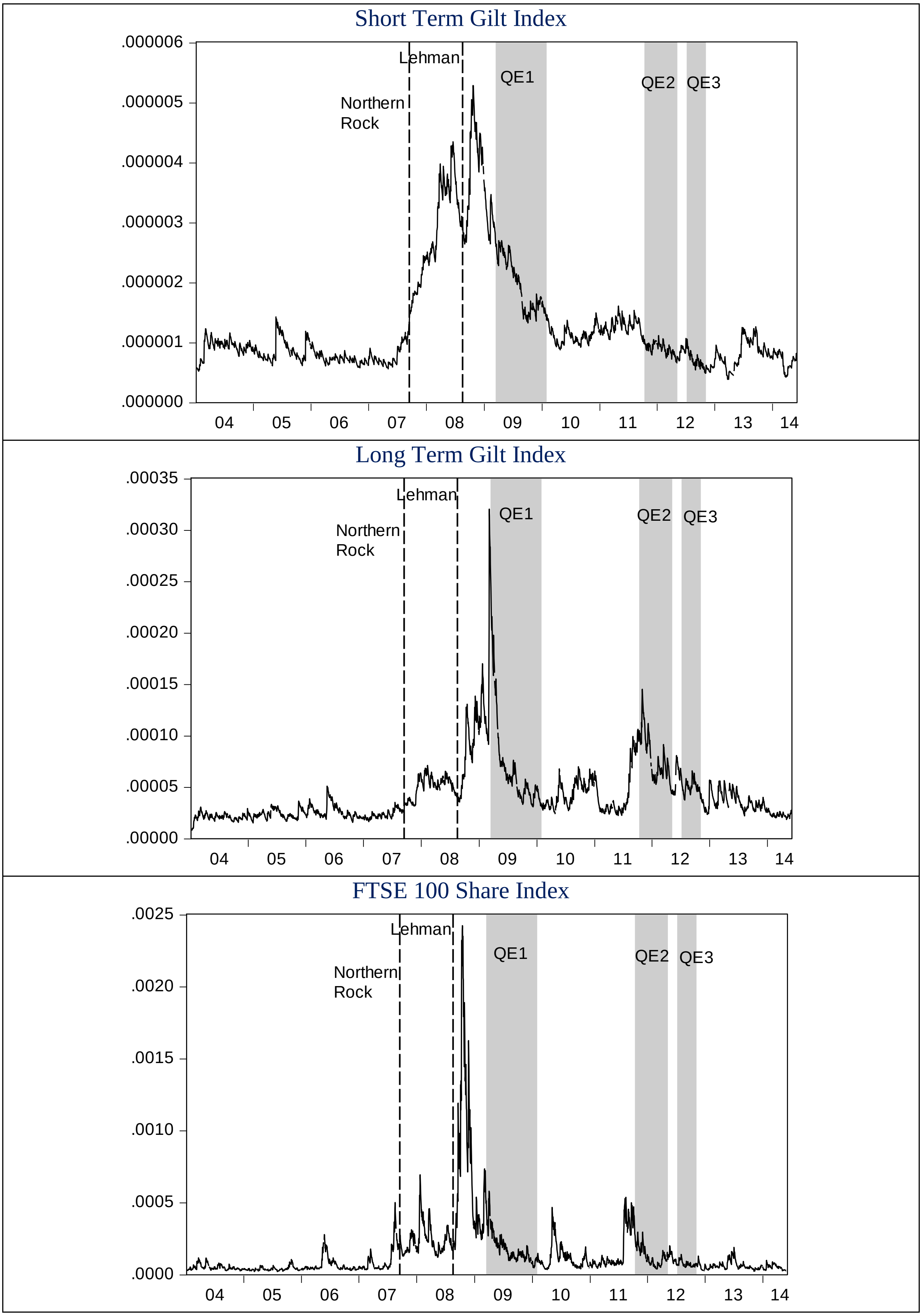

Figure 6: Estimated Conditional Variances and Correlations from multivariate DCC GARCH