Research in International Business and Finance 34 (2015) 110–125

Contents lists available at ScienceDirect

Research in International Business and Finance

journal homepage: www.elsevier.com/locate/ribaf

On quantitative easing and high frequency exchange rate dynamics☆

Dimitris Kenourgios[a,*], Stephanos Papadamou[b], Dimitrios Dimitriou[a]

[a] *Faculty of Economics, University of Athens, Greece*
[b] *University of Thessaly, Department of Economics, Greece*

ARTICLE INFO

Article history:
Received 19 December 2013
Received in revised form 23 December 2014
Accepted 15 January 2015
Available online 28 January 2015

JEL classification:
E52
E58
F31
G15

Keywords:
Quantitative easing
Exchange rates
Intraday
Volatility
Dynamic conditional correlation

ABSTRACT

This paper examines the effects of quantitative easing (QE) announcements by the European Central Bank, the Bank of Japan and the Bank of England on exchange rate dynamics. Using intraday data of three major exchange rates (EUR/USD, GBP/USD, JPY/USD), we apply a univariate APARCH(1,1) model and include QE dummies to empirically investigate how exchange rates are affected in mean and volatility. The empirical results indicate: (i) a direct negative impact on GBP and JPY and no effect of their volatility around the QE announcements of the corresponding central banks, (ii) a delayed devaluation of EUR and an increase of its volatility before and after the ECB's announcements. Furthermore, the behavior of dynamic conditional correlation among currencies is investigated across the QE announcements. We find a decline in the conditional correlation between EUR and GBP around the announcements by the BoE. These findings highlight the differences on the credibility and effectiveness of the monetary easing strategies and provide important implications from the investors' and policy makers' perspective.

☆ The authors acknowledge financial support from the Faculty of Economics, University of Athens through Special Account Research Grant 11105.

* Corresponding author at: Faculty of Economics, University of Athens, 1 Sofokleous Str., 10559 Athens, Greece. Tel.: +30 210 3689449.
E-mail address: dkenourg@econ.uoa.gr (D. Kenourgios).

http://dx.doi.org/10.1016/j.ribaf.2015.01.003
0275-5319/

1. Introduction

Unconventional monetary policy implemented by central banks during the last years takes many forms, but the most common contains massive expansion of central banks' balance sheets and efforts to influence interest rates other than the usual short-term official rates (Joyce et al., 2012). By focusing on four major central banks (Fed, BoE, BoJ, ECB), we can say that the first three have overwhelmingly bought government bonds and in some cases large quantities of agency debt and mortgage-backed securities guaranteed by the state agencies to provide liquidity to a decadent market. However, in the case of the ECB the expansion of its balance sheet derived mainly though repo operations – that is, the delivery of long-term loans (bank loans in most cases and not government bonds) in exchange for collateral.

Over the last years there is a growing strand of literature investigating the effect of the unconventional monetary policy tools implemented by the central banks as a response to the 2007–09 global financial crisis (for a survey, see Joyce et al., 2012). Most of this literature focuses on domestic markets and their underlying channels.[1] A common finding is the reduction of long-term yields since the QE announcements by the Fed (see for example Gagnon et al., 2010; Krishnamurthy and Vissing-Jorgensen, 2011; D'Amico et al., 2012; Fratzscher et al., 2013), the BoE (e.g., Christensen and Rudebusch, 2012; Breedon et al., 2012; Kapetanios et al., 2012) and the BoJ (e.g., Lam, 2011; Berkmen, 2012). Studies on the foreign exchange markets indicate a significant reduction on the currency of the central bank that follows QE policies (see for instance Faust et al., 2007; Swanson, 2011; Ueda, 2012; Glick and Leduc, 2012; Neely, 2012).

We contribute to this stream of the research by investigating the effect of QE announcements by three central banks (ECB, BoE and BoJ) on returns, volatilities and correlations of three major currencies (EUR, GBP and JPY) using intraday (1-h) data. By assuming rational expectations, the high frequency data may indicate the direct impact of unconventional monetary policy announcements on exchange rates over periods which are free from other macroeconomic effects. This may reveal useful information about the central bank credibility and effectiveness on employing QE strategies, given that these announcements can be considered to affect exchange rate dynamics by changing market participants' expectations and triggering a portfolio rebalancing.[2]

A QE strategy followed by a central bank, which is fully reflected on market responses, may contribute to a significant reduction of its currency without increasing its conditional volatility. Moreover, the conditional correlation of this currency with other highly correlated currencies is expected to be affected over the period of the announcement if the announced policy is credible. In order to shed light on this direction, we form two main research questions to be tested: (1) Do central banks affect their currencies without affecting their volatilities over the QE announcements? (2) Is the dynamic conditional correlation between currencies being affected by the QE announcements?

In order to provide answers to the above questions, firstly, we capture the effects of QE announcements on the currencies' mean returns and volatilities by including QE announcement dummies into an Asymmetric Power ARCH model. Secondly, we explore the dynamic co-movement between the exchange rates by employing the dynamic conditional correlation (DCC) model (Engle, 2002) into a multivariate APARCH(1,1) framework. This procedure investigates the second order moment correlation dynamics taking into account leverage effects. Further, given the existing empirical evidence on the time-varying structure of exchange rates across time (e.g., Perez-Rodriguez, 2006; Kitamura, 2010; Dimitriou and Kenourgios, 2013), it is well suited to identify the dynamic patterns of correlation

[1] The QE literature identifies at least three channels by which this kind of policy can affect asset prices and through these the economic activity. First, a signaling channel, through which an announcement that heightens risk concerns may lead investors to increase their demand for Treasuries, and thus their yields are reduced. Second, a risk premia channel, where bond purchases lead to a reduction of the risk premia needed for investors due to liquidity risk. Third, a portfolio balance channel which reflects the direct impact on asset prices when investors rebalance their portfolios in response to the central bank's QE-related asset purchases.

[2] In an open economy framework, a portfolio rebalancing usually implies the inclusion of foreign assets into a portfolio by selling the local currency. The signaling channel may significantly affect expectations about the conditions in one economy and, therefore, implies fund flows in and out the country with effects on the relative price of the currency compared to others.

changes across several time horizons (in terms of hours) before and/or after the QE announcements using appropriate dummy variables.

The empirical results reveal a pattern of decline in the mean of GBP and JPY across different time horizons around the QE announcements of the corresponding central banks, without any effect on the volatility of these currencies. This implies the credibility and effectiveness of the QE strategies followed by the BoE and BoJ. On the other hand, we find that the ECB's announcements cause a delayed devaluation of EUR and a positive impact on its volatility, implying an unclear signal of future monetary policy actions for investors. The results also show a statistically significant decline in the conditional correlation between EUR and GBP around the announcements by the BoE, implying an independent path for GBP and a significant degree of credibility for the BoE's QE actions.

The structure of the paper is organized as follows. Section 2 presents the literature review and Section 3 presents the data, the QE announcements and a description of the methodology followed. The empirical results are presented and discussed in Section 4, while Section 5 reports the summary and concluding remarks.

2. Literature review

There is a vast empirical work on the effects of conventional central bank interventions on exchange rate co-movements and volatility (for a review of this literature see Nikkinen and Vähämaa, 2009). Since the seminal paper of Engle et al. (1990), another strand of the literature also investigates volatility spillover linkages among exchange rates. In general, empirical evidence reveals intraday exchange rate volatility transmission (e.g., Fornari et al., 2002; Chang and Taylor, 2003; Inagaki, 2007), asymmetric exchange rate dependence structure (Patton, 2006; Kitamura, 2010), as well as time-varying linkages among currencies during a turmoil period (e.g., Kitamura, 2010; Bubák et al., 2011; Dimitriou and Kenourgios, 2013).[3]

Concerning studies focusing on QE effects on daily exchange rates, Ueda (2012) find that some of the policy measures adopted by the BoJ generated the expected impact on asset prices, with the exception of the exchange rate. Glick and Leduc (2012) show that QE announcements lead to lower long-term interest rates and a depreciation of the U.S. dollar and the British pound on announcement days. In this line of research, Neely (2012) shows that the first program of large-scale asset purchases (LSAP) by the Fed reduces bond yields not only in US but also in other countries and the US dollar depreciates significantly. Fratzscher et al. (2013) provide evidence that the first LSAP leads to fund inflows in US and an appreciation of USD, while the second LSAP leads to the opposite results. Their results also suggest that there are global spillovers and externalities from US monetary policy decisions in advanced and emerging economies.

A swift of the unconventional monetary policy literature toward the use of high frequency data provide evidence for a positive relationship between unexpected interest rate changes and exchange rate movements (Kearns and Manners, 2006; Faust et al., 2007). Swanson (2011) finds that the effects of "Operation Twist" followed by the Fed seem to have been diminished substantially as moving from Treasury securities toward to private sector credit instruments. According to the 'Operation Twist', the central bank sells short-term government bonds and uses the proceeds to buy long-term bonds without influencing the size of its balance sheet. Conrad and Lamla (2010) show that the ECB's statements about price stability, and not about economic activity and monetary aggregates, have the most significant impact on EUR/USD exchange rate.

We have to mention at that point that, while there are some studies investigating the effect of QE announcements on bond and stock markets' volatility, little attention has been given on foreign exchange market volatility, a gap that this study attempts to cover. For example, Joyce et al. (2011) support that the onset of QE caused a significant drop in stock index volatility. Steeley and Matyushkin (2015) argue that QE in UK contributed to a significant drop in the volatility of the gilt-edged market.

[3] A number of studies on exchange rate behavior also provide evidence that unexpected news or heterogeneous interpretations of news can extend adjustment periods for hours (see for example Ehrmann and Fratzscher, 2005, and Love and Payne, 2008).

3. Data and methodology

3.1. Data

The data comprises intraday (1-h) dollar exchange rates expressed in each of the three investigated foreign currencies (EUR, GBP, JPY).[4] Intraday data may reveal significant information about the exchange rate dynamics not easily seen on a daily basis. Further, it allows statistical analysis of relatively longer periods of time than a higher-frequency data, while it avoids any potential lack of data in smaller time intervals. The 1-h interval data set spans a period from 3rd February 2009 until 31st December 2012 in order to secure a sufficient number of QE announcements by the three central banks. The three exchange rates are selected due to their major importance to international FX market, as measured by their trading volumes. All variables are in log difference form.

Tables A1–A3 report the number and the characteristics of QE announcements by the BoJ, the BoE and the ECB, respectively, along with the announcement dates and hours. The announcements which examined in this study relate to the following actions: (i) the enhancement of monetary easing by the BoJ, (ii) the increases of the size of asset purchase program by the BoE, and (iii) the long-term refinancing operations (LTROs) with allotted amount greater than 100 billion Euro by the ECB.[5]

The BoJ in 2009 expanded its policy actions as a response to the global financial crisis to include outright purchases of corporate bonds and commercial papers, expansion of outright purchases of Japanese government bonds, fixed rate fund supplying operations, and a fund provisioning measure to support growth. In October 2010, the BoJ embarked on a new "comprehensive monetary easing" (CME) policy, since the recovery began to slow during the autumn of 2010. Besides a "virtually zero interest rate" policy, the CME included a new asset purchase program, covering corporate bonds, commercial paper, exchange-traded funds (ETFs), and real estate investment trusts (REITs), in addition to government securities, in an effort to reduce term and risk premia (Berkmen, 2012).

In the case of the Fed and the BoE, government bonds purchased within the framework of credit easing or quantitative easing programs largely substituted repos operations from 2009 onwards. On the other hand, the ECB does finance part of the sovereign debt, but it uses another vehicle: the banks. In fact, the ECB does not acquire any sovereign debt directly, but it loans out large amounts of money to the banks which then buy their countries' debt. This has been called the equivalent of quantitative easing, as done by the Fed, the BoJ and the BoE.[6] In order to take into account the magnitude of these loans, we focus on loans greater than €100 billion. Among these loans, there have been two "megabombs" of approximately €500 billion each in December 2011 and in February 2012. These loans helped lowering Italy's and Spain's interest rates, which were then rising dangerously.

3.2. The methodology

To account for possible asymmetries in the behavior of currency returns, the Asymmetric Power ARCH (APARCH) model introduced by Ding et al. (1993) is applied.[7] The APARCH is an extension of the GARCH model (Bollerslev, 1986). The advantage of this model is its flexibility, since it includes a large number of alternative GARCH specifications. Specifically, it increases the flexibility of the conditional variance specification by allowing (a) an asymmetric response of volatility to positive and negative shocks, and (b) the data to determine the power of returns for which the predictable structure in the volatility pattern is the strongest.

[4] The data source is Dukascopy Swiss Forex Bank.

[5] Given that the BoJ QE actions are announced at local time, while those from the Fed and BoE at GMT time, all QE announcements by the three central banks used into the analysis are expressed at GMT time.

[6] According to Pisani-Ferry and Wolff (2012), the Fed, the BoE and the ECB have increased their balance sheets by roughly comparable amounts, but the composition of the increase is entirely different. Specifically, at the end of February 2012, the purchased assets accounted for 103% of the increase in the overall size of the Fed balance sheet since February 2007, and 116% in the UK. In the Eurozone, the repos operations accounted for 64% of the increase in the size of the balance sheet between February 2007 and February 2012, against 20% for government bonds purchased within the framework of the Securities Market Programme and the Covered Bonds Programme.

[7] For applications of this model in economics, see Campos and Karanasos (2008) and the references therein.

The general form of the APARCH(1,1) model is given as follows:

$$r_t = \mu + \varepsilon_t \tag{1}$$

$$\sigma_t^{\delta} = \omega + \alpha(|\varepsilon_{t-1}| - \gamma\varepsilon_{t-1})^{\delta} + \beta\sigma_{t-1}^{\delta} \tag{2}$$

In the mean Eq. (1), r_t is the vector of currency's returns, ε_t is the vector of zero mean white noises, while μ is the vector of expected returns. In the volatility Eq. (2), $\gamma(-1 < \gamma < 1)$ represents the leverage effect, while the power term parameter δ is a Box-Cox transformation of standard deviation σ_t and takes finite positive values. The leverage effect means that a positive (negative) value of γ implies that the past negative (positive) shocks have a deeper impact on current conditional volatility than past positive shocks.

In our univariate APARCH(1,1) specification model, a dummy variable is included in Eqs. (1) and (2) in order to empirically investigate how the currency i (EUR, GBP or JPY) is affected in mean and volatility around the QE announcements of the corresponding central bank. In this part of analysis, we create four dummy variables which are equal to unity for: (i) 1 h after the QE announcements by the three central banks, (ii) 2 h before and 1 h after their announcements, (iii) 1 h before and 1 h after their announcements and (iv) 3 h after their announcements (zero, otherwise). Using various time horizons allows us to identify possible short or long-term effects (in terms of hours) on the mean currency return and volatility around the QE announcements and whether market participants discount the news or not.

After identifying possible effects on mean return and volatility, cross correlations are investigated around the QE announcements by using a multivariate DCC model of Engle (2002).[8] The DCC model involves two-stage estimation of the conditional covariance matrix H_t. In the first stage, a univariate APARCH model is fitted for each of the exchange rates returns and estimates of $\sigma_{ii,t}^{\delta/2}$ are obtained. In the second stage, exchange rates-return residuals are transformed by their estimated standard deviations from the first stage. That is, $\eta_{i,t} = \varepsilon_{i,t}/\sigma_{ii,t}^{\delta/2}$, where $\eta_{i,t}$ is then used to estimate the parameters of the conditional correlation. So, the multivariate conditional variance is specified as:

$$H_t = D_t Corr_t D_t \tag{3}$$

where $D_t = diag\,(\sigma_{11t}^{\delta/2} \ldots \sigma_{NNt}^{\delta/2})$, $\sigma_{ii,t}^{\delta/2}$ is defined as the conditional standard deviation obtained from the APARCH model of the first stage. The evolution of correlation in the DCC model is given by:

$$Q_t = (1 - \alpha - \beta)\bar{Q} + \alpha\eta_{t-1}\eta'_{t-1} + \beta Q_{t-1} \tag{4}$$

where $Q_t = (q_{ij,t})$ is the $n \times n$ time-varying covariance matrix of residuals, $\bar{Q} = E[\eta_t\eta'_t]$ is the $n \times n$ time-invariant variance matrix of η_t, while α and β are nonnegative scalar parameters satisfying $\alpha + \beta < 1$. Since Q_t does not have unit elements on the diagonal, the correlation matrix $Corr_t$ is obtained by scaling it as follows:

$$Corr_t = (diag(Q_t))^{-1/2} Q_t (diag(Q_t))^{-1/2} \tag{5}$$

A typical element of $Corr_t$ has the form:

$$\rho_{ij,t} = q_{ij,t}/\sqrt{q_{ii,t}q_{jj,t}}, \quad i, j = 1, 2 \ldots n, \quad \text{and} \quad i \neq j \tag{6}$$

Thus, the correlation coefficient at time t is defined as follows:

$$\rho_{ijt} = \frac{(1-\alpha-\beta)\bar{q}_{ij} + \alpha\eta_{i,t-1}\eta_{j,t-1} + \beta q_{ij,t-1}}{\sqrt{(1-\alpha-\beta)\bar{q}_{ii} + \alpha\eta_{i,t-1}^2 + \beta q_{i,t-1}}\sqrt{(1-\alpha-\beta)\bar{q}_{jj} + \alpha\eta_{j,t-1}^2 + \beta q_{jj,t-1}}} \tag{7}$$

which is the key element in this methodology, as it represents the conditional correlation between each pair of currencies.[9]

[8] The DCC model of Engle (2002) is applied within a GARCH framework.

[9] According to Engle (2002), the log likelihood function is estimated as follows:

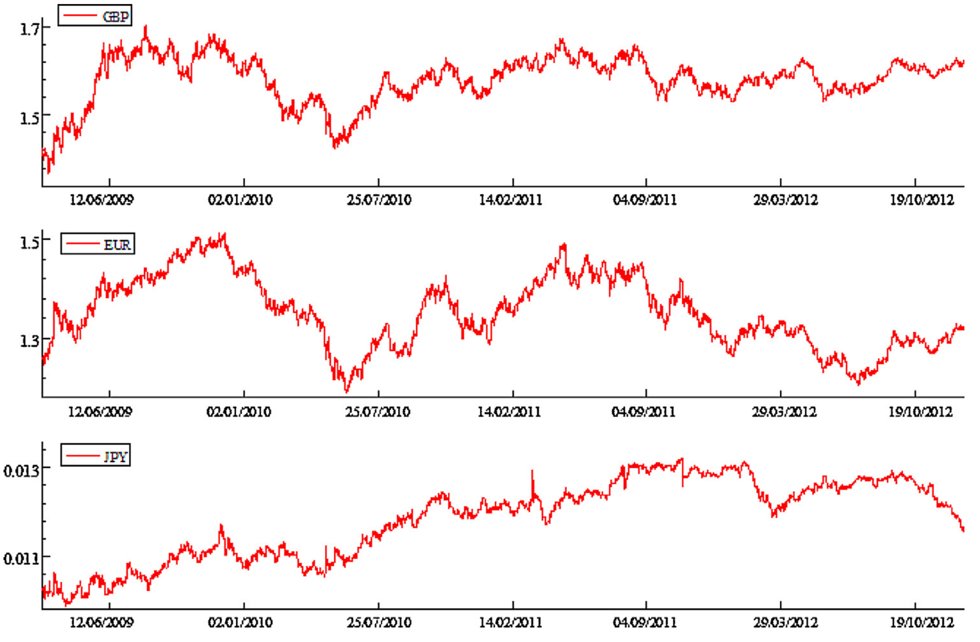

Fig. 1. Exchange rates behavior over time.

In this study we use the following AR(1) equation in order to describe the behavior of DCCs and identify any possible effects of QE announcements on the estimated conditional correlations.

$$D\hat{C}C_{ij,t} = c_0 + \psi_1 D\hat{C}C_{ij,t-1} + \beta_i Dummy_{i,t} + \beta_j Dummy_{j,t} + \lambda_t \tag{8}$$

where $D\hat{C}C_{ij,t}$ is the estimated conditional correlation between i and j currencies (i, j = EUR, GBP and JPY, $i \neq j$) and c_0 is a constant term. For each of the four time horizons, $dummy_{i,t}$ corresponds to the QE announcements by the central bank of currency i and $dummy_{j,t}$ corresponds to the QE announcements by the central bank of currency j. A statistically significant dummy coefficient indicates that the correlation around the QE announcements is significantly different from that of the rest of the period.

4. Empirical results

4.1. Preliminary analysis

Fig. 1 illustrates the evolution of exchange rates during the period from 3rd February 2009 until 31st December 2012. The figure shows significant changes in the mean over time, while JPY follows a totally different path compared to the other two currencies. Fig. 2 plots the currencies' returns over time. The figure shows that all currencies trembled by different intensity during the sample period.

$$l_t(\theta, \phi) = -\frac{1}{2}\left[\sum_{t=1}^{T}(n\log(2\pi) + \log|D_t|^2 + \varepsilon_t' D_t^{-2}\varepsilon_t) + \sum_{t=1}^{T}(\log|Corr_t| + \eta_t' Corr_t^{-1}\eta_t - \eta_t'\eta_t)\right]$$

where θ and ϕ are the parameters in D and $Corr$, respectively. The first part of the above equation represents the volatility and is the sum of individual APARCH likelihoods. The log-likelihood function is maximized by using a two-stage approach. At the first stage, the log-likelihood function can be maximized over the D parameters. At the second stage, given the estimated parameters in the first stage, the correlation component of the likelihood function is maximized (the second part of the equation) in order to estimate correlation coefficients.

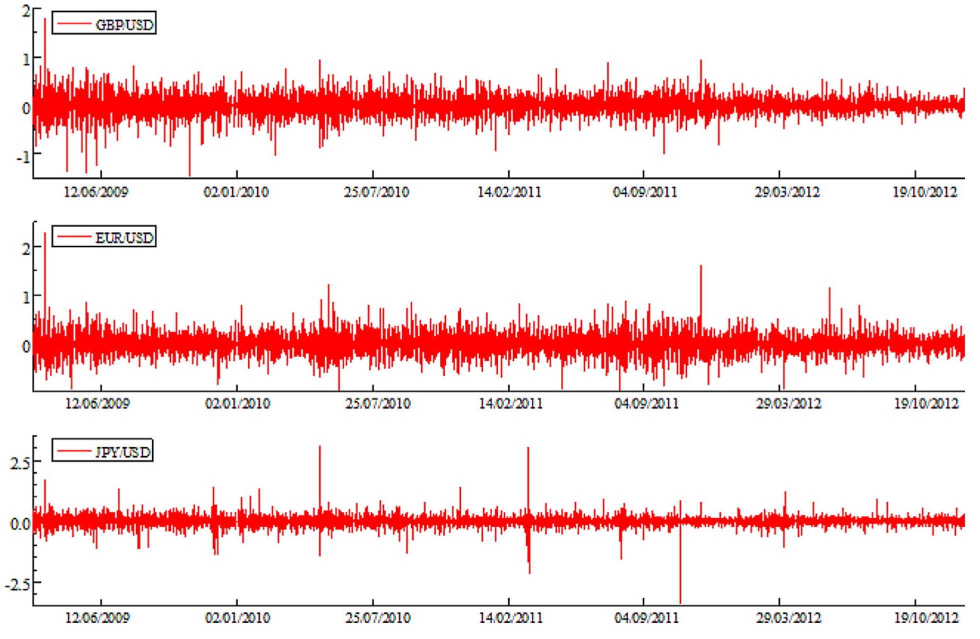

Fig. 2. Exchange rates returns over time.

They also exhibit volatility clustering, revealing the presence of heteroskedasticity and strong ARCH effects.

Summary statistics for the exchange rates returns are displayed in Table 1. From this table, we observe that JPY has the highest level of kurtosis, indicating that extreme changes tend to occur more frequently for this currency. Also, all returns exhibit high values of kurtosis. To accommodate the presence of "fat tails", we assume student-*t* distributed innovations. Skewness is present in all returns, supporting the existence of asymmetric effects. Furthermore, the Jarque-Bera statistic rejects normality at the 1% level for all currencies returns, unit root and stationarity tests (not reported here for economy of space reasons) show that all the return series are stationary, I(0), while they exhibit strong ARCH effects. Thus, APARCH is an appropriate specification in order to capture volatility clustering, leverage and asymmetric characteristics.

Table 1
Descriptive statistics.

	Currency's returns		
	EUR	GBP	JPY
Mean	2.03E−06	4.46E−06	4.22E−06
Median	0.0000	0.0000	0.0000
Max.	0.0231	0.0178	0.0311
Min.	−0.0095	−0.0144	−0.0333
Std. deviation	0.0011	0.0011	0.0011
Skewness	0.3682	−0.1015	0.3305
Kurtosis	15.8440	15.5627	73.465
Jarque-Bera	23,1854.50[a] [0.0000]	22,1140.40[a] [0.0000]	695,621.00[a] [0.0000]
ARCH (5)	124.94[a]	253.15[a]	249.11[a]

Notes: Exchange rates are in 1-h frequency. The horizon under consideration ranges from February 2009 to December 2012. ARCH (5) is the ARCH LM test up to 5 h (F-statistic is reported here). The numbers in brackets are *p*-values.

[a] Statistical significance at 1% level.

Table 2
Estimation results of ECB's QE effects on mean return and volatility of EUR.

Estimates of univariate APARCH(1,1)				
Time horizons	(−2 h, +1 h)	(−1 h, +1 h)	(+1 h)	(+3 h)
Arch	0.0406[b]	0.0404[b]	0.0406[b]	0.0408[b]
(*t*-stat.)	(3.532)	(3.464)	(3.422)	(3.446)
Garch	0.9481[b]	0.9486[b]	0.9468[b]	0.9487[b]
(*t*-stat.)	(88.34)	(88.44)	(88.24)	(87.87)
Gamma (γ)	0.1011[a]	0.1036[a]	0.1044[a]	0.1068[a]
(*t*-stat.)	(2.210)	(2.255)	(2.261)	(2.298)
Delta (δ)	1.7795[b]	1.7664[b]	1.7556[b]	1.754[b]
(*t*-stat.)	(8.963)	(8.882)	(8.840)	(8.683)
β_{ECB} (Mean)	0.0059	0.0109	−0.0027	−0.0169[a]
(i-stat.)	(0.686)	(1.177)	(−0.254)	(−2.166)
β_{ECB} (Volatility)	0.0017[b]	0.0020[b]	0.0027[b]	0.0013[b]
(*t*-stat.)	(4.204)	(3.795)	(3.448)	(3.030)
df	5.9990[b]	5.9990[b]	5.9996[b]	5.9980[b]
(*t*-stat.)	(104.70)	(104.80)	(104.60)	(104.80)

Notes: Optimal lags of the model are selected by Akaike (AIC) and Schwarz (SIC) information criteria (not reported). γ is the leverage term, δ is the power term of returns and df is Student's distribution's degrees of freedom. β_{ECB} is the dummy coefficient corresponding to the time horizons around the QE announcements by the ECB, which is included in the mean and variance equations of the APARCH model. The leverage terms (γ), the power terms (δ), as well as the *t*-student degrees of freedom parameters (df) are all statistically significant, supporting the selection of the APARCH specification. Furthermore, the ARCH and GARCH parameters are statistically significant, non-negative and their sum is below unity, justifying the appropriateness of our model.

[a] Denote statistical significance at 5% level.

[b] Denote statistical significance at 1% level.

4.2. *The effects of QE on exchange rates' returns and volatilities*

Tables 2–4 present the estimation results of the univariate APARCH(1,1) specification for all three exchange rates (EUR/USD, GBP/USD, JPY/USD) by including the QE dummies of the corresponding central bank in the mean and volatility. The results for EUR around the QE announcements of the ECB are presented in Table 2. The dummy coefficients of the mean equation (β_{ECB}) are statistically significant only for the time horizon of +3 h, implying a delayed reaction of EUR to monetary policy news announcements. The negative sign of the dummy coefficient shows the reduction of EUR 3 h after the ECB's QE announcements. Moreover, the dummy coefficients on the variance equation are positive and statistically significant, implying an increased volatility for EUR across all four different time horizons around the ECB's announcements. The results for GBP and JPY are presented in Tables 3 and 4, respectively. The dummy coefficients of the mean equation (β_{BoE} and β_{BoJ}) are negative and statistically significant across the time horizons before and after the BoE's QE announcements and for 1 h and 3 h after the BoJ's announcements. These findings indicate a direct decline of British Pound and Japanese Yen due to the QE announcements. Moreover, no significant effects on currencies' volatilities are found.

By comparing our findings for the three currencies, we can summarize that the BoE's and BoJ's QE announcements cause an immediate devaluation of GBP and Yen, respectively, while there is no impact on their respective variances. This effect implies the credibility and effectiveness of the QE announcements by the BoE and BoJ and a clear trend on investors' reactions. On the other hand, the reduction of EUR is delayed and accompanied by increased variability across all sub-periods around the announcements, implying an unclear signal of future monetary policy actions for investors.

4.3. *The multivariate APARCH(1,1)-DCC estimates*

By looking at Table 5, the pairwise unconditional sample correlation values among currencies during the period 2009–2012 on a yearly basis provide some interesting information. The results provide a clear evidence of "jumps" in correlation levels across the years, especially between GBP-JPY and EUR-JPY. Specifically, the changes in dependence among the forth mentioned currency pairs

Table 3
Estimation results of BoE's QE effects on mean return and volatility of GBP.

Estimates of univariate APARCH(1,1)				
Time horizons	(−2 h, +1 h)	(−1 h, +1 h)	(+1 h)	(+3 h)
Arch	0.0912[c]	0.0911[c]	0.9119[c]	0.0912[c]
(*t*-stat.)	(12.080)	(12.060)	(12.040)	(12.010)
Garch	0.8924[c]	0.8923[c]	0.8919[c]	0.8924[c]
(*t*-stat.)	(109.80)	(109.50)	(109.71)	(109.20)
Gamma (γ)	0.0561[a]	0.0570[a]	0.0582[b]	0.0577[b]
(*t*-stat.)	(1.922)	(1.950)	(1.985)	(1.967)
Delta (δ)	2.2852[c]	2.2873[c]	2.2859[c]	2.2824[c]
(*t*-stat.)	(17.620)	(17.590)	(17.660)	(17.530)
β_{BoE} (Mean)	−0.0764[a]	−0.1347[b]	−0.1781[c]	−0.1256[b]
(*t*-stat.)	(−1.695)	(−2.410)	(−2.599)	(−2.217)
β_{BoE} (Volatility)	0.0020	0.0029	0.0030	0.0015
(*t*-stat.)	(1.091)	(1.149)	(0.952)	(0.704)
df	3.1938[c]	2.9885[c]	3.4415[c]	3.1165[c]
(*t*-stat.)	(31.87)	(32.49)	(34.16)	(33.62)

Notes: Optimal lags of the model are selected by Akaike (AIC) and Schwarz (SIC) information criteria (not reported). γ is the leverage term, δ is the power term of returns and df is Student's distribution's degrees of freedom. β_{BoE} is the dummy coefficient corresponding to the time horizons around the QE announcements by the BoE, which is included in the mean and variance equations of the APARCH model. The leverage terms (γ), the power terms (δ), as well as the *t*-student degrees of freedom parameters (df) are all statistically significant, supporting the selection of the APARCH specification. Furthermore, the ARCH and GARCH parameters are statistically significant, non-negative and their sum is below unity, justifying the appropriateness of our model.

[a] Denote statistical significance at 10% level.
[b] Denote statistical significance at 5% level.
[c] Denote statistical significance at 1% level.

Table 4
Estimation results of BoJ's QE effects on mean return and volatility of JPY.

Estimates of univariate APARCH(1,1)				
Time Horizons	(−2 h, +1 h)	(−1 h, +1 h)	(+1 h)	(+3 h)
Arch	0.0429[b]	0.0439[b]	0.0445[b]	0.0452[b]
(*t*-stat.)	(5.216)	(5.866)	(5.773)	(5.681)
Garch	0.9492[b]	0.9484[b]	0.9480[b]	0.9475[b]
(*t*-stat.)	(18.14)	(15.25)	(14.86)	(14.39)
Gamma (γ)	−0.1598[a]	−0.1564[a]	−0.1557[a]	−0.1543[a]
(*t*-stat.)	(−2.008)	(−2.011)	(−2.023)	(−2.111)
Delta (δ)	1.7008[b]	1.7150[b]	1.7193[b]	1.7258[b]
(*t*-stat.)	(11.045)	(10.866)	(10.963)	(10.236)
β_{BoJ} (Mean)	−0.0619	−0.0884	−0.2214[b]	−0.1834[b]
(*t*-stat.)	(−0.521)	(−0.745)	(−2.967)	(−3.083)
β_{BoJ} (Volatility)	0.0323	0.0435	0.0621	0.0411
(*t*-stat.)	(0.998)	(0.870)	(0.715)	(0.646)
df	5.4655[b]	5.0931[b]	5.4815[b]	5.9990[b]
(*t*-stat.)	(27.05)	(25.67)	(26.58)	(27.96)

Notes: Optimal lags of the model are selected by Akaike (AIC) and Schwarz (SIC) information criteria (not reported). γ is the leverage term, δ is the power term of returns and df is Student's distribution's degrees of freedom. β_{BoJ} is the dummy coefficient corresponding to the time horizons around the QE announcements by the BoJ, which is included in the mean and variance equations of the APARCH model. The leverage terms (γ), the power terms (δ), as well as the t-student degrees of freedom parameters (df) are all statistically significant, supporting the selection of the APARCH specification. Furthermore, the ARCH and GARCH parameters are statistically significant, non-negative and their sum is below unity, justifying the appropriateness of our model.

[a] Denote statistical significance at 5% level.
[b] Denote statistical significance at 1% level.

Table 5
Sample correlation analysis among currencies.

Year	Pairwise sample correlation		
	GBP-EUR	GBP-JPY	EUR-JPY
2009	0.6529	0.0361	0.1886
2010	0.6365	−0.0190	0.0198
2011	0.6556	0.1686	0.1962
2012	0.6426	0.0312	0.0420

Notes: This table presents the evolution of pairwise unconditional sample correlations among currencies from 2009 to 2012 on a yearly basis.

Table 6
Estimation results of the multivariate APARCH(1,1)–DCC model.

	EUR	GBP	JPY
Panel A: Estimates of univariate APARCH(1,1)			
Arch	0.0315[b]	0.0913[b]	0.0603[b]
(*t*-stat.)	(3.337)	(11.960)	(7.353)
Garch	0.9698[b]	0.9023[b]	0.9342[b]
(*t*-stat.)	(90.220)	(111.300)	(60.75)
Gamma (γ)	0.1052[a]	0.0554[*]	−0.1203[a]
(*t*-stat.)	(2.275)	(1.897)	(−2.374)
Delta (δ)	1.6885[b]	2.2680[b]	2.3494[b]
(*t*-stat.)	(8.743)	(17.900)	(5.828)
Panel B: Estimates of multivariate DCC			
Alpha	0.0154[b]		
(*t*-stat.)	(5.272)		
Beta	0.9678[b]		
(*t*-stat.)	(93.60)		
df	7.5974[b]		
(*t*-stat.)	(8.364)		
Panel C: Diagnostic tests			
Hosking (20)	27.341 [0.1845]		
Hosking^2 (20)	4.718 [0.6297]		
McLeod-Li (20)	27.184 [0.1860]		
McLeod-Li^2 (20)	4.682 [0.6307]		

Notes: Optimal lags of the model are selected by Akaike (AIC) and Schwarz (SIC) information criteria (not reported). γ is the leverage term, δ is the power term of returns, alpha and beta are the ARCH and GARCH parameters and df is Student's distribution's degrees of freedom. 20 lags are used for both Hosking (1980) and McLeod and Li (1983) multivariate Portmanteau statistics on standardized and squared standardized residuals. The numbers in brackets are *p*-values.

[*] Denotes statistical significance at 10% level.

[a] Denote statistical significance at 5% level.

[b] Denote statistical significance at 1% level.

varied widely across the years. This finding suggests the adoption of more sophisticated econometric models such as the DCC, which explores the evolution of correlation values across time.

The estimation results of the multivariate APARCH(1,1)-DCC model are reported in Table 6. In the first stage, we estimate the univariate APARCH(1,1) model for each currency (Panel A). The leverage term γ is statistically significant for all currencies, indicating an asymmetric response of volatilities to positive and negative shocks. According to Patton (2006), such asymmetric effects can be explained by the asymmetric behaviors of central banks in their currency interventions. The exchange rates may display higher volatility during periods of depreciation compared to periods of appreciation when central banks emphasize on competitiveness over price stability. Further, the power terms (δ) are statistically significant, ranging from 1.6885 to 2.3494. When the series are very likely to follow a non-normal error distribution, then the superiority of a squared term ($\delta = 2$) is lost and other power transformations may be more appropriate (Conrad et al., 2011). Thus, these estimates support the selection of the APARCH specification for modeling conditional variance of returns.

Table 7
Descriptive statistics of dynamic conditional correlations.

	EUR-GBP	EUR-JPY	GBP-JPY
Mean	0.6210	0.1994	0.1155
Median	0.6327	0.2074	0.1180
Max.	0.9232	0.8041	0.7666
Min.	0.0034	−0.3948	−0.5969
Std. deviation	0.0758	0.1426	0.1330
Skewness	−1.3332	−0.1607	−0.1291
Kurtosis	7.3143	3.5247	4.5860
Jarque-Bera	36,034.65[a] [0.0000]	530,515.00[a] [0.0000]	361,709.00[a] [0.0000]
ARCH (5)	56,297.37[a]	93,003.15[a]	77,676.29[a]

Notes: This table presents the descriptive statistics for the dynamic conditional correlations between the exchange rates. The horizon under consideration ranges from February 2009 to December 2012. ARCH (5) is the ARCH LM test up to 5 h (*F*-statistic is reported here). The numbers in brackets are *p*-values.

[a] Statistical significance at 1% level.

In the second stage of estimations, we employ the dynamic conditional correlation (DCC) model of Engle (2002). The model is estimated using the quasi-maximum likelihood method to generate consistent standard errors that are robust to non-normality. Estimation results are reported in Table 6 (Panel B). The ARCH and GARCH parameters are statistically significant and non-negative, justifying the appropriateness of our model. Also, the sum of the estimated ARCH and GARCH coefficients in the variance equation is close to unity, implying that the volatility displays a highly persistent pattern. The *t*-student degrees of freedom parameter (df) is also highly significant, supporting the choice of this distribution. Finally, the null hypothesis of no serial correlation is accepted based on the results of Hosking (1980) and McLeod and Li (1983) autocorrelation tests presented in Table 6 (Panel C).

Table 7 presents the descriptive statistics for the dynamic conditional correlations (DCCs) among the three pairs of currencies. The EUR-GBP pair has the highest average DCC (0.6210), indicating that these two currencies are highly correlated. On the other hand, the pair of GBP-JPY has the lowest mean correlation (0.1155). Finally, normality is rejected, while all DCCs exhibit skewness and strong ARCH effects.

Figs. 3 and 4 describe the evolution of the estimated conditional variances and the conditional correlations (DCCs) among the currencies, respectively. Conditional variances indicate some extremes increases during different periods for each currency, while the DCCs among the three pairs display fluctuations over the entire sample period, suggesting that the assumption of constant correlations is not appropriate. These findings motivate a further analysis by employing dummies to estimate the DCCs before and/or after the QE announcements.

4.4. The analysis of DCC around QE announcements

The estimates of conditional correlations based on Eq. (8) are presented in Table 8. The coefficients of the constant terms (c_0) and the AR terms (ψ_1) are both statistically significant for all pairs, with the latter taking values close to unity, indicating a strong persistence in the correlations among the examined exchange rates. Table 8 (Panel A) reports the results for the pair of EUR-GBP. The dummy coefficient β_{BoE} is negative and statistically significant for each of the four time intervals around the announcements by the BoE, indicating that these announcements have a negative impact on the dynamic conditional correlation among the two currencies. One possible explanation for this outcome stems from the diverse behavior of the two currencies during QE announcements. When the BoE announces a QE action, EUR and GBP follow a different path. This behavior supports the "competitive" character of the two currencies and reflects that the monetary policy followed by two central banks is strongly competitive. On the other hand, the dummy coefficient β_{ECB} is statistically insignificant for all periods, suggesting that there is no impact on the correlation between EUR and GBP around the ECB announcements. Therefore, the actions announced by the BoE, which have clear

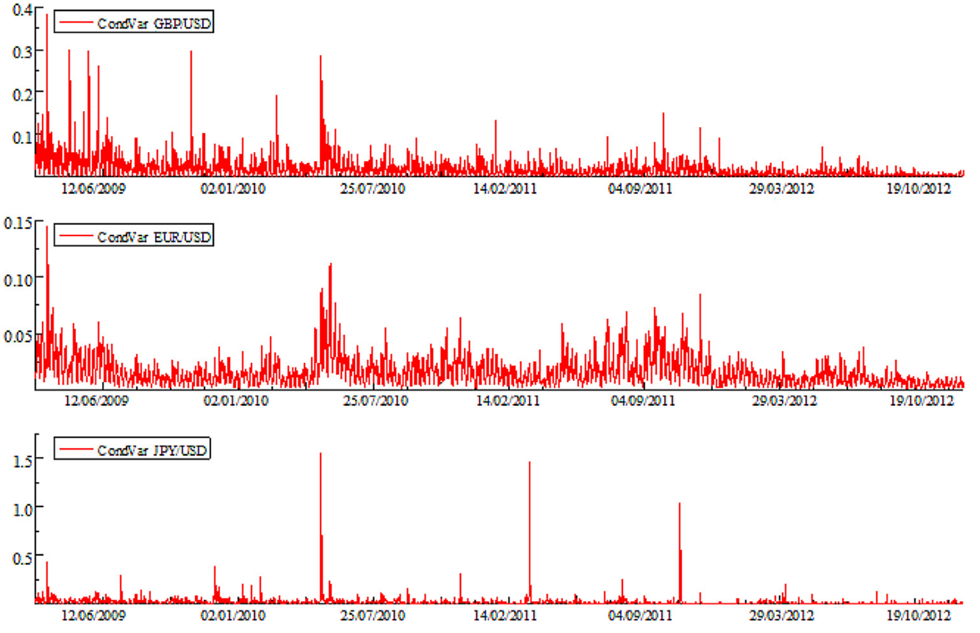

Fig. 3. Conditional variance for each currency.

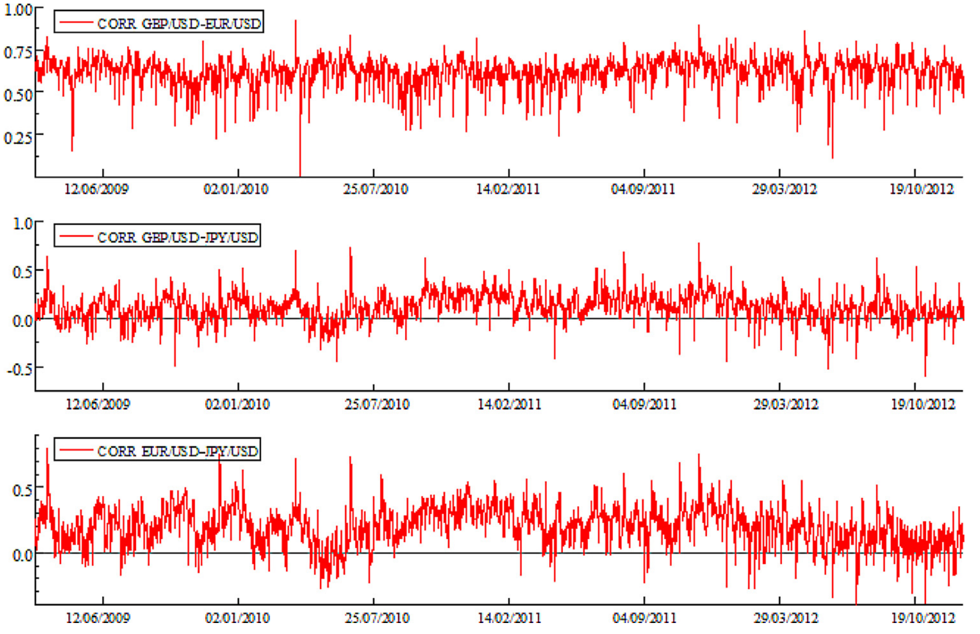

Fig. 4. Dynamic conditional correlations between exchange rates over time.

Table 8
Tests of changes in dynamic correlations among currencies.

Coefficients/time horizons	(−2 h, +1 h)	(−1 h, +1 h)	(+1 h)	(+3 h)
Panel A: EUR – GBP				
c_0	0.0163[c]	0.0163[c]	0.0163[c]	0.0164[c]
(t-stat.)	(17.0597)	(17.0586)	(17.0623)	(17.0669)
ψ_1	0.9736[c]	0.9736[c]	0.9736[c]	0.9735[c]
(t-stat.)	(646.365)	(646.343)	(646.306)	(645.826)
β_{ECB}	−0.0034	−0.0021	−0.0012	−0.0012
(t-stat.)	(−0.7625)	(−0.6782)	(−0.1577)	(−0.7753)
β_{BoE}	−0.0106[a]	−0.0153[b]	−0.0231[a]	−0.0201[b]
(t-stat.)	(−1.7305)	(−1.9687)	(−1.9273)	(−2.4749)
Adj. R^2	0.9477	0.9477	0.9478	0.9478
Panel B: GBP – JPY				
c_0	0.0020[c]	0.0021[c]	0.0021[c]	0.0021[c]
(t-stat.)	(11.9644)	(12.0045)	(12.010)	(12.1174)
ψ_1	0.9816[c]	0.9816[c]	0.9816[c]	0.9816[c]
(t-stat.)	(992.555)	(992.828)	(992.895)	(992.981)
β_{BoE}	0.0105	0.0103	0.0164	0.0011
(t-stat.)	(1.1739)	(0.8826)	(1.0683)	(0.0893)
β_{BoJ}	0.0021	0.0009	0.0012	−0.0056
(t-stat.)	(0.8760)	(0.5806)	(0.4818)	(−1.0857)
Adj. R^2	0.9636	0.9636	0.9636	0.9636
Panel C: EUR – JPY				
c_0	0.0028[c]	0.0028[c]	0.0028[c]	0.0028[c]
(t-stat.)	(14.0860)	(14.1109)	(14.1084)	(14.1697)
ψ_1	0.9855[c]	0.9855[c]	0.9855[c]	0.9855[c]
(t-stat.)	(1258.290)	(1258.595)	(1258.773)	(1258.597)
β_{ECB}	−0.0072[a]	−0.0084[a]	−0.0107	−0.0014
(t-stat.)	(−1.8101)	(−1.8354)	(−1.5241)	(−0.3069)
β_{BoJ}	0.0017	3.06E−05	0.0003	−0.0080
(t-stat.)	(0.8215)	(0.0159)	(0.9014)	(−1.6325)
Adj. R^2	0.9713	0.9713	0.9713	0.9713

Notes: Estimates are based on Eq. (8) in the text. ψ_1 is the coefficient of $D\hat{C}C_{ij,t}$, which is the correlation coefficient with one lag between each pair of the currencies. The lag length is determined by AIC and SIC criteria (not reported). β is the dummy coefficient corresponding to the time horizons around the QE announcements by the ECB (β_{ECB}), BoE (β_{BoE}) and BoJ (β_{BoJ}). Newey-West consistent estimators are employed to correct heteroskedasticity and autocorrelation problems. The high values of adjusted R^2 suggest that the regression models are well specified.

[a] Statistical significance at 10% level.
[b] Statistical significance at 5% level.
[c] Statistical significance at 1% level.

QE characteristics compared to the ECB measures during the examined period, seem to be one of the driving forces of the time-varying correlation between EUR and GBP.

The results of Table 8 (Panel B) for the pair of GBP-JPY show that the dummy coefficients β_{BoE} and β_{BoJ} are statistically insignificant around the QE announcements by the BoE and the BoJ. This finding indicates that the QE announcements by both central banks have neither short nor long-term impact on the dynamic correlation between GBP and JPY. Thus, the two currencies cannot be characterized as competitive currencies as in case of EUR and GBP. It seems that other type of news may drive the correlation between the two currencies, given that the BoE and the BoJ follow a similar QE strategy as a response to the global crisis, in contrast to the ECB.

Finally, the results for the pair of EUR-JPY reported in Table 8 (Panel C) show that the dummy coefficients β_{ECB} and β_{BoJ} are not statistically significant around the QE announcements by the ECB and the BoJ. The only exemption is the coefficient β_{ECB} corresponding to the time horizons (−2 h, +1 h) and (−1 h, +1 h) around the ECB announcements. During these time horizons, the coefficient takes negative and statistically significant values at 10% level of significance. This suggests that traders discounted the announced events and their actions lead EUR and JPY to a weak diverse path around the QE announcements by the ECB.

5. Conclusions

This paper examines the effects of central banks' QE announcements on mean returns, volatilities and dynamic conditional correlations (DCCs) of three major international currencies (EUR, GBP and JPY) on an intra-day basis.

The findings for the QE impact on mean and volatility show a delayed negative response of EUR accompanied with increased variability before and after the ECB' announcements. This implies an unclear signal of future monetary policy actions for investors, which can be attributed to the price stabilization policy followed by the ECB ("strong currency" policy). On the other hand, the BoE's and BoJ's QE announcements cause a more direct and significant reduction on their currencies without producing increased volatility. These findings highlight the increased credibility and effectiveness of the BoE's and BoJ's monetary easing policies and support the existence of a signaling channel in the foreign exchange markets. Monetary authorities should take into account these differences in the transmission of QE announcements on foreign exchange markets. High frequency data may reveal the perception of markets concerning the credibility of the central banks to employ QE actions.

The analysis of the DCCs behavior among currencies provides several interesting findings with important implications from the investors' and policy makers' perspective. The conditional correlation between two competitive high correlated currencies, EUR and GBP is affected negatively around the QE announcement by the BoE. This result implies that, although EUR shares the higher correlation with GBP during the full sample period, the BoE announced QE actions lead the two currencies to follow a different path. This dynamic conditional correlation behavior may be considered as evidence of non-cooperative monetary policies and highlight the need for some form of policy coordination among the BoE and the ECB on reducing recent crisis effects. It also implies a high degree of competiveness between the two currencies in an international portfolio and a portfolio rebalancing. On the other hand, the dynamic correlation between GBP and JPY remains unaffected around the QE announcements by both the BoE and BoJ, while EUR and JPY follow a weak diverse path over the period of the ECB's QE announcements.

Appendix.

Tables A1–A3

Table A1
Bank of Japan's quantitative easing announcements.

Nr.	Date	Announcement
1	Dec. 1, 2009	Enhancement of Easy Monetary Conditions (Announced at 3:38 p.m.)
2	Mar. 17, 2010	Statement on Monetary Policy (Expansion of the measure to encourage a decline in longer-term interest rates, Announced at 12:49 p.m.)
3	May 21, 2010	Statement on Monetary Policy (Policy unchanged, Preliminary Framework for the Fund-Provisioning Measure to Facilitate Strengthening of the Foundations for Economic Growth, Announced at 12:42 p.m.)
4	Jun. 15, 2010	Statement on Monetary Policy (Policy unchanged, Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth, Announced at 12:56 p.m.)
5	Aug. 30, 2010	Enhancement of Easy Monetary Conditions (Announced at 12:11 p.m.)
6	Oct. 5, 2010	Comprehensive Monetary Easing (Announced at 1:38 p.m.)
7	Oct. 28, 2010	Statement on Monetary Policy (Policy unchanged, Establishment of the Asset Purchase Program, Announced at 1:31 p.m.)
8	Nov. 5, 2010	Statement on Monetary Policy (Policy unchanged, Purchases of ETFs and J-REITs, Announced at 11:36 a.m.)
9	Mar. 14, 2011	Enhancement of Monetary Easing (Announced at 2:48 p.m.)
10	Jun. 14, 2011	Statement on Monetary Policy (Policy unchanged, New Line of Credit Established for the Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth, Announced at 12:42 p.m.)

Table A1 (*Continued*)

Nr.	Date	Announcement
11	Aug. 4, 2011	Enhancement of Monetary Easing (Announced at 2:00 p.m.)
12	Oct. 27, 2011	Enhancement of Monetary Easing (Announced at 1:31 p.m.)
13	Feb. 14, 2012	Enhancement of Monetary Easing (Announced at 12:43 p.m.)
14	Mar. 13, 2012	Statement on Monetary Policy (Enhancement of the Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth, Announced at 2:07 p.m.)
15	Apr. 10, 2012	Statement on Monetary Policy (A New U.S. Dollar Lending Arrangement Established as part of the "Fund-Provisioning Measure to Support Strengthening the Foundations for Economic Growth," Announced at 12:09 p.m.)
16	Apr. 27, 2012	Enhancement of Monetary Easing (Announced at 12:46 p.m.)
17	Jul. 12, 2012	Statement on Monetary Policy (Announced at 12:51 p.m.)
18	Sep. 19, 2012	Enhancement of Monetary Easing (Announced at 12:44 p.m.)
19	Oct. 30, 2012	Enhancement of Monetary Easing (Announced at 2:46 p.m.)
20	Dec. 20, 2012	Enhancement of Monetary Easing (Announced at 1:01 p.m.)

Source: Bank of Japan (Local time in parentheses).

Table A2
Bank of England's quantitative easing announcements.

Nr.	Date	Announcement
1	May 7, 2009	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £50 Billion to £125 Billion (announced at 12.00 p.m.)
2	Aug. 6, 2009	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £50 Billion to £175 Billion (announced at 12.00 p.m.)
3	Nov. 5, 2009	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £25 Billion to £200 Billion (announced at 01.00 p.m.)
4	Oct. 6, 2011	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £75 billion to £275 billion (announced at 01.00 p.m.)
5	Feb. 9, 2012	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £50 billion to £325 billion (announced at 12.00 p.m.)
6	Jul. 5, 2012	Bank of England maintains Bank Rate at 0.5% and increases size of Asset Purchase Programme by £50 billion to £375 billion (announced at 01.00 p.m.)

Source: Bank of England (GMT time in parentheses).

Table A3
European Central Banks' quantitative easing announcements (LTROs with allotted amount greater than 100 billion Euro).

Nr.	Date	Announcement
1	Mar. 10, 2009	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
2	Apr. 7, 2009	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
3	May 12, 2009	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
4	Jun. 24, 2009	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
5	Jun. 30, 2010	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
6	Sep. 29, 2010	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
7	Dec. 22, 2010	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
8	Mar. 30, 2011	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
9	Jun. 29, 2011	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
10	Sep. 28, 2011	LTRO – Liquidity providing – Standard Tender, Fixed Rate (announced at 11.15 a.m.)
11	Dec. 21, 2011	ECB allots 489 billions to 523 banks in first 36 month LTRO (announced at 11.15 a.m.)
12	Feb. 29, 2012	ECB allots 530 billions to 800 banks in second 36 month LTRO (announced at 11.15 a.m.)

Source: European Central Bank (GMT time in parentheses).

References

Berkmen, P., 2012. Bank of Japan's quantitative and credit easing: are they now more effective? IMF Working Paper 12/2. International Monetary Fund, Washington.
Bollerslev, T., 1986. Generalized autoregressive conditional heteroskedasticity. J. Econom. 31, 307–327.
Breedon, F., Chadha, J., Waters, A., 2012. The financial market impact of UK quantitative easing. Oxf. Rev. Econ. Policy 28, 702–728.

Bubák, V., Kočenda, E., Žikeš, F., 2011. Volatility transmission in emerging European foreign exchange markets. J. Bank. Finance 35, 2829–2841.
Campos, N.F., Karanasos, M.G., 2008. Growth, volatility and political instability: non-linear time-series evidence for Argentina, 1896–2000. Econ. Lett. 100, 135–137.
Chang, Y., Taylor, S.J., 2003. Information arrivals and intraday exchange rate volatility. J. Int. Financ. Mark. Inst. Money 13, 85–112.
Christensen, J., Rudebusch, G., 2012. The response of interest rates to U.S and U.K. quantitative easing. Econ. J. 122, 385–414.
Conrad, C., Karanasos, M., Zeng, N., 2011. Multivariate fractionally integrated APARCH modeling of stock market volatility: a multi-country study. J. Empir. Finance 18, 147–159.
Conrad, C., Lamla, M.J., 2010. The high-frequency response of the EUR-USD exchange rate to ECB communication. J. Money Credit Bank. 42, 1391–1417.
D'Amico, S., English, W., López Salido, D., Nelson, E., 2012. The Federal Reserve's large scale asset purchase programmes: rationale and effects. Econ. J. 122, 415–446.
Dimitriou, D., Kenourgios, D., 2013. Financial crises and dynamic linkages among international currencies. J. Int. Financ. Mark. Inst. Money 26, 319–332.
Ding, Z., Granger, C.W.J., Engle, R.F., 1993. A long memory property of stock market returns and a new model. J. Empir. Finance 1, 83–106.
Ehrmann, M., Fratzscher, M., 2005. Exchange rates and fundamentals: new evidence from real-time data. J. Int. Money Finance 24, 317–341.
Engle, R., Ito, T., Lin, W.L., 1990. Meteor showers or heat waves? Heteroskedastic intraday volatility in the foreign exchange market. Econometrica 58, 525–542.
Engle, R.F., 2002. Dynamic conditional correlation – a simple class of multivariate GARCH models. J. Bus. Econ. Stat. 20, 339–350.
Faust, J., Rogers, J.H., Wang, S., Wright, J.H., 2007. The high-frequency response of exchange rates and interest rates to macroeconomic announcements. J. Monet. Econ. 54, 1051–1068.
Fornari, F., Monticelli, C., Pericoli, M., Tivegna, M., 2002. The impact of news on the exchange rate of the lira and long-term interest rates. Econ. Model. 19, 611–639.
Fratzscher, M., Lo Duca, M., Straub, R., 2013. On the International Spillovers of US Quantitative Easing. European Central Bank, Working Paper Series no 1557.
Gagnon, J.E., Raskin, M., Remache, J., Sack, B.P., 2010. Large-scale asset purchases by the Federal Reserve: did they work? Federal Reserve Bank of New York Staff Report, No. 441.
Glick, R., Leduc, S., 2012. Central bank announcements of asset purchases and the impact on global financial and commodity markets. J. Int. Money Finance 31, 2078–2101.
Hosking, J.R.M., 1980. The multivariate portmanteau statistic. J. Am. Stat. Assoc. 75, 602–608.
Inagaki, K., 2007. Testing for volatility spillover between the British pound and the euro. Res. Int. Bus. Finance 21, 161–174.
Joyce, M., Lasaosa, A., Stevens, I., Tong, M., 2011. The financial market impact of quantitative easing. Int. J. Central Bank. 7 (3), 113–161.
Joyce, M., Miles, D., Scott, A., Vayanos, D., 2012. Quantitative easing and unconventional monetary policy – an introduction. Econ. J. 122, F271–F288.
Kapetanios, G., Mumtaz, H., Stevens, I., Theodoridis, K., 2012. Assessing the Economy-Wide Effects of Quantitative Easing. Bank of England Working Papers No 443.
Kearns, J., Manners, P., 2006. The impact of monetary policy on the exchange rate: a study using intraday data. Int. J. Central Bank. 2, 157–183.
Kitamura, Y., 2010. Testing for intraday interdependence and volatility spillover among the euro, the pound and Swiss franc markets. Res. Int. Bus. Finance 24, 158–171.
Krishnamurthy, A., Vissing-Jorgensen, A., 2011. The effects of quantitative easing on interest rates. Brook. Pap. Econ. Activity 2, 215–287.
Lam, W.R., 2011. Bank of Japan's Monetary Easing Measures: Are They Powerful and Comprehensive? IMF Working Paper 11/264. International Monetary Fund, Washington.
Love, R., Payne, R., 2008. Macroeconomic news, order flows, and exchange rates. J. Financ. Quant. Anal. 43, 467–488.
McLeod, A.I., Li, W.K., 1983. Diagnostic checking ARMA time series models using squared residual autocorrelations. J. Time Ser. Anal. 4, 269–273.
Neely, C., 2012. The large-scale asset purchases had large international effects. Federal Reserve Bank of St. Louis Working Paper Series, No. 2010-018D.
Nikkinen, J., Vähämaa, S., 2009. Central bank interventions and implied exchange rate correlations. J. Empir. Finance 16, 862–873.
Patton, A.J., 2006. Modelling asymmetric exchange rate dependence. Int. Econ. Rev. 47, 527–556.
Perez-Rodriguez, J.V., 2006. The euro and other major currencies floating against the US dollar. Atl. Econ. J. 34, 367–384.
Pisani-Ferry, J., Wolff, G., 2012. Is LTRO QE in disguise. http://www.voxeu.org/article/ltro-quantitative-easing-disguise
Steeley, J.M., Matyushkin, A., 2015. The effects of quantitative easing on the volatility of the gilt-edged market. Int. Rev. Financ. Anal. 37, 113–128.
Swanson, E.T., 2011. Let's twist again: a high-frequency event-study analysis of operation twist and its implications for QE2. Brook. Pap. Econ. Activity 42, 151–207.
Ueda, K., 2012. The effectiveness of non-traditional monetary policy measures: the case of the Bank of Japan. Jpn. Econ. Rev. 63 (1), 1–22.