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The effects of conventional and unconventional monetary policy on exchange rate volatility

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ABSTRACT

This study explores the effects of the conventional and unconventional monetary policies as well as other events related with debt Greek crisis on the behavior of exchange rates. Using a multivariate GARCH model with time-varying conditional variances and covariances, we estimate the effects of these macroeconomic events on both the variances and covariance between the Yen and the Euro in terms of the US dollar. Our findings suggest that the conventional and unconventional measures and specific events relating to Greek debt crisis have significantly increased the exchange rate volatility of the EUR/USD on the one hand, on the other the conditional variance of the JPY/USD are significantly increased by conventional and unconventional monetary policies only. We also find that the conventional measures have decreased the covariance whereas the unconventional measures have significantly increases the covariance of the two currencies. Additionally the BDS test statistic is applied for both the standardised residuals and the squared standardised residuals of the VECH-GARCH model with and without dummies as far as the EUR/USD and JPY/USD concerned. The null hypothesis that the data are white noise is accepted for all dimensions. Finally, the nonparametric causality test is used to examine possible nonlinear causality and the results indicate causality runs unidirectionally from the variance of EUR/USD to the variance of JPY/USD.

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GLOSSARY

1. INTRODUCTION

The foreign exchange market (forex, FX, or currency market) is a global, worldwide decentralized financial market for trading currencies. Financial centers around the world function as anchors of trading between a wide range of different types of buyers and sellers around the clock, with the exception of weekends. The foreign exchange market determines the relative values of different currencies. The primary purpose of the foreign exchange is to assist international trade and investment, by allowing businesses to convert one currency to another currency. It also supports direct speculation in the value of currencies, and the carry trade, speculation on the change in interest rates in two currencies.

The functions of the foreign exchange market are carried out by a number of institutions:

- Commercial banks
- Central banks
- Foreign exchange dealers
- Retail foreign exchange brokers
- Commercial institutions
- Investment management firms
- Hedge fund institutions
- Multinational corporations or MNCs
- Retail foreign exchange traders

Exchange rates are determined in the foreign exchange market, which is open to a wide range of different types of buyers and sellers where currency trading is continuous: 24 hours a day except weekends, i.e. trading from 20:15 GMT on Sunday until 22:00 GMT Friday. There are a wide variety of factors which influence the exchange rate, such as interest rates, inflation and the state of politics and the economy in each country also called rate of exchange or foreign exchange rate or currency exchange rate.

Currency exchange rates tend to be affected by macroeconomic variables, such as the major economic indicators released by governments at fixed intervals. For instance, the Gross Domestic Product (GDP), unemployment rate, and even current interest rates (prime rates) can all affect currency exchange rates. However, it is possible for major political events (such as elections, wars, etc.) to also affect currency exchange rates. Even

commodities (gold, oil prices, wheat, etc.) may affect the exchange rates between countries.

The global financial turmoil that erupted in 2007 and the subsequent sharp downturn in economic activity have elicited an unprecedented response from major central banks. They have cut policy rates aggressively and adopted several measures loosely termed "unconventional monetary policies". This approach to monetary policy has generated much discussion in academia and in the popular press. A number of key issues have become the subject of a heated debate. These discussions, however, are often hampered by varying definitions of such policies and disparate views regarding their transmission channels. Forms of monetary policy, particularly used when interest rates are at or near zero and there are concerns about deflation or deflation is occurring, are referred to as unconventional monetary policy. These include credit easing, quantitative easing, and signalling.

In introducing the Federal Reserve's response to the 2008–9 financial crisis, Fed Chairman Ben Bernanke distinguished the new programme, which he termed "credit easing" from Japanese-style quantitative easing. In credit easing, a central bank purchases private sector assets, in order to improve liquidity and improve access to credit.

Signalling can be used to lower market expectations for future interest rates. For example, during the credit crisis of 2008, the US Federal Reserve indicated rates would be low for an "extended period", and the Bank of Canada made a "conditional commitment" to keep rates at the lower bound of 25 basis points until the end of the second quarter of 2010.

Quantitative easing (QE) is an unconventional monetary policy used by central banks to stimulate the national economy when conventional monetary policy has become ineffective. However, when short-term interest rates are either at, or close to, zero, normal monetary policy can no longer lower interest rates. Quantitative easing may then be used by the monetary authorities to further stimulate the economy by purchasing assets of longer maturity than only short term government bonds, and thereby lowering longer-term interest rates further out on the curve. Quantitative easing can be used to help ensure inflation does not fall below target. Risks include the policy being more effective than intended in acting against deflation – leading to higher inflation, or of not being effective enough – if banks do not lend out the additional reserves.

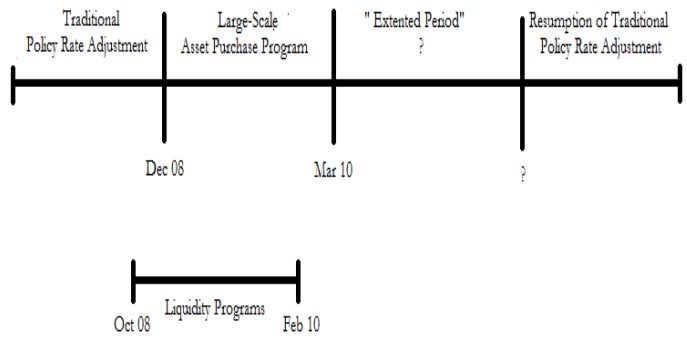
According to Bullard (2010) traditional policy rate adjustment is noted on the left side (Figure 1).The liquidity programs appear beneath and extend from October 2008

until the first quarter of 2010—February or March 2010. These liquidity programs were the response to the crisis, but they are set off to the side because they're not part of the traditional policy response or an attempt to run stabilization policy. Once the rate approached zero in December of 2008, they began our large-scale asset purchase program, which is shown as continuing through March 2010. The Large Scale Asset Purchases Program includes purchases or sales of Treasury securities on an outright basis have been used historically as a tool to manage the supply of bank reserves to maintain conditions in the market for reserves consistent with the federal funds target rate set by the Federal Open Market Committee (FOMC). The timeline then shows a period with some question marks that refers to the extended period language that the FOMC has adopted. During this period, they continued to keep rates as well as they adjusted their asset purchases in one direction or the other as information arrives, perhaps before they wanted to make a decision on the interest rate margin. And then at some point down the road they'd make a decision on the interest rate; they'd return to a traditional policy rate adjustment and would go on from there. So this is just a suggestion about how to think about policy in 2010 and beyond.

The purpose of this thesis is firstly to analyse how specific macroeconomic events related to traditional monetary policy, international events excluding swaps, large scale asset purchases program, unconventional monetary policy and to Greek debt crisis have affected the exchange rate volatility of EUR/USD and JPY/USD. In addition, we examine the direction of causality between the two conditional variances. The rest of the thesis is organised as follows. Section 2 presents literature review. Section 3 outlines the data. Section 4 describes the methodology used in this thesis. Empirical results are presented in the penultimate section while the last section concludes.

Figure 1

Timeline of Monetary Policy



2. LITERATURE REVIEW

There is a growing literature related to the effects of unconventional monetary policies on asset prices and especially to the effect of the large scale asset purchases (LSAP) program which is the main alternative to forward guidance in the unconditional policy arena today on long bond yields and exchange rates. Gagnon et al (2010) review the Federal Reserve's experience with implementing the LSAPs between December 2008 and March 2010 and describe some of the challenges raised by such large purchases in a relatively short time. That is to say, LSAPs have a remarkable impact on the interest rate of assets being purchased as well as on other assets with identical characteristics. A transparent communication among market participants as far as the Federal Reserve's goals, the strategy for LSAPs and to execute such large purchases while maintaining healthy market functioning concerned are some of the primary implements. For instance purchase of agency debt and Treasury securities offered less of a challenge as they were handled by the New York Fed whereas purchases of MBS offered the greatest operational challenge due to the more complex nature and heterogeneity of them. Furthermore, the authors discuss the economic mechanisms through which LSAPs may be expected to stimulate the United States economy and present some empirical evidence on those effects. Specifically, through a combination of portfolio balance effect and market functioning effects, LSAPs may affect market interest rates. In order to estimate the overall effects of the LSAP programs they use both time-series and event-study

methodologies. They found that LSAPs were successful as they show that by reducing the net supply of assets with long maturities, the purchases led to economically meaningful and long-lasting reductions in longer term interest rates on a range of securities. These reductions primarily reflect lower risk premium, including term premiums as a result of the first effect. Regarding the second effect the LSAP programs had an especially powerful effect on longer term interest rates on agency debt and agency MBS by improving market liquidity and removing assets with high prepayment risk from private portfolios.

Joyce et al (2010) study the impact of the Bank of England's quantitative easing (QE) policy on financial markets. They present the basic channels through which QE might affect asset prices are the macro/policy news channel, the portfolio rebalancing channel and the liquidity premia channel. They found that asset prices in the UK recruited significantly during 2009, but not all of the amelioration is due to QE. There are many other domestic and international factors will have also affected asset prices. They line out the United Kingdom's unconventional policy measures that took in response to the financial crisis. Initially, they were drive at providing liquidity support to the markets rather than modifying the implementation of monetary policy. Afterwards, the Bank of England established the Bank of England Asset Purchase Facility Fund as the Fund is completely recouped by the Treasury from any losses arising out of or in conjunction with the Asset Purchase Facility (APF), affirming that the Bank will not bring about any losses arising from the asset purchase programme. The last measure was the operation of the gilt purchase programme where the Bank's gilt purchases were conducted through reverse auctions, whereby counterparties submitted prices at which they offered to sell specific quantities of individual gilts. As the gilts constitute a vast amount of the Bank of England's asset purchases they first examine the market reactions on gilts both through prices and liquidity. In order to quantify how QE has affected UK government securities markets through prices they used event-study methodology and calibration. Specifically, an event-study approach involves focusing on the reaction of market prices over a relatively short interval around each QE announcement. As a result of this method gild yields appear to be 100 basis points lower than they would otherwise have been without QE, with most of the effect coming through the portfolio rebalancing channel. A second way to estimate the impact on yield of QE purchases, based on calibration, is to weight the announcement reactions by the amount of news each announcement contained. Through liquidity APF purchases of gilts have an impact on

the gilt market. Moreover, they try to examine how QE has affected other financial asset prices like equities and corporate bonds. Corporate bond yields fell substantially following QE announcements which can give investors information about the economy's outlook. It is not clear what we would expect the immediate QE impact on equity prices to be. Finally, they use an alternative approach including the estimation of two different portfolio balance models which are the vector autoregressive (VAR) model and a multivariate generalised autoregressive conditional heteroscedasticity (GARCH) in mean model in order to quantify the prospective effects of the Monetary Policy Committee's (MPC's) asset purchases on asset prices. The results of these estimates suggested noticeable uncertainty about the size of the impact. So, authors found that the purchased have had a meaningful impact on financial market and especially gilt yields.

Swanson (2011) appraises the benefits of quantitative policy, termed as 'QE2' by measuring the effect on long-term interest rates of Operation Twist which is a very similar quantitative policy. He used a high-frequency event-study analysis for the effects of Operation Twist as it focus on major announcements. Also, Swanson showed that there are considerable similarities in every significant aspect between that program and QE2. Swanson re-examine this effect using this method because previous studies of Operation Twist used lower-frequency regression methods like Modigliani and Sutch (1966, 1967). He justifies this re-examination analyzing three basic reasons. Next, he initially distinguished major announcements in the course of Operation Twist and then carried out an event-study analysis. He found out that each of these announcements-which are in this case five-reflected a reduction in the net supply of long-term bonds as well as three of these five announcements did have statistical significant effects. On the whole the cumulative effect of the five announcements is highly statistically significant but at 15 basis points, the effect is not very significantly economically.

Neely (2010) finds that the LSAP program significantly reduced the 10-year yields of Australia, Canada, Germany, Japan and the United Kingdom and also depreciated the US dollar versus the Australian dollar, the Canadian dollar, the German mark, the Japanese yen and British pound. Furthermore, at the time of the LSAP announcement, the exchange rates changes are smaller than those implied by an 'overshooting' effect caused by uncovered interest parity (UIP) and long-run purchasing power parity (PPP). On the whole, the evidence is consistent with a powerful but plausible portfolio balance effect. He examined eight announcements, five of those referring to purchases or suggested future purchase and the rest of them caused the

public to anticipate slower or reduced purchases. So, looking at announcements effects can be defined the impact of these purchases. The author investigated that the LSAP announcement not only reduced medium and long-term US bond yield but also significantly reduced long-term foreign bond yields and the spot value of the dollar. According to the fact that international bond returns are imperfectly correlated, the announcement of purchases of US bonds reduced US bond yields more that foreign bond yields. These changes both on US and foreign bond yield are roughly consistent with a simple portfolio choice model as well as these asset prices changes were much too large to have been generated by chance and they closely followed LSAP announcements. Neely states that a high-frequency event-study method of the LSAP announcement effects is most appropriate as asset prices react relatively rapidly to 'news'. He also showed that the simple portfolio balance model implies expected real return changes that LSAP program might produce by reducing the non-US-government portfolio weight on US debt by 22 percent. Likewise, the LSAP announcement prompt smaller exchange rate responses than parity conditions imply, but the actual responses are qualitatively consistent with those predictions. Eventually, he concludes that the FED through the LSAP can manipulate the economy at a zero bound rate.

Multivariate GARCH (MGARCH) models were initially developed in the late 1980s and the first half of the 1990s and after a period of tranquillity in the second half of the 1990s, this area seems to be experiencing again a quick expansion phase (see also the discussion in Bauwens et al 2006). MGARCH models are partly covered in Franses and van Dijk (2000), Gourieroux (1997) and most of the surveys on ARCH models, whereas Bauwens et al 2006 provide an extensive and up to date review including the most recent findings. The most obvious application of MGARCH (multivariate GARCH) models is the study of the relations between the volatilities and co-volatilities of several markets.

A large number of important practical tasks can be accomplished using a multivariate GARCH model. Beine (2004) used a multivariate GARCH (VECH) model to investigate CBIs on the correlation and covariance of the JPY/USD and DM (Euro)/USD exchange rates from 1991-2001. He finds that coordinated CBIs increase conditional variances and covariances as well as the conditional correlation. Also, Chortareas et al (2007) examined the effects of foreign exchange rate interventions by the Bank of Japan (BoJ) on the volatility of the USD/JPY exchange rates and their spillover effect on the Euro/JPY exchange rates from January, 2000-October, 2004. Performing a

multivariate GARCH (VECH) model result in estimations where the BoJ intervention decreases the volatility of the USD/JPY exchange rates whereas the spillover effect has the opposite effect, that is increases the volatility of the Euro/JPY exchange rates.

Antonakakis (2009) study the impact of the G4 Central Bank Interventions (CBIs) of the Federal Reserve (FED), Bank of Japan (BoJ), Bundesbank or European Central Bank (BB/ECB) and the Bank of England (BoE) on exchange returns, their volatility and correlations. This investigation was extended with the application of a multivariate GARCH (DCC) model. The author found that the impact of CBI on the mean returns is significant and reduce volatility only when interventions are conducted unilaterally. On the other hand, in the case of the impact of CBIs on volatility, it is found that both unilateral and coordinated interventions affect volatility, however, in the latter case are more counterproductive the greater the number of central banks intervening in coordination. He showed that coordinated interventions of two central banks can in some cases significantly decrease volatility. However, coordinated interventions of three central banks in the same currency can only increase volatility. Christiansen (2000) investigated how the covariance structure of U.S. government bonds reacts to releases of macroeconomic news. The effects of macroeconomic news on the bond market are conducted using a multivariate model (CCORR) which is an extended version of the constant conditional correlations model. He results suggest that the conditional variances, conditional covariances, and correlations are greater on announcement days than on non-announcement days.

3. DATA

The data of the present study consist of the official daily prices of two major currencies against the United States Dollars (USD). These currencies are the European Union (Euro) and the Japanese Yen (JPY). Exchange rates are noon buying rates in New York City for cable transfers in foreign currencies. The daily observations run from 1st January 2007 to 4th November 2011, giving 1264 data points. The data are collected from Federal Reserve Bank of St.Louis. The two currency pairs are plotted in Figure 2.

Table 1

Summary Statistics of Exchange Rates Returns

	EUR/USD	JPY/USD
Mean	-2.78E-05	-0.000332
Median	-7.48E-05	-0.000350
Maximum	0.030031	0.030593
Minimum	-0.046208	-0.052156
Std. Dev.	0.007076	0.007362
Skewness	-0.277345	-0.441686
Kurtosis	6.232625	8.091313
Jarque-Bera	566.1158	1405.183
Probability	0.000000	0.000000
Sum	-0.035131	-0.418807
Sum Sq. Dev.	0.063187	0.068399
Observations	1263	1263

The summary statistics of the exchange rate returns are presented in Table 1. Both series have similar characteristics to those stylised properties of high frequency financial time series returns documented in the literature. They have approximately zero mean, slightly skewed and fat tailed distributions, as evident from Figure 3.

Additionally, the financial data of our analysis exhibit the following features:

▪ Volatility clustering – The clustering of periods of volatility that is large movements followed by further large movements; the variance of exchange rate returns is not constant over time. This is an indication of shock persistence.

▪ Leptokurtosis effect – By viewing the value of kurtosis, one can conclude that the distribution of exchange rate return exhibit fatter tails than those of a normal distribution as high kurtosis indicates a larger possibility of extreme movements. The standardized fourth moment for a normal distribution is 3, whereas for many financial time series like here is well above 3.

▪ Leverage effect – Volatility increases more after low returns than after high returns. A simple explanation for this is that negative returns imply a larger proportion of debt which leads to a high volatility after smaller changes.

▪ Skewness – All of two exchange rate returns show evidence of some degree of skewness. The effect of skewness may be positive or negative, which describes their departure from symmetry.

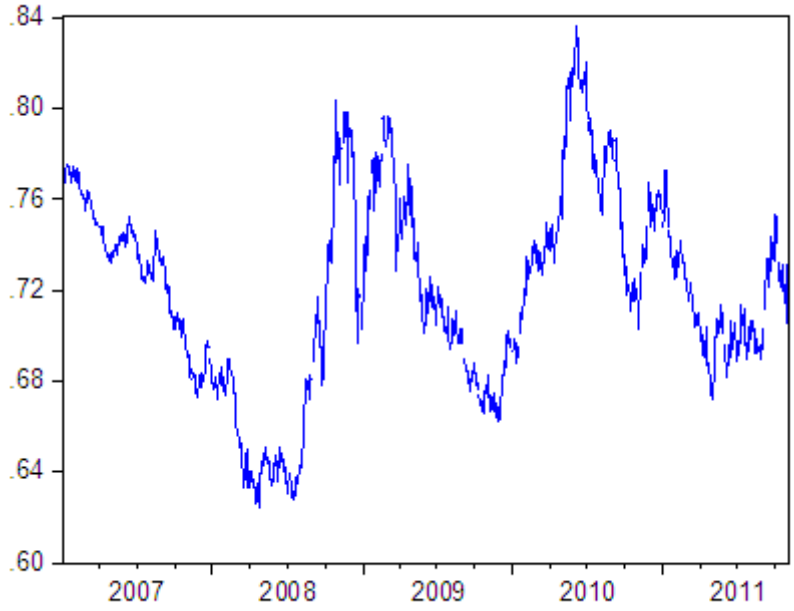
▪ Long memory – The existence of this effect reflects persistence temporal dependence even between distant observations.

In addition, the Jarque-Bera statistics reject the null hypothesis that the log return series are normally distributed as the probability of BJ test are all equal to zero.

Finally, the last graph (Figure 4) shows the non parametric fit of the empirical distribution of the exchange rate returns (fat tails).

Figure 2

Euro price of the dollar



Yen price of the dollar

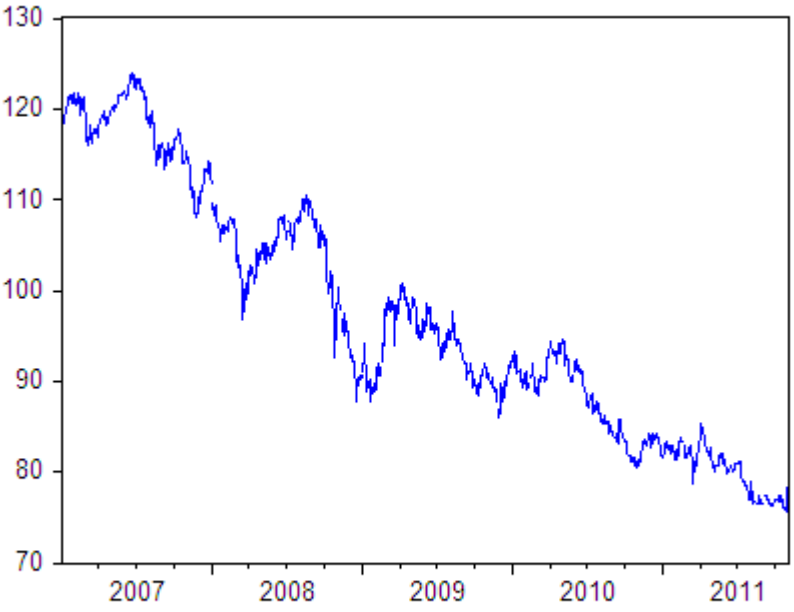
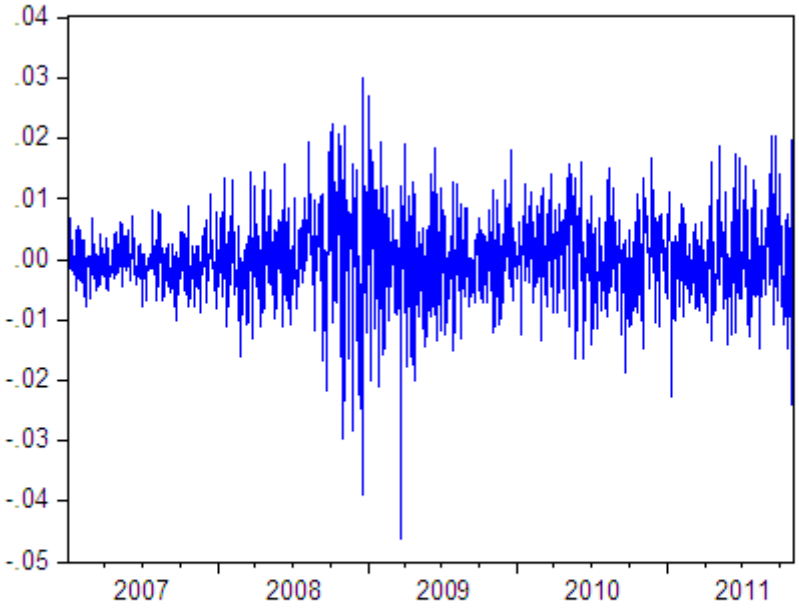


Figure 3

EUR/USD exchange rate return



JPY/USD exchange rate return

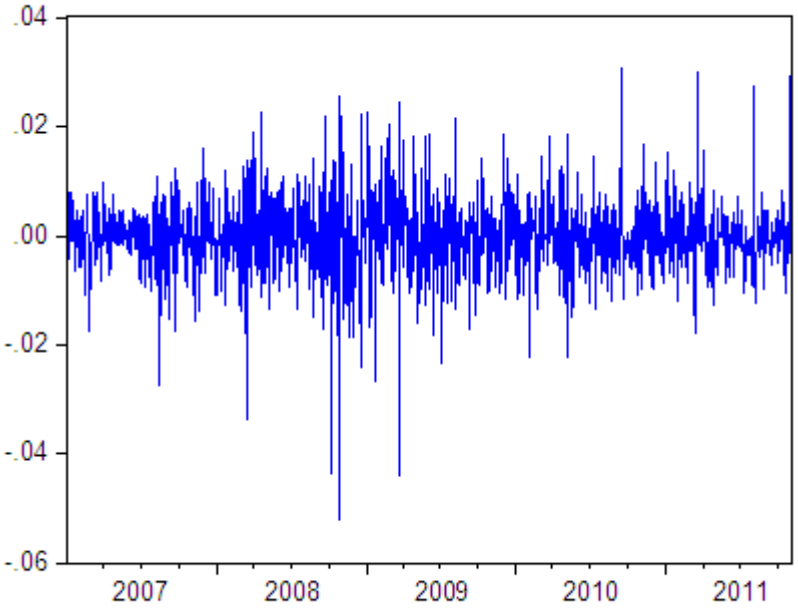
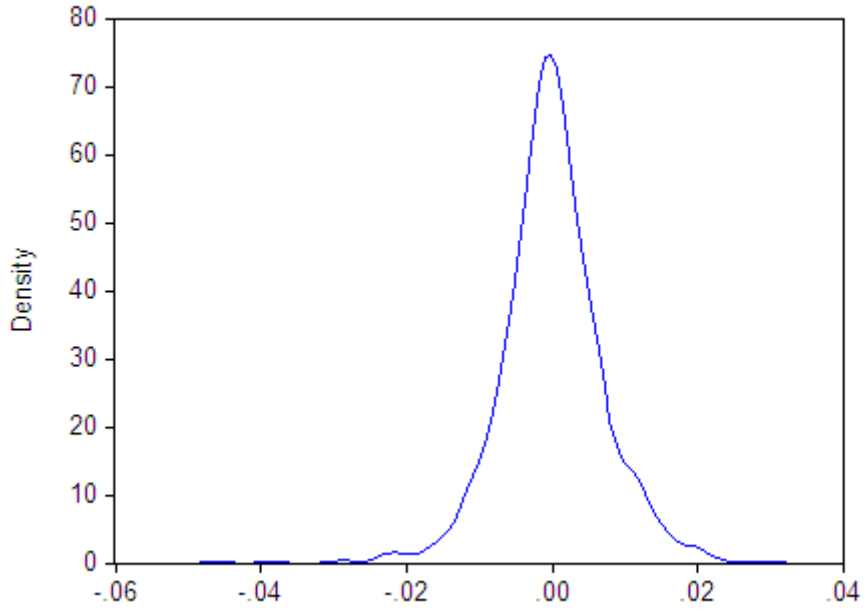
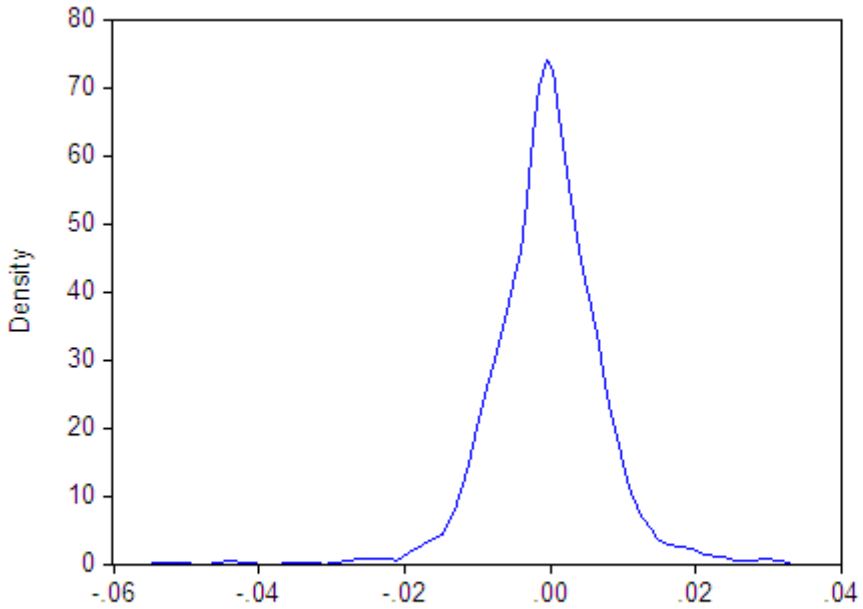


Figure 4

Kernel Density for the EUR/USD exchange rate return



Kernel Density for the JPY/USD exchange rate return



4. METHODOLOGY

Denoting the observed exchange rate at time *t* by P_t let $e_t = \ln(P_t/P_{t-1})$ be the continuously compounded rate returns series. So, the return series is depicted by the following equation $e_t = b + \Xi_t$ (1). Given the evidence for the presence of ARCH effects in daily exchange rate returns we employ a multivariate GARCH model.

4.1 The Multivariate GARCH model

Multivariate GARCH models are used to estimate and to forecast covariances and correlations. The basic formulation is similar to that of GARCH model, but where the covariances as well as the variances are permitted to be time- varying. The popularly used specifications of the Multivariate GARCH model in the literature include the VECH model, the BEKK model and their diagonal counterparts.

The conditional variance-covariance equations of the unrestricted VECH model may be written as

$$
\begin{aligned}
& e_t = b + \Xi_t \\
& VECH(H_t) = C + AVECH(\Xi_{t-1}\Xi_{t-1}^{'}) + BVECH(H_{t-1}) \qquad (1a) \\
& \Xi_t | \psi_{t-1} \sim N(0, H_t)
\end{aligned}
$$

where e_t is a 2×1 vector of exchange rate returns, b is a 2×1 vector of constants, H_t is a 2×2 conditional variance-covariance matrix, Ξ_t is a 2×1 disturbance vector, ψ_{t-1} represents the information set at time t − 1, C is a 3 × 1 parameter vector, A and B are 3×3 parameter matrices, containing the parameters on the lagged disturbance squares or cross-products and on the lagged variances or covariances respectively. $VECH(\cdot)$ denotes the column-stacking operator applied to the upper portion of the symmetric matrix. The matrices of the elements are written out below. Define

$$
H_t = \begin{bmatrix} h_{11t} & h_{12t} \\ h_{21t} & h_{22t} \end{bmatrix}, \quad \Xi_t = \begin{bmatrix} u_{1t} \\ u_{2t} \end{bmatrix}, \quad C = \begin{bmatrix} c_{11} \\ c_{21} \\ c_{31} \end{bmatrix}, \quad A = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix}, \quad B = \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix},
$$

$$VECH\left(H_t\right) = \begin{bmatrix} h_{11t} \\ h_{22t} \\ h_{12t} \end{bmatrix}$$

where $h_{ii,t}$ represent the conditional variances at time t of the two-exchange rate return series (i=1,2) used in this model, and $h_{ij,t}$ ($i \neq j$) represent the conditional covariances between the exchange rate returns.

A potentially serious issue with the unrestricted VECH model described by equation (1a) is that it requires estimation of a large number of parameters. This over-parameterisation led to the development of the simplified diagonal VECH model by Bollerslev et al (1988), where the A and B matrices are forced to be diagonal, resulting in a reduction of the number of parameters in the variance and covariance equations. Thus, the diagonal VECH is much simpler and is specified as follows:

$$h_{ij,t} = \gamma_{ij} + \alpha_{ij}\, u_{i,t-1}\, u_{j,t-1} + \beta_{ij}\, h_{ij,t-1} \qquad \text{for } i, j = 1, 2$$

where γ_{ij}, α_{ij} and β_{ij} are parameters.

Our interest is also to estimate the impact of macroeconomic announcements on volatility, and the diagonal VECH-GARCH(1,1) model will be extented by adding exogenous variables into the variance and covariance equations. The extented model can be written as follows:

$$\begin{aligned}
e_{1,t} &= b_1 + b_2\, e_{1,t-1} + u_{1,t} \\
e_{2,t} &= b_3 + b_4\, e_{2,t-1} + u_{2,t} \qquad (2) \\
h_{11,t} &= \gamma_{11} + \alpha_{11}\, u_{1,t-1}^2 + \beta_{11}\, h_{11,t-1} + \psi_{11}\, d_{1,t} + \psi_{12}\, d_{2,t} + \psi_{13}\, d_{3,t} + \psi_{14}\, d_{4,t} + \psi_{15}\, d_{5,t} \\
h_{22,t} &= \gamma_{22} + \alpha_{22}\, u_{2,t-1}^2 + \beta_{22}\, h_{22,t-1} + \psi_{21}\, d_{1,t} + \psi_{22}\, d_{2,t} + \psi_{23}\, d_{3,t} + \psi_{24}\, d_{4,t} + \psi_{25}\, d_{5,t} \\
h_{12,t} &= \gamma_{12} + \alpha_{12}\, u_{1,t-1} u_{2,t-1} + \beta_{12}\, h_{12,t-1} + \psi'_{22}\, d_{1,t} + \psi'_{23}\, d_{2,t} + \psi'_{24}\, d_{3,t} + \psi'_{25}\, d_{4,t} + \psi'_{26}\, d_{5,t}
\end{aligned}$$

where $e_{1,t}$, $e_{2,t}$ are the EUR/USD and JPY/USD exchange rate returns series. $h_{11,t}$, $h_{22,t}$ and $h_{12,t}$ are conditional variances and the covariance respectively. $d_{i,t}$ (i=1,…,5) denotes the dummy variable for macroeconomic announcements. This variable takes on

the value one when the announcement happens on day t and takes the value zero otherwise. The coefficient ψ_{ij} from different time points will be analyzed to understand how these announcements affect the volatility. We have included five dummy variables which describe following: d_1 refers to the Federal Reserve's traditional policy adjustments reflected in the Federal Funds rate movements, d_2 refers to coordinated interest rate adjustments by the Federal Reserve, the European central Bank and the Bank of England, d_3 refers to the Federal Reserve's LSAP program, d_4 refers to unconventional monetary policy measures implemented by the Bank of Japan, Bank of England, National Swiss Bank, Riksbank, and d_5 refers to Greek debt crisis.

In order for an estimated multivariate GARCH model to be plausible, H_t is required to be positive definite for all values of the disturbances, but even checking this condition is a non-trivial issue for VECH or diagonal VECH models of moderate size or larger. To circumvent this problem, Engle and Kroner (1995) proposed a quadratic formulation for the parameters that ensured positive definiteness, and this became known as the 'Diagonal BEKK' model which is represented by

$$H_t = WW' + AA'H_{t-1} + B'\Xi_{t-1}\Xi_{t-1}'B$$

where A and B are 2×2 matrices of parameters and W is an upper triangular matrix of parameters. The positive definiteness of the covariance matrix is ensured owing to the quadratic nature of the terms on the equation's RHS. The extented diagonal BEKK-GARCH(1,1) model can be written as follows:

$$\begin{aligned}
e_{1,t} &= b_1 + b_2\, e_{1,t-1} + u_{1,t} \\
e_{2,t} &= b_3 + b_4\, e_{2,t-1} + u_{2,t} \qquad (3)\\
h_{11,t} &= \gamma_{11} + \alpha_{11}^2\, u_{1,t-1}^2 + \beta_{11}^2\, h_{11,t-1} + \psi_{11}\, d_{1,t} + \psi_{12}\, d_{2,t} + \psi_{13}\, d_{3,t} + \psi_{14}\, d_{4,t} + \psi_{15}\, d_{5,t} \\
h_{22,t} &= \gamma_{22} + \alpha_{22}^2\, u_{2,t-1}^2 + \beta_{22}^2\, h_{22,t-1} + \psi_{21}\, d_{1,t} + \psi_{22}\, d_{2,t} + \psi_{23}\, d_{3,t} + \psi_{24}\, d_{4,t} + \psi_{25}\, d_{5,t} \\
h_{12,t} &= \gamma_{12} + \alpha_{11}\alpha_{12}\, u_{1,t-1}u_{2,t-1} + \beta_{11}\beta_{12}\, h_{12,t-1} + \psi_{22}'\, d_{1,t} + \psi_{23}'\, d_{2,t} + \psi_{24}'\, d_{3,t} + \psi_{25}'\, d_{4,t} + \psi_{26}'\, d_{5,t}
\end{aligned}$$

Moreover, we included the lag value of the return variable to the equation to eliminate the possible autocorrelated error. Here, we assume that the error term of the return equation has a normal distribution with zero mean and time varying conditional variance of h_t $\left(u_t \sim N(0, h_t)\right)$.

Models (2, 3) are estimated by maximum likelihood with the conditional likelihood function given by

$$l_t = -\frac{1}{2}m\log(2\pi) - \frac{1}{2}m\log(|H_t|) - \frac{1}{2}\varepsilon_t H_t^{-1}\varepsilon_t$$

where m is the number of mean equations, and ε_t is the m vector of mean equation residuals.

Once a nonlinear model has been fitted, the next step would be to assess whether the model has explained the data characteristics in a satisfactory manner. The most powerful test for randomness is the BDS. The BDS test developed by Brock et al (1987) (and later published as Brock et al 1996) is arguably the most popular test for randomness. It was originally designed to test for the null hypothesis of independent and identical distribution (iid) for the purpose of detecting non-random chaotic dynamics. However, many studies have shown that BDS test has power against a wide range of linear and nonlinear alternatives, for example, see Brock et al (1991) and Barnett et al (1997). In addition, it can also be used as a portmanteau test or mis-specification test when applied to the residuals from a fitted model. In particular, when applied to the residuals from a fitted linear time series model, the BDS test can be used to detect remaining dependence and the presence of omitted nonlinear structure. If the null hypothesis cannot be rejected, then the original linear model cannot be rejected; if the null hypothesis is rejected, the fitted linear model is mis-specified, and in this sense, it can also be treated as a test for nonlinearity.

Here in this analysis the BDS statistic tests the null hypothesis that the elements of a time series are independently and identically distributed (iid). For a time series which is iid, the distribution of the statistic:

$$W_m(\varepsilon) = \frac{\sqrt{n\left\{C_m(\varepsilon) - C_1(\varepsilon)^m\right\}}}{\sigma_m(\varepsilon)} \qquad (4)$$

$$W_m(\varepsilon) \sim N(0,1) \qquad (5)$$

$W_m(\varepsilon)$ is known as the BDS statistic. $C_m(\varepsilon)$ denotes the fraction of m-tuples in the series, which are within a distance of each other and $\sigma_m(\varepsilon)$ is an estimate of the standard deviation under the null hypothesis of IID. BDS is asymptotically normally distributed with zero mean and a known complicated variance under the null

hypothesis. The null is rejected if the test statistic is absolutely large, (say greater than 1.96) or if the *p*-value is absolutely small, (say less than 5%). If the null hypothesis of IID cannot be accepted this implies that the residuals contain some kind of hidden structure, which might be non-linear – or even chaotic. In other words the BDS test follows a standard normal distribution under the null hypothesis. If the proposed model is adequate, the standardized residuals should be white noise, while if the postulated model is insufficient to capture all of the relevant features of the data, the BDS test statistic for the standardized residuals will be statistically significant. The main concept behind the BDS test is the correlation integral, which is a measure of the frequency with which temporal patterns are repeated in the data.

Here, we are going to specify the default value of 0.7 used in calculating ε. This value provides a good starting point for the default method when testing shorter dimensions. Also, we are intending to specify the maximum correlation dimension from 2 to 6 by setting ε to one standard deviation of the sample observations. As EUR/USD and JPY/USD are series that have unusual distributions, the distribution of the BDS test statistic can be quite different from the asymptotic normal distribution. To compensate for this, we are going to calculate bootstrapped *p*-values for the test statistic. The data are simulated 1000 times in order to provide a more accurate estimate of the *p*-values, but the procedure will take longer to perform.

One advantage of the BDS test is that it is a statistic which requires no distributional assumption on the data to be tested. Another advantage of the BDS test is that when applied to model residuals, the first order asymptotic distribution of BDS statistic given in (5) is independent of estimation errors under certain sufficient conditions. In general, de Lima (1996) shows that for linear additive models, or models that can be transformed into that format, the BDS test is nuisance parameter free and does not require any adjustment when applied to fitted model residuals. Thus the BDS test can be used as a test for nonlinearity, or as a test for model mis-specification.

Having considered the two alternative types of the multivariate GARCH model, we proceed to examine the information content between the two conditional variances of the exchange rates by means of a non-parametric causality test proposed by Diks and Panchenko (2004, 2006). In this study we will employ the modified tests statistic proposed by Diks and Panchenko (2006).

The general test for nonparametric Granger causality is first developed by Baek and Brock (1992) and, later on, modified by Hiemstra and Jones (1994) as the linear

Granger test is inefficient in detecting any nonlinear causal relationship. Under the assumptions of the Hiemstra-Jones test short-term temporal dependence between two variables is allowed; while the Baek-Brock test is suited for independently identically distributed time series.

The Hiemstra-Jones test can be conducted on time series x_t and y_t $t=(1,2....)$ which are weakly dependent, mixed, and strictly stationary. In this thesis we take the conditional variances of $\left(\sigma_{e1,t}^2,\sigma_{e2,t}^2\right)$ which are the conditional variances of EUR/USD and JPY/USD respectively. Adopting the notation used by Hiemstra and Jones, we denote X_t^m and $X_{t-L_x}^{L_x}$ as m-length lead and L_x-length lag vector of X_t respectively; while $Y_{t-L_y}^{L_y}$ represents L_y-length lag vector of Y_t. Here m, L_x and L_y are integers greater than or equal to 1.

Diks et al (2004, 2006) using the notation from Hiemstra and Jones (1994) series $\{Y_t\}$ does not strictly Granger cause another series $\{X_t\}$ nonlinearly if and only if:

$$\Pr\left(\left\|X_t^m - X_s^m\right\| < \varepsilon \middle| \left\|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\right\| < \varepsilon, \left\|Y_{t-L_y}^{L_y} - Y_{s-L_y}^{L_y}\right\| < \varepsilon\right)$$

$$= \Pr\left(\left\|X_t^m - X_s^m\right\| < \varepsilon \middle| \left\|X_{t-L_x}^{L_x} - X_{s-L_x}^{L_x}\right\| < \varepsilon\right) \quad (7)$$

where $\Pr(.|.)$ denotes conditional probability and $\|\cdot\|$ denotes the maximum norm which is defined as $|X-Y| = \max\left(|x_1-y_1|,|x_2-y_2|,....,|x_n-y_n|\right)$ for any two vectors $X=(x_1,.....,x_n)$ and $Y=(y_1,.....,y_n)$. Equation (7) states that the conditional probability that two arbitrary m-length lead vectors of $\{X_t\}$ are within distance ε, given that the corresponding lagged L_x-length lag vectors of $\{X_t\}$ are ε-close, is the same as when in addition one also conditions on the L_y-length lag vectors of $\{Y_t\}$ being ε-close.

For an observed bivariate time series $\{(X_t,Y_t)\}$, t = 1, 2, the Hiemstra-Jones test consists of choosing a value for ε (typical values are between 0.5 and 1.5 after normalizing the time series to unit variance), and testing (7) by estimating the conditional probabilities as ratios of unconditional probabilities. Here, we are going to take suggestively the typical values 0.5, 1 and 1.5. For notational convenience,

let $C1\left(m+L_x,L_y,\varepsilon\right), C2\left(L_x,L_y,\varepsilon\right),$ $C3\left(m+L_x,\varepsilon\right)$ and $C4\left(L_x,\varepsilon\right)$ denote the corresponding probabilities in equation (7). So, equation (7) can be expressed as

$$\frac{C1\left(m+L_x,L_y,\varepsilon\right)}{C2\left(L_x,L_y,\varepsilon\right)}=\frac{C3\left(m+L_x,\varepsilon\right)}{C4\left(L_x,\varepsilon\right)}$$

Based on this equality, they construct the following test statistic

$$\sqrt{n}\left(\frac{C1\left(m+L_x,L_y,\varepsilon\right)}{C2\left(L_x,L_y,\varepsilon\right)}-\frac{C3\left(m+L_x,\varepsilon\right)}{C4\left(L_x,\varepsilon\right)}\right)\overset{a}{\sim} N\left(0,\sigma^2\left(m,L_{x,}L_{y,}\varepsilon\right)\right) \quad (8)$$

One-sided critical values are used, based on this asymptotic result, rejecting when the observed value of the test statistic in (8) is too large.

5. RESULTS

Table 2 reports the estimates from two versions of the diagonal VECH model for the two currencies. The estimates suggest that this model fits the data rather well as all the parameters are highly significant at 1% and 10% level. The very simple specification used for the conditional mean seems sufficient to capture the dynamics of the exchange rate returns, as suggested by the absence of residual serial autocorrelation (see the Ljung–Box adjusted statistics Q_i on the standardized residuals reported for 5 lags). The estimated values for the b_{ij} parameters suggest that both the conditional variances and covariances display a high degree of persistence.

The analysis shows that the dummy variables, but not all of them, have quite a significant effect on the variances. Specifically, the traditional monetary policy ($d_{1,t}$), the LSAP Program ($d_{3,t}$) and the Greek debt crisis ($d_{5,t}$) have significant effects on conditional variance of EUR/USD exchange rate. An economic interpretation of these findings is that a decrease in the federal funds interest rate due to an excessively high level of economic activity causes inflation pressures that they can lead to a significant loss of purchasing power, thus we turn our attention to implementation of LSAP program. Also, the uncertainty of the euro area has resulted in extreme financial market volatility, risk aversion in the market, deleveraging of banks, increased fiscal austerity, and declining business and consumer confidence. As a result, global economic activity has weakened.

On the other hand, the conditional variance of the JPY/USD exchange rate is significantly affected by the coordinated monetary policies of the Federal Reserve, the European Central Bank and Bank of England ($d_{2,t}$), the LSAP Program ($d_{3,t}$) and the unconventional monetary policy of other central banks ($d_{4,t}$), suggesting that the unconventional monetary policy including all the forms like quantitative and credit easing of the BOJ may has played the major role in stabilizing the economic activity. The signs of all dummies are positive (+) so in this respect these dummies are associated with increases in exchange rate volatility of the dollar against the two major currencies the risk and the uncertainty are increasing. Turning to the impact on the covariance, it turns out that the coordinated monetary policies of the Federal Reserve, the European Central Bank and Bank of England ($d_{2,t}$) decreased significantly the covariance between the EUR and the JPY at 10% level, whereas the LSAP Program ($d_{3,t}$) increased significantly the covariance between the EUR and the JPY at 1% level. The decrease of the ($d_{2,t}$) will curb economic growth and help contain inflation pressures, and thus can promote the sustainability of an economic expansion. The latter seems to reflect the negative effects of the purchases on the medium-term performance the United States' economy, by creating an inflation risk which will affect the path of the dollar.

Table 2: The VECH model for the EUR/USD and JPY/USD exchange rates

			MGARCH	MGARCH_D
Conditional mean	**EUR/USD $e_{1,t}$**	b_1	-0.00019	-0.000215
			(0.2023)	(0.1304)
		b_2	0.054245*	0.046315
			(0.0680)	(0.1269)
	JPY/USD $e_{2,t}$	b_3	-0.000188	-0.000221
			(0.3246)	(0.2538)
		b_4	-0.050188	-0.062004*
			(0.1009)	(0.0400)
Conditional Variance	**EUR/USD $h_{11,t}$**	γ_{11}	3.68E-08*	2.00E-08
			(0.0345)	(0.1498)
		α_{11}	0.037980***	0.029438***
			(0.000)	(0.000)
		β_{11}	0.964674***	0.964268***
			(0.000)	(0.000)
		ψ_{11}		8.15E-06***
				(0.0036)
		ψ_{12}		7.52E-05
				(0.2141)

		ψ_{13}		3.22E-05***
				(0.0013)
		ψ_{14}		6.89E-07
				(0.6418)
		ψ_{15}		6.28E-06***
				(0.0009)
Conditional Covariance	$h_{12,t}$	γ_{12}	2.90E-07***	2.45E-07*
			(0.000)	(0.0128)
		α_{12}	0.050153***	0.038437***
			(0.000)	(0.000)
		β_{12}	0.928972***	0.921356***
			(0.000)	(0.000)
		ψ'_{22}		5.46E-06
				(0.2045)
		ψ'_{23}		-0.000218*
				(0.0633)
		ψ'_{24}		3.06E-05***
				(0.0002)
		ψ'_{25}		4.70E-06
				(0.3466)
		ψ'_{26}		1.30E-06
				(0.4024)
Conditional Variance	**JPY/USD**$h_{22,t}$	γ_{22}	2.29E-06***	3.02E-06***
			(0.000)	(0.000)
		α_{22}	0.066229***	0.050186***
			(0.000)	(0.000)
		β_{22}	0.894591***	0.880354***
			(0.000)	(0.000)
		ψ_{21}		3.65E-06
				(0.5065)
		ψ_{22}		0.000630*
				(0.0202)
		ψ_{23}		2.90E-05*
				(0.0440)
		ψ_{24}		3.21E-05***
				(0.0084)
		ψ_{25}		2.69E-07
				(0.6686)
		Q_1	0.9822	0.9477
		Q_2	0.9534	0.9331
		Q_3	0.8044	0.710□
		Q_4	0.7688	0.7503
		Q_5	0.7311	0.7443
		Log lik.	9099.01	9129.50
		AIC	-14.404	-14.436
		SBC	-14.363	-14.355

Notes: (a) *p*-values are reported in parenthesis. ***, **,* denote, respectively, significance at 1% 5% and 10% levels.

(b) Q_i for i=1,…,5 denotes the *p*-values of Adjusted *Q*-Statistics computed from the standardized residuals of the exchange rate equations at a lag equal to 5.

Results after estimating model (3) without and with dummy variables are presented below, which are exactly the same with these of model (2).

Table 3: The BEKK model for the EUR/USD and JPY/USD exchange rates

			MGARCH	MGARCHD
Conditional mean	**EUR/USD e_{1t}**	b_1	-0.000190	-0.000215
			(0.2023)	(0.1304)
		b_2	0.054245*	0.046315
			(0.0680)	(0.1269)
	JPY/USD e_{2t}	b_3	-0.000188	-0.000221
			(0.3246)	(0.2538)
		b_4	-0.050188	-0.062004*
			(0.1009)	(0.0400)
Conditional Variance	**EUR/USD h_{11t}**	γ_{11}	3.68E-08*	2.00E-08
			(0.0345)	(0.1498)
		α^2_{11}	0.037979***	0.029438***
			(0.000)	(0.000)
		β^2_{11}	0.964674***	0.964267***
			(0.000)	(0.000)
		ψ_{11}		8.15E-06***
				(0.0036)
		ψ_{12}		7.52E-05
				(0.2141)
		ψ_{13}		3.22E-05***
				(0.0013)
		ψ_{14}		6.89E-07
				(0.6418)
		ψ_{15}		6.28E-06***
				(0.0009)
Conditional Covariance	**h_{12t}**	γ_{12}	2.90E-07***	2.45E-07*
			(0.0004)	(0.0128)
		$\alpha_{11}\alpha_{22}$	0.050153***	0.038436***
			(0.000)	(0.000)
		$\beta_{11}\beta_{22}$	0.928972***	0.921356***
			(0.000)	(0.000)
		ψ'_{22}		5.46E-06
				(0.2045)
		ψ'_{23}		-0.000218*
				(0.0633)
		ψ'_{24}		3.06E-05***
				(0.000)
		ψ'_{25}		4.70E-06
				(0.3466)

Conditional Variance	**JPY/USDh$_{22t}$**	ψ'_{26}		1.30E-06
				(0.4024)
		γ_{22}	2.29E-06***	3.02E-06***
			(0.000)	(0.000)
		α^2_{22}	0.066229***	0.0501861***
			(0.000)	(0.000)
		β^2_{22}	0.894591***	0.880354***
			(0.000)	(0.000)
		ψ_{21}		3.65E-06
				(0.5065)
		ψ_{22}		0.000630*
				(0.0202)
		ψ_{23}		2.90E-05*
				(0.0440)
		ψ_{24}		3.21E-05***
				(0.0084)
		ψ_{25}		2.69E-07
				(0.6686)
		Q_1	0.9517	0.9477
		Q_2	0.9298	0.9331
		Q_3	0.6705	0.7104
		Q_4	0.7281	0.7503
		Q_5	0.7106	0.7443
		Log lik.	9099.01	9129.50
		AIC	-14.404	-14.436
		SBC	-14.363	-14.355

Notes: (a) *p*-values are reported in parenthesis. ***, **,* denote, respectively, significance at 1% 5% and 10% levels.

(b) Q_i for i=1,…,5 denotes the *p*-values of Adjusted *Q*-Statistics computed from the standardized residuals of the exchange rate equations at a lag equal to 5.

Figures 5 and 6 present the conditional variances and covariance of both the benchmark model and the one with the dummies. Two features are worth mentioning at this point. First the low or negative covariance between the EUR/USD and JPY/USD as exchange rate returns move inversely. A low covariance indicates that due to crisis the degree to which the exchange rate returns of these two currencies are correlated is very low and will provide very much diversification. Second the variance of the JPY/USD is different compared to the variance of EUR/USD with a single spike in 2008. Table 4 presents the Wald tests and confirm that the VECH-GARCH with dummies is superior from this one without dummies.

Table 4: Wald Tests

Wald Test	
Null Hypothesis	*p*-value
ψ11=ψ'22=ψ21=0	0.0000
ψ12=ψ'23=ψ22=0	0.0000
ψ13=ψ'24=ψ23=0	0.0000
ψ14=ψ'25=ψ24=0	0.0000
ψ15=ψ'26=ψ25=0	0.0000
ψ11=……=ψ25=0	0.0000

Figure 5: Multivariate GARCH

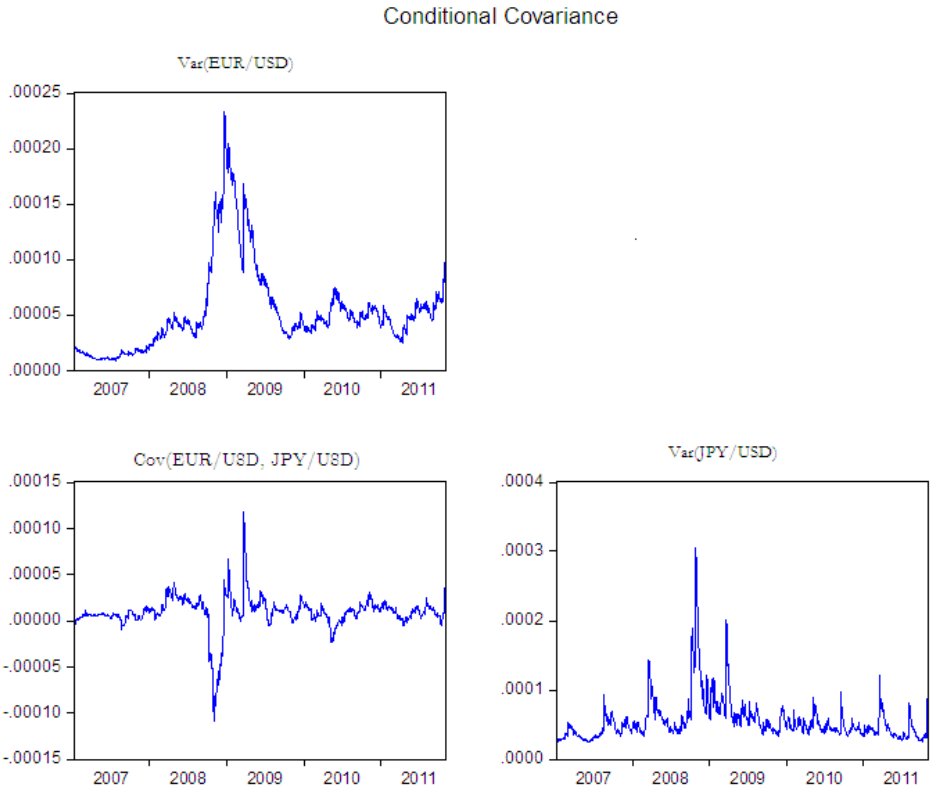
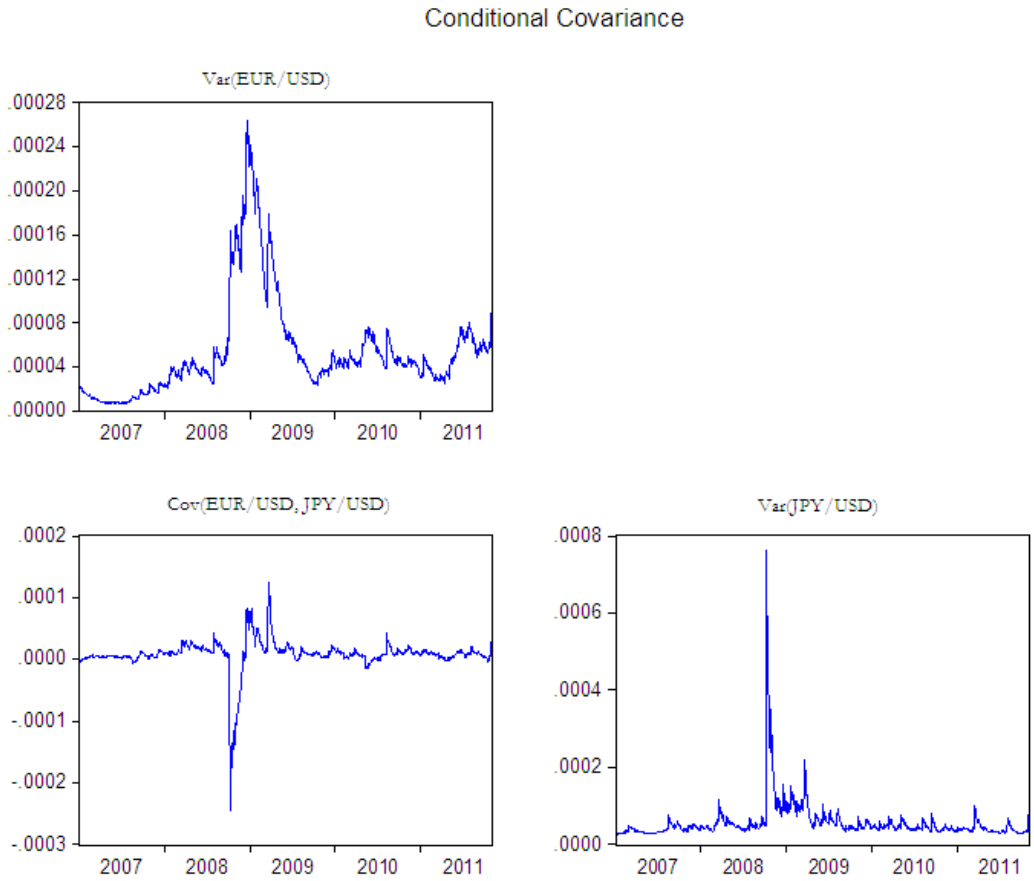


Figure 6: Multivariate GARCH with Dummies



The results in table 5 show that applying the BDS test for randomness in the standardised residuals of the VECH-GARCH model with and without dummy variables as far as the EUR/USD and JPY/USD concerned the null hypothesis that the data is iid is accepted for all dimensions. This outcome we can see from the fact that *p*-values are higher than 1%. As far as the squared standardised residuals (de Lima) concerned we can see that the results in table 6 confirms the results in table 5 which means that the multivariate GARCH model adequate captures all the volatility clustering that exists in the series. Volatility clustering as we have said previously is one of the features that have been exhibited from the exchange rate returns. All these results are exactly the same with those of Diagonal BEKK model as they can see in the second panel of table 5 and 6.

Table 5: The BDS test for the standardized residuals of the VECH model

(Cholesky of variance)

Diagonal VECH		stand_resid_1		stand_resid_2	
MGARCH	Dimension	Normal Prob.	Bootstrap Prob.	Normal Prob.	Bootstrap Prob.
	2	0.3280	0.384	0.0364	0.036
	3	0.5561	0.626	0.0467	0.046
	4	0.4407	0.496	0.0990	0.108
	5	0.3028	0.344	0.2158	0.216
	6	0.3492	0.386	0.4611	0.442
MGARCH_D	2	0.1656	0.172	0.0176	0.032
	3	0.3236	0.364	0.0239	0.034
	4	0.2621	0.274	0.0397	0.052
	5	0.1547	0.196	0.0743	0.076
	6	0.1458	0.178	0.2457	0.244
Diagonal BEKK MGARCH	2	0.3280	0.328	0.0364	0.042
	3	0.5561	0.554	0.0467	0.064
	4	0.4407	0.442	0.099	0.140
	5	0.3028	0.318	0.2158	0.284
	6	0.3492	0.402	0.4611	0.476
MGARCH_D	2	0.1656	0.192	0.0176	0.012
	3	0.3236	0.364	0.0239	0.020
	4	0.2621	0.316	0.0397	0.022
	5	0.1547	0.18	0.0743	0.050
	6	0.1458	0.168	0.2457	0.242

Table 6: The BDS test for the squared standardized residuals of the VECH model BDS (Cholesky of variance)

Diagonal VECH MGARCH		stand_resid^2_1		stand_resid^2_2	
	Dimension	Normal Prob.	Bootstrap Prob.	Normal Prob.	Bootstrap Prob.
	2	0.2568	0.270	0.5277	0.564
	3	0.6972	0.716	0.8421	0.886
	4	0.5007	0.542	0.5219	0.566
	5	0.2022	0.208	0.5011	0.570
	6	0.1261	0.128	0.4347	0.476
MGARCH_D	2	0.0966	0.088	0.6138	0.674
	3	0.3529	0.374	0.8552	0.792
	4	0.2002	0.190	0.8534	0.934
	5	0.0720	0.078	0.8113	0.852
	6	0.0493	0.048	0.7288	0.746
Diagonal BEKK MGARCH	2	0.2568	0.252	0.5277	0.590
	3	0.6972	0.674	0.8421	0.870
	4	0.5007	0.448	0.5219	0.540
	5	0.2022	0.19	0.5011	0.524
	6	0.1261	0.13	0.4347	0.450
MGARCH_D	2	0.0966	0.084	0.6138	0.632
	3	0.3529	0.362	0.8552	0.800
	4	0.2002	0.198	0.8534	0.916
	5	0.0720	0.062	0.8113	0.846
	6	0.0493	0.042	0.7288	0.762

The nonparametric causality tests for both specifications are reported in table 7. The test statistic was carried out for different values of ε and different dimensions. The results indicate that the variance of EUR/USD exchange rate has information content that helps predict the variance of JPY/USD exchange rate at 5% significant level for almost all dimensions, with and without dummies in the GARCH models (the second p-value is always greater than first). In other words, we observe that non-linear causality exists and runs unidirectionally from the variance of EUR/USD to the variance of JPY/USD. That is the volatility of σ^2_{y2} (yen) does not cause σ^2_{y1} (euro), the null hypothesis can not be rejected . Again as previously, the results are exactly the same with those of Diagonal BEKK model as they can see in the second panel of table 7.

Table 7: Nonparametric causality test (Diks and Panchenko 2006)

Diagonal VECH		ε=1.5		ε=1		ε=0.5	
	Dimension	MGARCH	MGARCHD	MGARCH	MGARCHD	MGARCH	MGARCHD
		p-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value
	1	0.00190	0.00223	0.00038	0.00009	0.00003	0.00139
		0.05513□	0.082	0.05382	0.14826	0.00541	0.20369
	2	0.00246	0.00326	0.00046	0.00035	0.00031	0.00849
		0.05568	0.08744	0.07187	0.13498	0.00668	0.19633
H_0: σ^2_x does not cause σ^2_y							
H_0: σ^2_y does not cause σ^2_x	3	0.00365	0.00453	0.001	0.00161□	0.00141	0.02388
		0.06777	0.09354	0.05414	0.12991	0.01244	0.31284
	4	0.00581	0.01073	0.0016	0.00557	0.00639	0.0464
		0.07005	0.09184	0.04293	0.14318	0.01692	0.35972
	5	0.00796	0.01231	0.00212	0.00746	0.01721	0.04041
		0.05678	0.09678	0.0269	0.15207	0.01747	0.38773

Diagonal BEKK		ε=1.5		ε=1		ε=0.5	
	Dimension	MGARCH	MGARCHD	MGARCH	MGARCHD	MGARCH	MGARCHD
		p-value	*p*-value	*p*-value	*p*-value	*p*-value	*p*-value
	1	0.00190	0.00223	0.00038	0.00009	0.00003	0.00139
		0.05513	0.082	0.05382	0.14826	0.00541	0.20369
	2	0.00246	0.00326	0.00046	0.00035	0.00031	0.00849
		0.05568	0.08744	0.07187	0.13498	0.00668	0.19633
H_0: σ^2_x does not cause σ^2_y							
H_0: σ^2_y does not cause σ^2_x	3	0.00365	0.00453	0.001	0.00161	0.00141	0.02388
		0.06777	0.09354	0.05414□	0.12991	0.01244	0.31284
	4	0.00581	0.01073	0.0016	0.00557	0.00639	0.0464
		0.07005	0.09184	0.04293	0.14318	0.01692	0.35972
	5	0.00796	0.01231	0.00212	0.00746	0.01721	0.04041
		0.05678	0.09678	0.0269	0.15207	0.01747	0.38773

6. CONCLUSION

In this study, we have provided evidence that the conventional and unconventional monetaty policies as well as other events related with debt Greek crisis tend to influence the conditional variances and covariance between two major exchange rates, the Japanese yen and the Euro against the USD. Focusing on the period from 1st January 2007 to 4th November 2011, we show that within a multivariate GARCH setting, on the one hand the traditional monetary policy ($d_{1,t}$), the LSAP Program ($d_{3,t}$) and the Greek debt crisis ($d_{5,t}$) have significantly increased the volatility of the EUR/USD exchange rate. An economic interpretation of these results is that a decrease in the federal funds interest rate due to an excessively high level of economic activity causes inflation pressures that they can lead to a significant loss of purchasing power, thus we turn our attention to implementation of LSAP program. In addition, the uncertainty of the euro area has resulted in extreme financial market volatility, risk aversion in the market, deleveraging of banks, increased fiscal austerity, and declining business and consumer confidence. As a result, global economic activity has weakened. On the other hand, the coordinated monetary policies of the Federal Reserve, the European Central Bank and Bank of England ($d_{2,t}$) together with the Federal Reserve's LSAP Program ($d_{3,t}$) and the unconventional monetary policy of other central banks ($d_{4,t}$) have impacted positively the conditional variance of the JPY/USD exchange rate, suggesting that the unconventional monetary policy, including all the forms like quantitative and credit easing of the BOJ, may have played a major role in stabilizing the economic activity. Turning to the impact on the covariance, the analysis shows that the coordinated monetary policies of the Federal Reserve, the European Central Bank and Bank of England ($d_{2,t}$) has decreased the covariance between the EUR and the JPY rate, whereas the Federal Reserve's LSAP Program ($d_{3,t}$) has significantly increased the covariance of the two currencies. The decrease of the ($d_{2,t}$) will curb economic growth and help contain inflation pressures, and thus can promote the sustainability of an economic expansion. The latter seems to reflect the negative effects of the purchases on the medium-term performance the United States' economy, by creating an inflation risk which will affect the path of the dollar. A positive sign of the estimated dummy coefficient is associated with an increase conditional variance which implies increased

uncertainty. However, in the case where the signs of dummies are negative we observe a decrease in exchange rate volatility of the dollar against the two major currencies the risk and the uncertainty are decreasing. Applying the BDS test for randomness both in the standardised residuals and the squared standardised residuals of the VECH-GARCH model with and without dummy variables as far as the EUR/USD and JPY/USD concerned the null hypothesis that the data are white noise is accepted for all dimensions. As a result, suggests that the model explains the dynamics of the series. An interesting aspect of the nonparametric causality tests is the evidence that there non-linear causality exists and running unidirectionally from the variance of EUR/USD to variance of JPY/USD. All these results are qualitatively similar with those of Diagonal BEKK model.

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APPENDIX 1

Results after estimating model (2) without and with dummy variables are presented below:

VECH-GARCH model without dummies

$e_{1,t}$ = -0.000190 + 0.054245* $e_{1,t-1}$ + $u_{1,t}$

(0.2023) (0.0680)

$e_{2,t}$ = -0.000188 - 0.050188 $e_{2,t-1}$ + $u_{2,t}$

(0.3246) (0.1009)

$h_{11,t}$ = 3.68E-08* + 0.037980*** $u^2_{1,t-1}$ + 0.964674*** $h_{11,t-1}$

(0.0345) (0.000) (0.000)

$h_{22,t}$ = 2.29E-06*** + 0.066229*** $u^2_{2,t-1}$ + 0.894591*** $h_{22,t-1}$

(0.000) (0.000) (0.000)

$h_{12,t}$ = 2.90E-07*** + 0.050153*** $u_{1,t-1}u_{2,t-1}$ +0.928972*** $h_{12,t-1}$

(0.000) (0.000) (0.000)

VECH-GARCH model with dummies

$e_{1,t}$ = -0.000215 + 0.046315 $e_{1,t-1}$ + $u_{1,t}$

(0.1304) (0.1269)

$e_{2,t}$ = -0.000221 - 0.062004* $e_{2,t-1}$ + $u_{2,t}$

(0.2538) (0.0400)

$h_{11,t}$ = 2.00E-08 + 0.029438*** $u^2_{1,t-1}$ +0.964268*** $h_{11,t-1}$ +8.15E-06*** $d_{1,t}$ +7.52E-05 $d_{2,t}$

(0.1498) (0.000) (0.000) (0.0036) (0.2141)

+3.22E-05*** $d_{3,t}$ + 6.89E-07 $d_{4,t}$ + 6.28E-06*** $d_{5,t}$

(0.0013) (0.6418) (0.0009)

$h_{22,t}$ =3.02E-06***+0.050186*** $u^2_{2,t-1}$ +0.880354*** $h_{22,t-1}$ + 3.65E-06 $d_{1,t}$ + 0.000630* $d_{2,t}$

(0.000) (0.000) (0.000) (0.5065) (0.0202)

+2.90E-05* $d_{3,t}$ + 3.21E-05*** $d_{4,t}$ + 2.69E-07 $d_{5,t}$

(0.0440) (0.0084) (0.6686)

$h_{12,t}$ =2.45E-07* +0.038437*** $u_{1,t-1}u_{2,t-1}$ +0.921356*** $h_{12,t-1}$ + 5.46E-06 $d_{1,t}$

(0.0128) (0.000) (0.000) (0.2045)

$$-0.000218^{*}\, d_{2,t} \;+\; 3.06\text{E-}05^{***}\, d_{3,t} \;+\; 4.70\text{E-}06\, d_{4,t} + 1.30\text{E-}06\, d_{5,t}$$

(0.0633) (0.0002) (0.3466) (0.4024)

Note: *p*-values are reported in parenthesis. ***, **,* denote, respectively, significance at the 1% 5% and 10% levels.

APPENDIX 2

DUMMIES

d1: Traditional Monetary Policy (Federal Funds Rate Movements)

9/18/2007	Fed funds rate cut 50 basis points to 4.75
10/31/2007	Fed funds rate cut 25 basis points to 4.50
12/11/2007	Fed funds rate cut 25 basis points to 4.25
1/22/2008	Fed funds rate cut 75 basis points to 3.5
1/30/2008	Fed funds rate cut 50 basis points to 3
3/18/2008	Fed funds rate cut 75 basis points to 2.25
4/30/2008	Fed funds rate cut 25 basis points to 2
10/8/2008	Fed funds rate cut 50 basis points to 1.50
10/29/2008	Fed funds rate cut 50 basis points to 1
12/16/2008	Fed funds rate target set at between 0 and 0.25

d2: International Events Excluding Swaps

10/8/2008	Coordinated interest rate cuts of 0.5% (includes BoE, Fed, ECB)

d3: Large Scale Asset Purchases Program

7/30/2008	Housing and Economic Recovery Act of 2008 authorizes Treasury to purchase GSE obligations
11/25/2008	Purchases of agency MBS up to $500 bil. and debt up to $100 bil. announced
12/1/2008	Agency debt purchases begin, Chairman Bernanke first mentions long term Treasury purchases as a possibility in a speech
12/15/2008	FOMC statement first mentions possible purchases of long term Treasuries
12/30/2008	FRB announces that it expects to begin purchasing agency MBS in early January
1/28/2009	FOMC statement announces willingness to begin purchases of long term Treasuries
3/18/2009	Purchases of agency MBS and debt increased to $1.25 tril. and $200 bill., plans to purchase $300 bil. of long term Treasuries announced
8/10/2010	FOMC announced that it will reinvest principal repayments on agency debt and MBS holdings in longer term Treasury securities

d4: Unconventional Monetary Policy

12/19/2008	Japan	Purchases of Japanese government bonds increased to JPY 1.4 trillion per month as well as Bank of Japan will conduct temporary purchases of commercial paper to ease year-end financing

1/19/2009	United Kingdom	Bank of England announces GBP 50 billion in purchases of high-quality private sector assets
1/22/2009	Japan	Bank of Japan will purchase JPY 3 trillion of CP and asset-backed CP
2/3/2009	Japan	Bank of Japan will purchase JPY 1 trillion of bank stock
2/19/2009	Japan	Bank of Japan will continue purchasing commercial paper until September as well as it will purchase JPY 1 trillion of corporate bonds
3/5/2009	United Kingdom	Asset Purchase Plan increased to GBP 75 billion, will include purchases of gilts
3/12/2009	Switzerland	Central bank will purchase CHF denominated bonds
3/18/2009	Japan	Purchases of Japanese government bonds increased to JPY 1.8 trillion per month
5/7/2009	United Kingdom	Asset purchase plan increased to GBP 125 billion in assets
6/8/2009	United Kingdom	Asset purchases to be expanded to include secured commercial paper
7/2/2009	Sweden	Riksbank lowers monetary policy rates; deposit rate now negative 0.25%
8/6/2009	United Kingdom	Asset purchase plan increased to GBP 175 billion in assets
11/5/2009	United Kingdom	Asset purchase plan increased to GBP 200 billion in assets
3/17/2010	Japan	Bank of Japan expands fixed rate loans to JPY 20 trillion from JPY 10 trillion

d5: Dates Referring to Greek debt crisis

10/20/2009	The Finance Minister George Papakonstantinou announced to the ECOFIN that the deficit for 2009 will range as a percentage of GDP to 12.5% instead of 6% that calculate the previous government
10/22/2009	The rating agency Fitch downgraded Greece from level A to A-
12/8/2009	The rating agency Fitch downgraded Greece from level A- to BBB+
12/16/2009	The rating agency Standard and Poor's downgraded Greece from level A- to BBB+
12/23/2009	The rating agency Moody's downgraded Greece from level A1 to A2
1/8/2010	The European Commission publishes report related to debt and deficit Statistics of the Greek Government, which identifies problems of "deliberate false reporting of data" and make further doubts about the veracity of the data beyond the latest revision of October 20, 2009.
1/21/2010	The spread of the ten-year bonds exceeded 300 units
2/9/2010	The first package that was announced referring to the public sector
3/3/2010	The second larger package of economic measures was announced
4/9/2010	The rating agency Fitch downgraded Greece from level BBB+ to BBB-
4/22/2010	The rating agency Moody's downgraded Greece from level A2 to A3
4/23/2010	Greece has recourse to the support mechanism that consists of the International Monetary Fund, the European Union and the European Central Bank
4/27/2010	The rating agency Standard and Poor's downgraded Greece from level BBB+ to BB+

4/28/2010	The spread of the ten-year bonds exceeded 1000 units
5/10/2010	The loan agreement was signed between Greece and the IMF
6/14/2010	The rating agency Moody's downgraded Greece from level A3 to Ba1
1/14/2011	The rating agency Fitch downgraded Greece from level BBB- to BB+
3/7/2011	The rating agency Moody's downgraded Greece from level Ba1 to B1
3/29/2011	The rating agency Standard and Poor's downgraded Greece from level BB+ to BB-
5/9/2011	The rating agency Standard and Poor's downgraded Greece from level BB- to B
5/20/2011	The rating agency Fitch downgraded Greece from level BB+ to B+
6/1/2011	The rating agency Moody's downgraded Greece from level B1 to Caa1
6/3/2011	The rating agency Dagong downgraded Greece from level BB to CCC
6/9/2011	In parliament was recorded the medium-term fiscal strategy programme 2011-2014
6/14/2011	The rating agency Standard and Poor's downgraded Greece from level to B to CCC
6/17/2011	The reshuffle was announced. New finance minister was Evangelos Venizelos
6/29/2011	The medium-term fiscal strategy programme was voted
7/13/2011	The rating agency Fitch downgraded Greece from level B+ to CCC
7/21/2011	The summit of the European Union resulted in agreement on new lending in Greece, worth 158 billion euro
7/25/2011	The rating agency Moody's downgraded Greece in three steps from the level of Caa1 to Ca putting Greece at the last rung of the international ranking list
7/27/2011	The rating agency Standard & Poor's downgraded Greece from CCC to CC level, putting Greece in the last rung of the international ranking list
9/2/2011	Troika left abruptly after disagreement with the Finance Minister to cover the gap in fiscal
10/20/2011	The new law was voted
10/27/2011	Decision of the EU summit for haircutting Greek debt by 50%
10/31/2011	Greek Prime Minister George Papandreou says he will call for a referendum on further austerity measures needed to secure additional bailout funds

GLOSSARY

LSAPs PROGRAMME: commonly referred to as quantitative easing (QE).

AGENCY DEBT: is a security, usually a bond, issued by a U.S. government-sponsored agency. Agency debt is also called an agency security.

UNITED STATES TREASURY SECURITY: is a government debt issued by the United States Department of the Treasury through the Bureau of the Public Debt. Treasury securities are the debt financing instruments of the United States federal government, and they are often referred to simply as Treasurys. There are four types of marketable treasury securities: Treasury bills, Treasury notes, Treasury bonds, and Treasury Inflation Protected Securities (TIPS).

MBS: a mortgage-backed security is an asset-backed security that represents a claim on the cash flows from mortgage loans through a process known as securitization.

OPERATION TWIST: is a monetary policy that involves selling shorter-term assets in order to buy more longer-term assets. This is an attempt to do what Quantitative Easing (QE) tries to do, without printing more money and without expanding the Fed's balance sheet, therefore hopefully avoiding the inflationary pressure associated with QE.

PORTFOLIO BALANCE EFFECT: by purchasing a particular asset, the Federal Reserve reduces the amount of the security that the private sector holds, displacing some investors and reducing the holdings of others, while simultaneously increasing the amount of short-term, risk-free bank reserves held by the private sector. In order for investors to be willing to make those adjustments, the expected return on the purchased security has to fall. Put differently, the purchases bid up the price of the asset and hence lower its yield.

TIME SERIES ANALYSIS: comprises methods for analyzing time series data in order to extract meaningful statistics and other characteristics of the data. Time series are very frequently plotted via line charts. Time series data have a natural temporal ordering. This

makes time series analysis distinct from other common data analysis problems, in which there is no natural ordering of the observations.

EVENT-STUDY METHODOLOGY: is a statistical method to assess the impact of a particular news story or significant event related to a firm or a financial market. An event study tries to determine whether that event already has, or will have, a statistically significant effect on the firm or market such that it will affect its financial standing or performance.

RISK PREMIUM: is the minimum amount of money by which the expected return on a risky asset must exceed the known return on a risk-free asset, or the expected return on a less risky asset, in order to induce an individual to hold the risky asset rather than the risk-free asset. Thus it is the minimum willingness to accept compensation for the risk.

GILTS: UK government securities

MACRO/POLICY NEWS CHANNEL: the announcement of QE purchases may itself provide information to economic agents about the state of the economy and about how the MPC might be likely to react to future developments. This channel captures news about expected future policy rates – often referred to as the 'signalling channel'.

PORTFOLIO REBALANCING CHANNEL: imperfect substitutability therefore provides a channel through which QE-related asset purchases by the Bank will affect asset prices by inducing investors to rebalance their asset portfolios. The impact through this portfolio rebalancing channel may occur both on announcement and over time as investors are able to adjust their portfolios.

LIQUIDITY PREMIA CHANNEL: the presence of a central bank in the market may improve market functioning and reduce the extra compensation ('liquidity premium') that investors demand for buying assets that risk being more difficult to sell in the future.

VAR MODEL: Vector autoregression is a statistical model used to capture the linear interdependencies among multiple time series.

GARCH MODEL: if an autoregressive moving average model (ARMA model) is assumed for the error variance, the model is a generalized autoregressive conditional heteroskedasticity (GARCH, Bollerslev(1986)) model.

GARCH-M MODEL: the GARCH-in-mean (GARCH-M) model adds a heteroskedasticity term into the mean equation.

CORPORATE BOND: is a bond issue by a corporation. It is a bond that a corporation issues to raise money in order to expand its business.

BANK OF ENGAND ASSET PURCHASE FACILITY FUND: subsidiary of the Bank of Engand.

APF: the Bank has operated, since January 2009, an Asset Purchase Facility (APF) to buy 'high-quality' assets financed by the issue of Treasury bills.

GILD PURCHASE PROGRAMME: The Bank's gilt purchases were conducted through reverse auctions, whereby counterparties submitted prices at which they offered to sell specific quantities of individual gilts. These were held twice a week from March until August 2009 and three times a week after the August MPC meeting. The first gilt auction was conducted on 11 March 2009. At each auction the Bank accepted the cheapest offers (relative to pre-auction market prices), up to the total amount to be purchased.

UIP: uncovered interest rate parity refers to the parity condition in which exposure to exchange rate risk (unanticipated changes in exchange rates) is uninhibited.

PPP: purchasing power parity asks how much money would be needed to purchase the same goods and services in two countries, and uses that to calculate an implicit foreign exchange rate.

MPC: The Monetary Policy Committee is a committee of the Bank of England, which meets for two and a half days every month to decide the official interest rate in the United Kingdom (the Bank of England Base Rate). It is also responsible for directing

other aspects of the government's monetary policy framework, such as quantitative easing.

FED: The Federal Reserve System (also known as the Federal Reserve, and informally as the Fed) is the central banking system of the United States.

FOMC: The Federal Open Market Committee (FOMC), a committee within the Federal Reserve System, is charged under United States law with overseeing the nation's open market operations (i.e., the Fed's buying and selling of United States Treasury securities).