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QUANTITATIVE EASING AND ITS IMPACT ON THE USD/EUR EXCHANGE RATE

Master's Thesis

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I declare I have written the master's thesis independently.
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ABSTRACT

The objective of the master thesis was to estimate the effects of quantitative easing (QE) programmes, implemented by the Federal Reserve and the European Central Bank, on the USD/EUR exchange rate. The research gap that the current thesis targets, is related to the lack of thorough knowledge of the effects of QE policies that have found a wide implementation by the major central banks since the global financial crisis. The concerns regarding the effects of QE are currently particularly topical in Europe since the European Central Bank has just recently launched its first QE programme. Applying an event study methodology combined with generalised autoregressive conditionally heteroskedastic (GARCH) models showed that QE announcements by both central banks had significant effects on the USD/EUR exchange rate, but with magnitudes that differed across the programmes. The largest effects on the USD/EUR level were related to the Federal Reserve's QE1 programme and the initial announcement of the European Central Bank's QE programme. The "buy" events of the Federal Reserve generally led to depreciation of the US dollar against the euro while the European Central Bank's QE announcements had a strong opposite effect. The estimations of the GARCH models also suggest that some of the Federal Reserve's announcements had a small but statistically significant negative effect on the USD/EUR volatility, suggesting that the central bank communications somewhat helped to reduce uncertainty. Having a vital and almost immediate influence on international trade, the balance of payments, and the overall economic performance, the exchange rate is one of the key linkages through which QE can affect the broader economy. Thus, the results of this thesis support the idea that QE stimulated the US economy through export channels and might do the same for the Eurozone as well.

Keywords: quantitative easing, unconventional monetary policy, exchange rates, central banking, zero lower bound, event study, Federal Reserve, European Central Bank

INTRODUCTION

The principles and practices of monetary policy have changed substantially following the recent global financial crisis of 2007-2008. Over the past six years, leading central banks have introduced a variety of unconventional monetary policy measures, in particular the much debated quantitative easing (QE) in order to stimulate the economy. Implementing monetary policy in a post-crisis world with policy rates approaching the zero lower bound is currently one of the most critical challenges for central banks around the world. While standard monetary policy no longer appears to be effective, the actual effect and efficiency of these unconventional measures with only a little historical precedent remain important areas of ongoing research. The main concern over the past few years has been that QE is not effective enough to support economic growth. At the same time, these practices have been regarded as potential triggers for asset bubbles and risks that could lead the economy into another and possibly even deeper recession. Another, less frequently cited risk is hyperinflation, if QE is significantly more effective than intended. These concerns are not only topical for the economies at which QE is aimed due to the potential global spillover effects.

The research gap that the current thesis targets, is related to the lack of thorough knowledge of the effects of QE policies. Although a substantial body of empirical literature on QE effects has started to emerge, most of the research has focused on domestic effects and, in particular, on the effects on bond yields since these are affected most directly through central bank asset purchases. Regarding the international effects and the effects on the broader economy, the evidence becomes much more sparse. Moreover, most of the evidence is based on the first QE programmes and there is not much information of the effects of later QE programmes.

An alternative method to exploring the effects and the effectiveness of QE is through exchange rates. Having a vital and almost immediate influence on international trade, the balance of payments, and the overall economic performance, the exchange rate is one of the key linkages through which QE can affect the broader economy. If the QE policy is effective

in influencing the exchange rate (depreciating the domestic currency), it is likely to affect the broader economy as well.

Additionally, studying how QE can affect exchange rates will contribute to a better knowledge of the evolution of exchange rates, which has long been of interest to academics as well as policy makers and practitioners worldwide. It might also provide useful information for market participants to position their portfolios.

The objective of the current thesis is to estimate the impact of QE on the USD/EUR exchange rate. It aims to study the effects of QE on the basis of two leading economies: the United States (US) and the Eurozone. The US Federal Reserve was the first among the four major central banks to implement QE right after the 2007-2008 financial crisis, and the European Central Bank was the last to do so, as it launched its QE programme approximately six years later. This thesis attempts to contribute to the QE debate and widen the existing empirical literature in that it also includes the last QE programme of the Federal Reserve and the recent QE programme of the European Central Bank, the effects of which have not yet been thoroughly investigated.

The research questions of this thesis are the following:

- How have the Federal Reserve's and the European Central Bank's QE programmes affected the level and volatility of the USD/EUR exchange rate?
- How do the effects differ across the different programmes?

The research tasks of this thesis are the following. First, it is necessary to introduce essential concepts of QE. Since the QE policies are relatively new and the terminology is still evolving, it is useful to specify the measures of QE and explain their purposes. It is also necessary to identify the potential transmission channels of QE and consider how it could affect the exchange rates and the broader economy. The second task is to examine the empirical evidence of the effects of QE based on the existing literature. It includes providing an overview of the most common methods used in the current area of research and the conclusions of different authors on the basis of the previous findings. The final task is to conduct an empirical analysis. Conducting an empirical analysis includes selection of the data, constructing appropriate models, estimating the final models and analysing the results.

The empirical analysis of the thesis applies common event study techniques combined with generalised autoregressive conditionally heteroskedastic (GARCH) models in order to

look at QE effects more formally and estimate the effect on the USD/EUR exchange rate volatility.

The thesis is organised as follows. The first chapter explains the essence of QE including the economic context and motivations for unconventional policies. It discusses the forms of QE as practices employed by the major central banks and compares the different programmes. It also identifies a number of potential channels through which QE can affect the economy.

The second chapter provides an overview of the effects of QE based on existing literature. It outlines the results of different studies and their conclusions on the QE effects on the real economy and financial markets. It also discusses some crucial issues related to the global spillover effects of QE.

In the third chapter, an empirical analysis is carried out regarding the effects of QE on the USD/EUR exchange rate. The author first describes the data using charts and tables and explains the methodology used in the empirical analysis. Secondly, the results of the empirical analysis are being discussed. Finally, the author provides the main findings and conclusions.

1. THE ESSENCE OF QUANTITATIVE EASING

1.1. The Economic Context and Purpose of Quantitative Easing

In 2007-2008, the world experienced a major financial crisis followed by the deepest and most global recession since the Great Depression of the 1930s. The financial distress that began with subprime mortgage crisis in the US evolved rapidly to real economy and cross-border. A number of countries suffered from the credit crunch, failure of key businesses, shrinking demand, private defaults and massive layoffs. While the intensity of the recession and the impact of the crises varied over the countries, economies slowed worldwide, as credit availability tightened and international trade declined. Governments responded to the crisis with fiscal stimulus and institutional bailouts while central banks cut their key interest rates dramatically reflecting a traditional monetary policy reaction to a slowing economy. However, financial markets were still troubled as questions regarding bank solvency remained and investor confidence was damaged. Real output was declining or growing only sluggishly and inflation appeared to be falling below central banks' target levels. At the same time, standard monetary policy had become no longer effective since the short term interest rates were already set close to zero[1]. The challenge was how to further ease the stance of policy as the economic outlook deteriorated.

In this economic context, some of world's major central banks – the Federal Reserve, the Bank of Japan, the Bank of England and the European Central Bank have experimented with aggressive use of their balance sheets to stabilise financial markets and impose stimulation on the real economy and inflation. These balance sheet policies differed radically

[1] This limitation is known as "zero lower bound". Because currency (which pays a nominal interest rate of zero) can be used as a store of value, the short-term nominal interest rate cannot be pushed (much) below zero, which limits the effectiveness of conventional monetary policy (Bernanke, *et al.* 2004).

from temporary increases in the monetary base that are occasionally used to provide liquidity for short periods and became known as quantitative easing or QE (Fawley *et al.* 2013). These unconventional policies were not, however, unprecedented. The term "quantitative easing" was originally used to describe the Bank of Japan's policies in a comparable situation during 2001-2006 when Japan's deflationary economy was stuck at the zero lower bound.

The idea of QE was to increase money supply and liquidity by affecting the yields on certain financial assets (mostly long-term government bonds). The QE was implemented by purchasing specified amounts of financial assets from commercial banks and other private institutions while simultaneously increasing the monetary base. A specific communication strategy about the central bank's possible future actions has been also a crucial component of the QE policy. Such financial market intervention was the key characteristic of QE although the specifics of the QE programmes varied across central banks.

How QE is adapted may vary depending on economic context and particular motivations of the region in question, and naturally, the effectiveness of the different measures may vary as well (Putnam, 2013). The history of wider practices of these policies is relatively short and QE can be found to be defined in several ways in the recent literature. For example, the Bank of England defined its QE as the purchase of public and private sector assets using central bank money (Benford *et al.*, 2009), while the Federal Reserve initially termed its first round of asset purchases as "credit easing" – as it sought to improve the functioning of long-term bond markets and decrease long-term interest rates rather than simply increase the monetary base (Bernanke, 2009; Fawley *et al.* 2013). Studies on the effects of the Bank of Japan's initial QE policy (e.g. Ugai, 2007) emphasise three pillars: asset purchases, signalling strategy and commercial banks` reserves targeting, i.e. the liability side of the central bank balance sheet. Shiratsuka (2010) defines QE as a "package of unconventional measures designed to absorb the shocks given to the economy by making use of both the asset and liability sides of the central bank balance sheet". Some economists, for instance, Curdia and Woodford (2011), distinguish between "quantitative easing" in the strict sense – in which the policy of the Bank of Japan during the 2001-2006 fits fairly closely –, and targeted asset purchases. They argue that while the former is likely to be ineffective at all times, the latter can be effective when financial markets are sufficiently disrupted. In general terms, QE can be defined as a policy that expands the central bank's balance sheet, in order to increase the level of central bank money in the economy (Bernanke, Reinhart 2004).

The following subchapter will discuss the practices considered as QE by each of the major central banks and compares the different programmes in more detail.

1.2. The Practices of Quantitative Easing

1.2.1. Quantitative Easing in Japan

The Bank of Japan is regarded as the first major central bank to introduce a policy of quantitative easing. By the time new policy was employed the Japan's economy had experienced a decade of stagnation characterised by stagnation and declining prices since the bursting of the Japan's asset bubble in the early 1990s. Since the Bank of Japan's reduction of its policy rate failed to sufficiently stimulate the economy and as the economy was heading toward another recession triggered by the IT bubble collapsed in 2001, the Bank of Japan was pressured to adopt more aggressive monetary easing. The Japan's version of QE consisted mainly of three pillars (Ugai, 2007):

1) providing an ample liquidity supply by using the current account balances (CABs) held by financial institutions at the central bank, essentially bank reserves, as the operating policy target,
2) signalling that this liquidity provision would be maintained until the consumer price index stopped declining,
3) increasing the outright purchase of (long-term) Japanese government bonds (JGBs) if necessary to achieve the targeted increases in CABs.

The QE started in March 2001 with a CAB target of ¥5 trillion – ¥1 trillion higher than the required reserve level. The target was progressively raised to ¥30-35 trillion (6-7% of GDP) by January 2004 and left unchanged until the end of the QE policy. To meet the CAB target, the Bank of Japan gradually increased the amount of long-term JGB purchases from the initial ¥0.4 trillion per month to ¥1.2 trillion. In addition, as a limited-time measure, the Bank of Japan purchased asset-backed securities (ABS) to support the development of the ABS market and strengthening the transmission mechanism of monetary policy. The QE contributed to rapid expansion of the monetary base. After the size of the monetary base was expanded from ¥38 trillion in 1990 (9% of GDP) to ¥65 trillion (13% of GDP) just prior to initiation of the QE policy, it further swelled to ¥110 trillion (22% of GDP) by March 2006

(Shirai, 2014). Partly owing to the improvement in global sentiment as well the yen carry trade (i.e. borrowing in the Japanese yen and investing the proceeds in higher-yielding asset classes) that depreciated the yen, inflation rate finally turned positive from November 2005. The Bank of Japan formally ended QE in March 2006, and returned to the uncollateralised overnight call rate as its policy target.

After the Global Financial Crisis

The second episode of nonstandard measures began only a few years later as the economy was hit by global financial crisis. Along with the general deterioration of the economy, Japan's exports decreased significantly while the yen, as a relatively safe currency, began to appreciate. Against this economic environment, the Bank of Japan introduced Comprehensive Monetary Easing (CME) in October 2010. The new policy consisted the three main elements: 1) purchases of risky assets, such as exchange-traded funds (ETFs), Japan real estate investment trusts (J-REITs), and corporate bonds as well as increased purchases of JGBs; 2) a "virtually zero interest rate" policy 3) a forward guidance with the commitment to maintain zero interest rates and continue the asset purchase programme until the medium- to long-term price stability (2% price stability was the desired target) was in sight. The total outstanding amount of assets to be purchased and funds-supplying operations, initially set at about ¥35 trillion, was progressively increased to ¥111 trillion by the end of 2014 – in terms of the monetary base, equivalent to around ¥200 trillion (Sato, 2013).

Soon after the new Governor and Deputy Governors took office, the Bank of Japan carried out a policy change and introduced even more aggressive monetary easing, Qualitative and Quantitative Easing (QQE), also known as Abenomics, in April 2013. The main purpose of QQE was to achieve the price stability target of 2% at the earliest possible time, with a time horizon of about two years. With QQE, the Bank of Japan: 1) committed to increase the monetary base at an annual pace of about ¥60-70 trillion; 2) increased the purchases of JGBs to ¥50 trillion a year (from ¥20 trillion in 2012) with extending the average maturity from 3 to 7 years; 3) increased the purchases of ETFs and J-REITs; 4) committed to continue with QQE and pursue the 2 % price stability target as long as it is necessary (Introduction...).

At the Monetary Policy Meeting held on October 31, 2014 (Expansion...), the Bank of Japan decided to expand the QQE so that the monetary base would increase at an annual pace of about ¥80 trillion. With this, the size of JGB purchases would increase of about ¥80 trillion

a year and the average remaining maturity JGB purchases would extend to about 7-10 years. The purchases of ETFs and J-REITs would be tripled compared with the past, to an annual pace of ¥3 and ¥0.09 trillion respectively. It was also confirmed that the QQE will be continued as long as it is necessary to achieve the price stability target of 2%.

1.2.2. Quantitative Easing in the United States

The Federal Reserve was the first among the major central banks to implement aggressive unconventional measures in response to the global recession triggered by the 2007-2008 financial crisis. The initial round of QE was commenced in December 2008 and ended in August 2010. The Federal Open Market Committee (FOMC) stated that the goal was to "reduce the cost and increase the availability of credit for the purchase of houses, which in turn should support housing markets and foster improved conditions in financial markets more generally" (Federal Reserve...). According to the monthly reports on credit and liquidity programmes and the balance sheet, the Federal Reserve purchased $175 billion in direct obligations of housing-related government-sponsored enterprises (GSE) like Fannie Mae, Freddie Mac, and the Federal Home Loan Banks and $1.25 trillion in mortgage-backed securities (MBS) guaranteed by these enterprises over the course of the programme. In addition, the Federal Reserve purchased $300 billion of longer-term Treasury securities to help improve conditions in private credit markets.

Since the pace of recovery in output and employment was slow and concerns about deflationary risks were rising, the second round of QE was announced in November 2010. The Federal Reserve further expanded its holdings by purchasing an additional $600 billion of longer-term Treasury securities by the end of June 2011 to "promote a stronger pace of economic recovery and to help ensure that inflation, over time, is at levels consistent with its mandate" (FOMC statement on November 3, 2010).

Although risks of deflation and recession subsided, the sovereign debt crisis in the Eurozone was deepening and threatened to destabilise the second-largest economy in the world. To ensure US economic recovery, the Federal Reserve announced a third round of long-term Treasury purchases, the Maturity Extension Programme in September 2011 (FOMC statement on September 21, 2011). The programme, nicknamed as "Operation Twist", involved the sale of short-term securities and an equal purchase of long-term

securities. Extended in June 2012 to continue through the end of 2012, the programme resulted in the purchase, as well as the sale and redemption, a total of $667 billion in Treasury securities (FOMC statement on June 20, 2012). By putting downward pressure on longer-term interest rates, the maturity extension programme was intended to contribute to a broad easing in financial market conditions and provide support for the economic recovery. However, the Maturity Extension Programme is distinguished from QE programmes as it did not expand the monetary base because the long-term asset purchases were funded by short-term asset sales rather than money creation.

Despite the Maturity Extension Programme, growth in employment was slow, and the unemployment rate remained elevated. To "support a stronger economic recovery and to help ensure that inflation, over time, is at the rate most consistent with its dual mandate", the Federal Reserve further increased policy accommodation and launched the third round of QE by purchasing additional MBS at a pace of $40 billion per month (FOMC statement on September 13, 2012). In addition, the Federal Reserve began purchasing longer-term Treasury securities at a pace of $45 billion per month starting in January 2013. Since December 2013 the pace of additional MBS and longer-term Treasury securities purchases has been reduced and the programme was concluded on October 29, 2014 as the underlying strength in the broader economy was considered sufficient to support ongoing progress toward maximum employment in a context of price stability (FOMC statement on October 29, 2014).

1.2.3. Quantitative Easing in the United Kingdom

The Bank of England, as the second central bank expanding the balance sheet after the global financial crisis, followed the Federal Reserve fairly rapidly. With reducing the Bank Rate to 0.5%, effectively its lower bound, QE programme was launched in March 2009. The aim of the policy was to inject money into the economy in order to boost nominal spending and thus help achieve the 2% inflation target (Benford *et al.* 2009).

During the first round of QE, the central bank acquired £200 billion of assets, consisting almost exclusively of government bonds. Though the Bank purchased some private assets (corporate bonds and commercial paper), the overwhelming majority of its purchases consisted of UK government bonds (gilts). The gilts were purchased mainly from non-bank financial institutions (e.g. pension funds and insurance companies) with the intention of

increasing not only narrow money but also broad money (via an increase in deposits) (Benford *et al.* 2009). These asset purchases represented nearly 30% of the amount of outstanding gilts held by the private sector at the time and around 14% of annual nominal GDP (Joyce *et al.* 2011b).

Due to concerns associated with the euro-area crisis and weaker domestic and global outlook, the Bank resumed its QE purchases. £125 billion of assets were purchased between October 2011 and May 2012 ('QE2'); and a further £50 billion of assets were purchased between July 2012 and November 2012 ('QE3'). (Quarterly Bulletin 2012 Q4)

Since March 2013, the Bank of England has reinvested the cash flows associated with the maturing gilts in order to maintain the stock of asset purchases (i.e. stock of gilts) at £375 billion (Quarterly Bulletin Q3 2014).

1.2.4. Quantitative Easing in the Eurozone

After reducing the key interest rates to historically low levels, the European Central Bank adopted a number of non-standard measures since October 2008. These non-standard measures focused specifically on banks in the Eurozone and comprised several elements, such as fixed-rate full-allotment liquidity provisions, longer-term refinancing operations with exceptional maturities, expansion of list of assets eligible as collateral, and liquidity provision in foreign currencies (Trichet, 2010). In addition, it encompassed some asset purchase programmes, but in magnitude which was practically negligible. It was also envisaged that the liquidity created was fully "sterilised", reversing their effects on the monetary base. Thus, European Central Bank's approach – until the end of 2014 – appears to stand out among other three central banks: its non-standard measures were aimed not at providing additional direct monetary stimulus to the economy but primarily at supporting the effective transmission of its standard policy. By their nature, these non-standard measures were a complement to rather than a substitute for standard interest rate policy and they were conceptually distinct from QE (Cour-Thimann, Winkler, 2013).

What is considered as QE in the Eurozone, is the recent Expanded Asset Purchase Programme (EAPP), announced in January and started in March 2015. The programme will last until at least September 2016 and will have a sizeable impact on the Eurozone's balance sheet. The programme will consist of monthly asset purchases of €60 billion including mainly

bonds issued by the Eurozone central governments, and to a lesser extent those by agencies and European institutions. Approximately €10 billion of monthly purchases will represent purchases of asset-backed securities and covered bonds, as continuation of the programmes that were started in October 2014. (ECB announces…)

1.2.5. Comparison of Quantitative Easing Programmes

Although the discussed unconventional policies pursued by the Bank of Japan, the Federal Reserve, and the Bank of England are commonly known as "quantitative easing", there were considerable differences in purchase volumes and types of securities purchased (Table 1) as well as in terms of the specific motivations and economic and political situations.

Table 1. Summary of asset purchase programmes employed by the major central banks

Central Bank	Programme	Start	End	Volume	Type of Securities Purchased
Bank of Japan	Quantitative Easing Policy	March 2001	March 2006	¥4.8T (1% of GDP) per year, gradually raised to ¥14.4T (3% of GDP) per year	Long-term government bonds, asset-backed securities
	Comprehensive Monetary Easing	Oct 2010	Apr 2013	Total: ¥35T (7% of GDP), raised several times up to ¥111T (23% of GDP)	Government securities, corporate bonds, commercial paper, exchange-traded funds, real estate investment trusts
	Quantitative and Qualitative Monetary Easing	Apr 2013		¥50T (10% of GDP) per year, later raised to ¥80T (16% of GDP) per year	Government bonds, exchange-traded funds
US Federal Reserve	QE1	Dec 2008	Aug 2010	Total: $600B (4% of GDP), later raised to $1.75T (12% of GDP)	Agency mortgage-backed securities, agency debt, long-term government bonds
	QE2	Nov 2010	June 2011	Total: $600B (4% of GDP)	Long-term government bonds
	QE3	Sept 2012	Oct 2014	$480B (3% of GDP) per year, later raised to $1.02T (6% of GDP) per year	Agency mortgage-backed securities, long-term government bonds
Bank of England	Quantitative Easing 1	March 2009	Jan 2010	Total: £75B (5% of GDP), gradually raised to £200B (13% of GDP)	Medium and long-term government bonds

	Quantitative Easing 2	Oct 2011	May 2012	Total: £125B (8% of GDP)	Medium and long-term government bonds
	Quantitative Easing 3	July 2012	Nov. 2012	Total: £50B (3% of GDP)	Medium and long-term government bonds
European Central Bank	Expanded asset purchase programme	March 2015		€720B (7% of GDP) per year	2-30 year bonds issued by central governments and euro-area institutions, asset backed securities, covered bonds

Source: Compiled by the author

According to Bernanke (2009), the Federal Reserve's approach to supporting credit markets under QE1 was conceptually distinct from the QE regime of Japan during 2001-2006. While the Bank of Japan was explicitly targeting the quantity of reserves in commercial banks, the Federal Reserve was focusing on the asset side of the central bank balance sheet (i.e., on the mix of loans and securities that it held and on how this composition of assets affected credit conditions for households and businesses). At the same time, it would be fair to say that QE1, applied to an economy with a failing banking system in late 2008, was a different use of QE than the subsequent QE2, or QE3 applied to an economy already growing again and in recovery (Putnam, 2013).

Likewise, the Bank of England's approach differed from the Bank of Japan's approach in designing its asset purchases to target the assets held primarily by the nonbank private sector. But as the purchases consisted almost exclusively of government bonds, it was also distinct from the Federal Reserve's approach where the central bank buys private assets containing credit risk (Joyce, 2012). However, the Federal Reserve's and the Bank of England's policies were more similar by concentrating on bond purchases while the Bank of Japan (and the European Central Bank – so far) generously lent money to banks to inject reserves into it bank-centric economy (Fawley *et al.*, 2013).

The European Central Bank, constrained by politics and tradition, was the last of the major central banks to undertake a QE policy, while the Bank of Japan has been engaged in QE practices for over a decade already. The economic context is also somewhat different in Japan since it has experienced deflationary pressures for the past 25 years, as adverse demographic trends, such as the decline in the working-age population and the effects of an economic crash conspired to create two decades of stagnation.

Indeed, the economic (and political) situation is fundamentally unique in the Eurozone. Buying sovereign bonds is politically and legally more problematic in the 19-

nation Eurozone than it was for the Federal Reserve or for the Bank of Japan and the Bank of England. The crisis has shown that different economies with different financial institutions face different risks and problems, and for instance, even inflation rates vary substantially. Thus, the transmission mechanism of QE in the Eurozone will be more complicated and opaque.

1.3. Transmission Channels of Quantitative Easing

Recent literature on unconventional monetary policy identifies a number of potential channels through which QE can affect the economy. Although the classification and terminology differs slightly, mostly five main transmission channels are distinguished according to the literature. In compliance with Joyce *et al.* (2011b) and Hausken, Ncube (2013), these channels can be described using the following scheme (Figure 1):

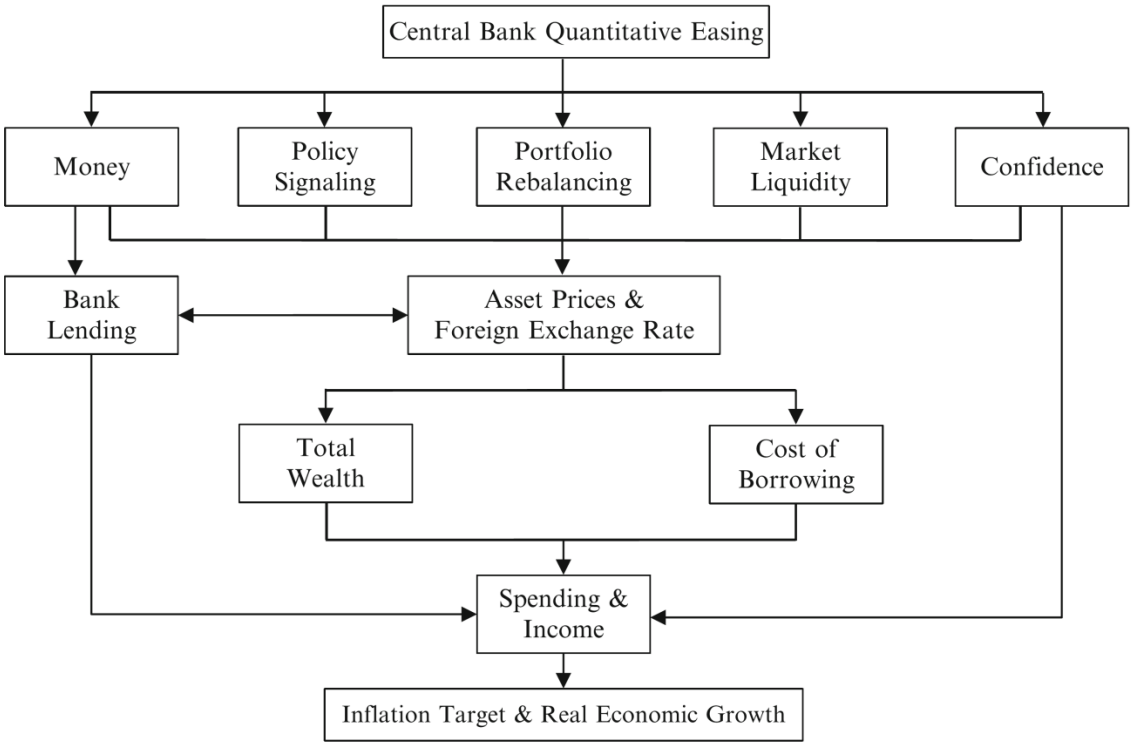

Figure 1. Transmission channels of Quantitative Easing
Source: Hausken and Ncube (2013)

These channels and their potential transmission mechanisms attracted the economists` interest already before the global financial crisis (for example, Bernanke *et al.* 2004) but with QE in place in the aftermath of the crisis, the topic started to gain wider attention. However, most empirical analysis has emphasised the so-called signalling channel and portfolio rebalancing channel.

According to the signalling channel, QE can work through market expectations. First, when announcing large-scale asset purchases, central banks provide information about the likely path of future monetary policies and thus, form the expectations of market participants through a signalling channel. For example, if the central bank announces that it will start purchasing a large quantity of long-term assets, market participants can expect policy rates to remain low for longer than otherwise. Also, a credible commitment that the central bank will do whatever it takes to meet the inflation target, should help to ensure that expectations of future inflation remain anchored to the target. In turn, lower interest rate expectations and higher inflation expectations should encourage greater spending and also influence price-setting behaviour by firms, leading to a more direct impact on inflation (Benford *et al.* 2009). More generally, policy announcements might contain 'news' about the underlying state of the economy, for example if agents relied on central bank analysis to inform their views on the economy (Joyce *et al.* 2011b).

Second, the portfolio rebalancing channel builds from the premise that the sellers of financial assets (that are purchased by the central bank) attempt to rebalance their portfolios by buying other assets which have similar characteristics to the assets sold. The excess money balances are transmitted to the sellers of those assets who may, in turn, rebalance their portfolios by buying further assets — and so on. Depending on how the relative demand for certain assets increases, the asset purchases by central banks should push up the prices not only for the assets purchased under QE but also for their close substitutes, and bring down the associated term premiums and yields (Hausken, Ncube 2013). Lower yields would lead to a lower cost of borrowing, while higher asset prices increase the wealth of asset holders. Both, the lower borrowing cost and wealth effect should encourage investments and spending of companies and individuals. That is expected to help to achieve inflation target, spur real economic growth and reduce unemployment rate.

The third channel through which QE can potentially affect asset prices is the liquidity channel. Whereas central bank asset purchases improve market functioning and increase

liquidity, the asset prices should increase through lower premium for illiquidity. However, since the effect of liquidity channel depends directly on the flow of purchases, the effects through this channel are expected persist rather shortly – only while the central bank is conducting the purchases (*Ibid.*)

In addition to working through the asset prices, QE can have an impact on inflation and economic growth through bank lending channel. As the result of asset purchases, the banking sector gains both new reserves at the central bank and a corresponding increase in customer deposits when assets are purchased from non-banks. These injections of reserves should encourage banks to finance higher new loans than they would otherwise have done. However, it is often argued (for example, Joyce *et al.* 2011b) that the actual impact through this channel remains rather small since banks attempt to hold central bank injections of money as a cushion rather than pass liquidity onto the real economy through lending. (Hausken, Ncube 2013)

Finally, QE may have broader effects through the confidence channel. Since QE is also expected to improve economic outlook, it might directly boost consumer confidence and thus encourage investment and spending. At the same time, the general improvement in confidence may in turn be reflected back in higher asset prices, especially by reducing risk premium. (*Ibid.*)

As a QE policy can work through various channels, it may be difficult to determine which channels work the best. It can be expected that QE should at least primarily influence the prices and yields of the asset classes that are affected most directly through the asset purchases by the central bank. If a QE policy were effective, then these interest rate effects of assets being purchased would spill over into the yields on the other assets as a result of portfolio rebalancing by the sellers of securities to the central bank. Further, purchases can affect international asset prices and exchange rates as a result of global capital market linkages. For instance, a decline in US interest rates would cause investors to reduce their portfolio shares of US securities in favour of foreign securities with higher interest rates, pushing up the prices of those foreign assets and leading to an appreciation of their currencies. Nonetheless, as the financial asset prices and exchange rates are fast moving financial variables that can incorporate all public information quickly, they may react to news about economic developments even before the actual purchases take place–just as soon as the market participants update their expectations. In other words, the effect of QE can occur

through the signalling channel because the market believes that it would work through the portfolio rebalancing channel.

If the QE policy is effective in influencing the exchange rate (i.e., depreciate the domestic currency), it is likely to affect the broader economy as well. For instance, lower currency would support the economy through exports, helping to boost output, employment, and spending, which would favour inflationary pressure. More directly, the exchange rate affects the import prices, which contribute to increases in inflation. Therefore, the exchange rate can also be viewed as one of the key parts in the chain of causation of QE, which can affect real growth as well as inflation.

2. LITERATURE OVERVIEW: THE EFFECTS OF QUANTITATIVE EASING

2.1. The Impact on Real Economy

Whether the QE programmes had statistically and economically significant effects on financial markets and the real economy, has been analysed in various studies using different empirical approaches. However, evidence on the impact of money injections on the real economy, in particular on output and inflation, is sparse since the adjustment can take a fairly long depending on how the policy action is transmitted through various channels. Another issue to reckon with is that central banks were loosening policy at the same time as the fiscal authorities were trying to boost demand and there may have been spillover effects from other countries that were taking similar measures. Thus, it is also difficult to quantify the specific impact of QE on the real economy, given the potential role of several other contributors over an expectedly large time window.

Considering the obvious lags involved before the effects get fully passed through to output and inflation, event study analysis is not appropriate for estimating the effects on real economy and analysis usually has to rely on constructing model-based policy and no-policy counterfactuals, which is obviously made difficult by the unusual circumstances of the financial crisis. As a further matter, the fact that there is little historical precedent for these policies compared to conventional monetary or fiscal policy means that the results from this sort of counterfactual exercise inevitably have to be heavily qualified. (Joyce *et al.* 2012)

Despite these difficulties, there is still a considerable set of studies that attempt to provide estimates of the macroeconomic effects of QE.

2.1.1. The Impact on Output and Inflation

Several studies that examined the Japanese QE episodes (e.g. Kimura *et al.* 2003; Fujiwara, 2006; Berkmen, 2012) found only minor positive effects on economic growth and inflation resulting from QE while these effects tend to be statistically insignificant. The reason commonly cited has been that QE failed to promote bank lending, a key element of the initial QE over the period, and neither Ugai (2007) nor Kimura (2003) found much effect from the large expansion of Japan's monetary base. On the other hand, some evidence regarding the impact on economic activity is somewhat stronger in later studies than those looking at the quantitative easing period up to 2006 which may reflect more effective credit channel as a result of improvements in the banking and corporate sectors (Berkmen, 2012). Schenkelberg and Watzka (2013) found that QE led to a significant decrease in long-term interest rates and significantly increased output, although only temporarily and with a considerable delay. Nevertheless, the target of an increase in inflation was not achieved.

The studies on the US and the UK QE episodes are slightly more promising. In one of those first studies, Baumeister and Benati (2010) created a time-varying parameter structural vector autoregression (VAR) model to investigate the macroeconomic impact of lower long-term bond spreads during the 2008–09 recession period. Using a counterfactual scenario analysis, they compared the impact of the first QE programmes on the real economy with the potential economic situation in the absence of central bank intervention. Their results indicated that QE prevented both the US and the UK from a deeper recession and deflation. Kapetanios *et al.* (2012) investigated the Bank of England's QE1 programme in the UK, add found that the effects of QE on GDP and inflation arise after around six to nine months and one year, respectively. They had a considerable uncertainty and variation across the models used, but taking the preferred average estimates, they suggested that QE may have raised the UK CPI inflation by at most 1.25% and the level of real GDP by at most 1.5%. Chung *et al.* 2012, found that the combination of QE1 and QE2 in the US raised the level of real GDP almost 3% above baseline by the second half of 2012 while the inflation was estimated 1% higher than would have been the case if the Federal Reserve had never initiated these programmes, implying that asset purchases prevented deflation. On the contrary, Chen, H. *et al.* (2012) found that the effect of QE2 on macroeconomic variables was rather modest: GDP growth increased by less than 0.4% and inflation barely changed relative to the absence of

intervention. Consistent with that, other studies that reviewed empirical evidence on the impact of QE in the US and in the UK (e.g. Martin, Milas (2012) and Putnam (2013)), concluded that while the judgment for the initial QE programmes was rather positive – as it was an effective response to the severe economic difficulties of late 2008 and 2009 – , there was only little evidence of subsequent QE programmes having much effect.

There may be several reasons why the effect of subsequent QE programmes on real economy has been harder to prove. For instance, it could be that initial QE programmes were already sufficient to demonstrate the commitment of policymakers to addressing the financial crisis, leaving little for subsequent programmes to add (Martin, Milas, 2012). Or it may be that impact of later purchases is just more difficult to measure as they were introduced after the economy had resumed growth and after the banking sector had recapitalised and returned to profitability (Putnam, 2013). In any case, it is difficult to estimate the impact of QE alone versus other factors, including spillover effects from other countries, and the conclusions remain heavily dependent on the assumptions embedded in the economic models used by the researchers.

2.2. The Impact on Financial Markets: Evidence of Announcement Effects

Regarding the effects of QE on the financial markets, the literature has been evolving more rapidly. Aside from several other reasons of interest to study the dynamics of financial markets and specific asset prices, it is also an alternative way to assess the effectiveness of QE. While the actual purpose of QE is to stimulate the economic growth and inflation, the specific impact of QE to these variables is difficult to quantify. However, if monetary policy decisions are effective in terms of affecting the asset prices, the effects of QE should pass through to the broader economy, and the real growth as well as inflation is likely be ultimately affected. Thus, the impact of QE programmes on government bond rates (or other assets or exchange rates) can be viewed as the impact on the part of a chain of causation that finally links to aggregate demand and then to output and inflation.

The advantage of the methodologies used to estimate the effects on the real economy is that the effects on financial markets are usually amenable to direct observation over shorter periods, which enables the reduction of the roles of several other economic policy measures

and contributory factors. Thus, most of the empirical studies that examined the effects on financial markets have used event studies as a key part of the analysis[2].

More narrowly, the literature can be divided into two main groups. The first is based on an examination of announcement effects, while the second augments announcements with actual purchases and other news. Most of the empirical literature has used the methods of the first category, assuming that announcements changed market expectations and, consistent with the efficient market hypothesis, immediately affected asset prices. Thus, if markets are efficient, the majority of the impact of QE purchases would occur not when purchases are actually made but when expectations of those purchases are formed (Joyce *et al.* 2011a). It also appears that most empirical studies focus on the effects on government bond rates, since in most cases, government bonds would be the first part of the *chain* and affected most directly through central bank purchases.

2.2.1. The Impact on Asset Prices

The early studies on the QE in the US by Gagnon *et al.* (2011a; 2011b) suggested that the announcement effect far outweighs operation effect (actual purchase). Thus, they analysed the direct effects of the announcements of the QE by observing the changes in several financial indicators within one- and two-day event windows. Using both event studies around key QE announcements and time series regressions relating risk premium to measures of the supply of government debt, they demonstrated evidence that the Federal Reserve's QE1 succeeded in reducing the longer-term interest rates on a variety of securities, including securities that were not included in the purchase programmes. The overall size of the reduction in the ten-year term premium was somewhere between 30 and 100 basis points. By

[2] An event study is an examination of asset price behaviour associated with some event, such as a merger, announcement, or intervention. Event studies are used to assess the market's reaction to the event, how the event influenced prices, and whether the market priced the event efficiently. The event study methodology is widely used in many other areas of research; one closely related topic is, for instance, the foreign exchange intervention –i.e., in traditional terms, the practice of monetary authorities to buy and sell currency in the foreign exchange market to influence exchange rates (for a comprehensive overview of the particular studies, see, e.g., Neely, 2005). The methods are similar because for their nature, QE (and announcements related to QE) can also be viewed as a type of intervention.

improving market liquidity and removing assets with high prepayment risk from private portfolios, the QE had an even more powerful effect on longer-term interest rates on agency debt and agency MBS. Based on this evidence, they concluded that the Federal Reserve's QE programmes did lower longer-term private borrowing rates, which should stimulate economic activity.

Several other studies (e.g., D'Amico and King (2010), Hamilton and Wu (2012), Neely (2014)) confirm the significant effects of QE1 in reducing medium and long-term interest rates. Simultaneously, another common finding is that the impact on financial markets was larger when the first stages were announced and became smaller for later extensions of the programmes (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; Meaning and Zhu, 2011; Neely, 2014). Krishnamurthy and Vissing-Jorgensen (2011) documented that both the Federal Reserve's QE1 and QE2 worked through several channels, and significantly lowered yields on all observed bonds (treasuries, agencies, corporate bonds, and mortgage-backed securities), but with magnitudes that differed across bonds, across maturities, and across QE1 and QE2. In general, effects of QE2 on yields were consistently much smaller than the effects found for QE1.

Meaning and Zhu (2011) draw similar conclusions on the QE in the UK. They found that both the US and UK asset purchases had an immediate and non-negligible impact on sovereign bond yields. Following most of the relevant announcements related to the purchase programmes, bond yields declined across maturities, with the largest impact on the five- and ten-year yields. The effects were greatest after the initial announcement of each programme, and the first round of QE had far greater impact than the later programmes in both countries.

Meier (2009) and Joyce *et al.* (2011a) found that the initial round of the Bank of England's QE had economically significant effects on gilt yields. According to an event study analysis by Meier (2009), the QE announcements up to the middle of 2009 reduced gilt yields at the very least by 35-60 basis points. Joyce *et al.* (2011a) estimated that the first round of QE may have depressed medium to long-term gilt yields by about 100 basis points overall, summing up the two-day reactions to the announcements. The wider impact on other asset prices was more difficult to distinguish from other influences, but they noted that corporate bond yields also fell markedly around the time of the announcements. Additionally, they assumed potentially large and negative effects on equity yields, although their econometric estimates were highly uncertain.

Similar to the case in the US, the first round of QE in the UK appeared to have greater impact than the later programmes. Meaning and Zhu (2011) suggested that the novelty or surprise factor associated with the first programme might have waned over time as "more of the same" failed to evoke market reactions of similar magnitude. Martin and Milas (2012) referred to bond yields that were already at a very low level by the time the subsequent QE programmes were introduced, and thus, could not decrease much further. As well, it is likely that the commitment effect was only effective during the first round of QE. That means, when sufficient announcements by the central bank are made, the market will anticipate that the central bank will make an effort to ensure price stability in the future and further measures will be taken, if necessary.

Although the evidence from Japan's earlier experience with the QE suggests that the Bank of Japan's monetary policy actions have helped to reduce yields, it appears that the major effect came instead from the Bank of Japan's commitment to keep policy rates low for some time into the future (Baba *et al.* 2005). The studies of the signalling and portfolio balance effect of JGB purchases under the QE found either small or insignificant effects on longer-term interest rates, including on corporate bonds (Oda and Ueda 2005; Ugai 2007). Bernanke (2004) also suggested that there was only a small effect of news regarding JGB purchases on longer-term yields. These small and largely insignificant effects probably reflect that the JGB purchases were not as large as a share of GDP and that they were skewed toward bonds with shorter maturities. According to Ugai (2007), the peak increase in the Bank of Japan's holdings of JGBs under the QE during 2001-2006 was about 4% of GDP, considerably less than the 12% of GDP increase in the Federal Reserve holdings under the QE1 (Gagnon *et al.* 2011a).

However, the studies on the Bank of Japan's more recent QE showed a more significant impact on asset prices including a significant decrease in long-term interest rates. Lam (2011) used an event study to measure the impact of QE announcements as well as actual purchases on various financial market indicators. He documented significant declines in the ten-year JGB yield (24 bp), two-year JGB yield (14 bp), and corporate yields across investment grades (15–22 bp) in a two-day window following easing events. Stock and futures markets strengthened, cumulatively increasing by 5–7% in the week after.

While the Bank of Japan's easing measures had a statistically significant impact on bond yields and equity prices, there was no notable effect on the exchange rate. The study

also affirmed that most of the impact on financial markets came from the announcement of new easing measures, rather than from subsequent purchases. Similarly, Ueda (2012) and Schenkelberg, Watzka (2013) found some expected impact on asset prices, but did not find any significant effect on the exchange rate suggesting that potential portfolio rebalancing effects – at least in terms of shifts towards assets denominated in foreign currency – have not been effective in lowering the exchange rate.

2.2.2. Global Spillovers

Since quantitative easing programmes are aimed at domestic economy, most of the research has focused on its effects on the domestic economy. However, it is expectable that because of global capital market linkages, the spillovers on foreign markets are inevitable.

Neely (2014) found that the US QE1 announcements also had substantial global impact reducing international long-term bond yields. These price changes closely followed the announcements and were too large to have been generated by chance. He found that when US QE1 reduced nominal 10-year US bond yields by 100 basis points, nominal 10-year foreign bond yields declined by around 44 basis points as a reaction to five "buy" announcements observed over 1-day windows[3]. Australian, Canadian, German, Japanese and British long-term bond yields cumulatively fell by 65, 56, 38, 18, and 43 basis points during the same event windows. At the same time, the US bonds as well as foreign bond yields did not react strongly to the three "sell" events. Apparently, the announcements of minor delays or reductions in the QE had much smaller effects than did the announcements associated with buys because they affected expectations much less. It was also affirmed that the announcements that were not associated with QE had small and inconsistent average effects on asset prices, especially at high frequency, and the policy announcements did not consistently influence international overnight interest rates.

[3] Neely (2014) classified the announcements as "buy" and "sell" events based on the announcement language. The announcements that referred to a looser monetary policy, e.g. the announcements discussed purchases or suggested future purchases, were classified as "buy" events while the announcements that referred to slowing and/or limiting purchases were classified as "sell" events. Other classifications can be found in literature based on the ex post price reaction.

Chen, Q. *et al.* (2012) suggested that the impact of the US QE on emerging economies was in general stronger than that on the advanced economies. QE1 and QE2 in the US influenced prices of a broad range of emerging market assets, raising equity prices, lowering government and corporate bond yields and compressing CDS spreads. Brazil and Hong Kong for instance, were among the economies most affected. Brazil suffered most from strong currency appreciation and CPI deflationary pressures, while the impact on Hong Kong was most strongly felt on equity prices, bank credit, and real GDP.

Moore *et al.* (2013) examined the linkage between QE1 and QE2 in the US and capital flows into emerging market economies (EMEs). Using panel data from a broad array of EMEs, their empirical estimate was that the decreases in the 10-year US Treasury yields increased the foreign ownership share of emerging market debt, and thus, likely contributed to the portfolio flows into EMEs', and consequently, lowered government bond yields in many EMEs. They asserted that while these increased investment flows may have furthered the development of local currency bond markets, negative effects on EMEs' government bond markets can arise from substantive outflows of foreign capital as monetary policy in developed economies normalise.

Fratzscher *et al.* (2013) reported somewhat controversial findings. By analysing the effects of QE in the US and on 65 foreign financial markets, they noticed that QE1 instead resulted in capital flows out of EMEs and into US equity and bond funds. However, QE2 induced a portfolio rebalancing in the opposite direction, pushing capital into EMEs. At the same time, QE2 boosted equities worldwide, while they had muted impact on yields across countries. Additionally, no evidence was found that policy-makers succeeded in insulating their countries from spillovers of QE policies by limiting exchange rate flexibility or imposing controls on capital account openness. These policies might have even amplified the pro-cyclical impact of QE suggesting that capital flows were linked to risk and a flight-to-safety phenomenon during the crisis.

2.2.3. The Impact on Exchange Rates

According to the theory of transmission channels of QE, exchange rate is also one of the key linkages through which QE can affect the broader economy. As exchange rates are key prices in the economy, changes in their level will have implications for resource

allocation and growth. For instance, lower currency would support economy through exports, helping to boost output, employment and spending which in turn would favour inflationary pressure. More directly, exchange rate affects the import prices which will contribute to increases in inflation. This is also related to global spillover effects. As discussed previously, several studies have shown that QE can have large international effects. Another central issue is related to the "currency wars"–a term that has been widely used in referring to QE policies after it was coined by Brazil's Finance Minister, Guido Mantega, in response to QE in the US. When QE2 was launched in the US, it also prompted widespread criticism from other countries, such as China and Germany. Several policy-makers in emerging markets have criticised QE, arguing that the increased capital that flows into EMEs caused by QE has led to appreciation pressures on EME currencies and loss of competitiveness. Hence, there are various reasons of interest to study the impact of QE on exchange rates. While the exchange rate is not directly targeted, the evidence could be even more meaningful.

Some of the previously discussed studies that estimated the QE impact on asset prices also examined the effects on exchange rates. Neely (2014) found that QE1 in the US, which significantly reduced the Australian, Canadian, German, Japanese and British long-term bond yields, also depreciated the USD versus the currencies of those countries. Within the one-day event windows, the USD cumulatively declined by 3.5% to 7.8%, depending on the currency over the eight "buy/sell" dates of QE1. These declines were very large compared to sums of dollar movements over eight randomly chosen days. In contrast, the dollar depreciated far less, on average, during the windows for the 13 FOMC control events, and the declines were inconsistent across exchange rates. These findings support the idea that QE stimulated the US economy through export channels. The previous evidence of a strong effect of the Federal Reserve's QE on exchange rates is consistent with evidence in Rosa's study (2012) on the effect of original, narrative measures of conventional and unconventional monetary policy shocks with a long-term sample (1999-2011) using an intraday event-study analysis. Rosa found a statistically significant correlation between certain QE "buy" (or "sell") announcements and depreciations (or appreciations) of the US dollar against major currencies including the British pound, Canadian dollar, Japanese yen, Swiss franc, and the euro.

However, similar to the results of the impact on bond yields, the subsequent QE programmes also appear to have less impact on exchange rates. Meaning and Zhu (2011) found that the announcements preceded significant depreciations in the exchange rates of the

US dollar (7.7% in two days) during QE1 and the British pound (3.7%) during the first round of QE in the UK, but had little impact on later programmes. Other studies by Glick and Leduc (2012) and Joyce *et al.* (2011a) found similar results suggesting that the initial QE announcements had more significant effects than the subsequent announcements and also that the QE by the Federal Reserve had a significantly larger impact on the dollar than the QE by the Bank of England had on the British pound. Glick and Leduc (2012) examined the impact of QE1 and QE2 by the Federal Reserve and the first round of QE by the Bank of England on the US dollar and British pound. They argued that QE announcements led to depreciations of the US dollar and the British pound against major currencies including the euro, the yen, and the Canadian and Australian dollars on announcement days. Using one-day windows, the value of the dollar fell cumulatively by 3-8% against all these currencies, with all effects significant at a 1% confidence level. However, the daily currency movements appeared to be accentuated on days of QE1 announcements compared to days of QE2 announcements. Although the effect on the value of the British pound was not found to be statistically significant, the point estimates indicated that the pound tended to depreciate against all currencies in the range of 2-3%. Joyce *et al.* (2011a) found much the same, noting only a modest fall in the British pound. Summing the immediate reactions to the six QE news announcements, the British pound exchange rate index depreciated by 4% overall, which was also much less than the 8% depreciation they implied based on a simple uncovered interest rate parity calculation.

In Glick and Leduc's study (2013), the authors also included the first three announcements of the third round of QE in the US and instead used high-frequency, intraday data to study the dollar's movements against the currencies of major US trading partners. They also considered changes in long-term Treasury rate futures to identify the surprise component of the announcements. The authors documented that one standard deviation of surprise easing resulted in a roughly 40 basis-point decline in the value of the dollar within an hour. For comparison, in the conventional policy period, one standard deviation of surprise easing in the federal funds rate led to a six basis-point decline. Using an adjustment parameter related to long-term rates, the authors rescaled the unconventional surprises standard deviations into those for conventional surprises and found that an (adjusted) one standard deviation of surprise in the unconventional policy easing led to a five to six basis-point depreciation in the dollar, similar to conventional surprises. These results are encouraging and

suggest that the exchange rate effect of the new QE policy was as effective as it was when the Federal Reserve could rely on changes in the federal funds rate to conduct monetary policy. In addition, they estimated the effects of monetary policy announcement surprises across individual QE rounds as well and found that the dollar depreciation was smaller following the selected FOMC announcements about QE2 and QE3. Although the limited degrees of freedom for individual QE rounds forfeited statistical significance in their regression, they documented that the magnitude of the trade-weighted dollar depreciation was 43, 72, and 5 basis points, as observed over an hour after the QE announcements, in response to one standard deviation of quantitative easing surprise during QE1, QE2, and QE3, respectively.

3. EMPIRICAL ANALYSIS

3.1. Data and Methodology

3.1.1. The Key Events and USD/EUR Dynamics

The empirical analysis in this thesis investigates the daily exchange rate returns, which are calculated based on the daily closing prices obtained from Bloomberg, and the calendar dates of announcements related to the Federal Reserve's QE programmes known as QE1, QE2, and QE3, and the more recent QE programme of the European Central Bank. The selected dates are generally consistent with those presented in the previous studies, such as Neely (2014), Glick and Leduc (2013; 2012), Fratzscher *et al.* (2012), Meaning and Zhu (2011), but the observation period in this thesis is longer and thus, more announcement dates are included.

The observation period includes the three QE programmes carried out in the US and the recently announced QE programme in the Eurozone. The period characterised by QE policy actions by the Federal Reserve spans the period from November 2008 to November 2014, including QE1, QE2, and QE3 that followed one another in relatively short intervals. Less than three months after the ending of the third programme in the US, QE was announced by the European Central Bank. Thus, the observed period is extended so that it also includes the beginning of the QE episode by the European Central Bank. Therefore, the observation period of this thesis ranges from November 1, 2008, which starts from the first month of the first round of QE by the Federal Reserve, to the end of March 2015.

The USD/EUR Exchange Rate

From a purely econometric point of view, the USD/EUR exchange rate displayed in Figure 2, presents some characteristics of a non stationary random walk, with three main periods corresponding to the 2 years of depreciation of the euro/ appreciation of the dollar (i.e.

the initial years after the introduction of the euro), followed by the reverse phenomenon from 2001 to 2008, and the more volatile period since the global financial crisis which is also characterised by unconventional policies employed by the central banks. The observation sample includes the most part of the third period, starting with an episode of extremely high volatility caused by the financial turmoil during the global financial crisis. The volatility was also relatively high during 2010-2012 that can be related to the European debt crisis, and is reaching the same levels again since January 2015. At the same time, the depreciation of the euro against the dollar over the past few months has been remarkable – it has fallen through all its lowest levels since the global financial crisis and even more, achieving the level last seen in 2003. This can be related to the beginning of the QE in the Eurozone (and the ending of the QE in the US).

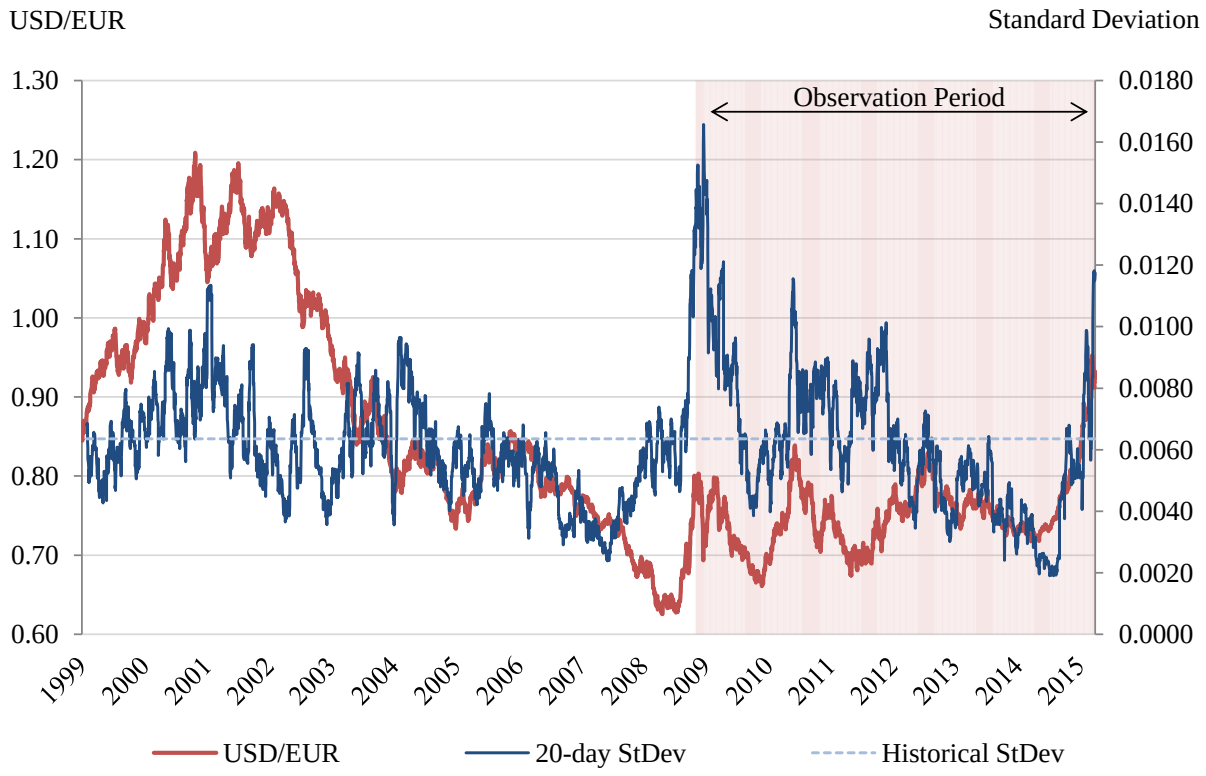

Figure 2. The USD/EUR exchange rate history

Source: Compiled by the author on the basis of exchange rate data observed from Bloomberg

The daily returns for the USD/EUR exchange rate, are the continuously compounded returns calculated as the difference in the logarithm of the closing prices for two consecutive days. The descriptive figures for the observed period, as well as for the whole period since the euro was introduced, are summarised in Table 2.

Table 2. Descriptive figures for the daily returns of the USD/EUR exchange rate

Statistics	January 1, 1999 - March 31, 2015	November 1, 2008 - March 31, 2015
Observations	4238	1672
Mean	0.000021	0.000102
Maximum	0.025218	0.024118
Minimum	-0.034654	-0.034654
Std. Dev.	0.006353	0.006575
Skewness	-0.033316	-0.160849
Kurtosis	4.330094	4.839299
Jarque-Bera	313.1866	242.8936
Probability	0.000000	0.000000

Source: Compiled by the author

The figures reported are the sample size, mean, maximum, minimum, standard deviation, skewness, kurtosis and the Jarque-Bera test statistic and probability (p-value of the Jarque-Bera statistic). The sample size for the observation period is 1672 and 4238 for the full period of USD/EUR history. The mean is almost zero, for both periods, indicating that, on average, both of the currencies have been appreciating/depreciating about the same other over the other period (the dollar has been only marginally more appreciating than depreciating). The skewness and kurtosis show that the distribution of the daily returns for the USD/EUR exchange rate is non-normal in both periods which is also confirmed by the Jarque-Bera test. The skewness also indicates a distribution with an asymmetric tail slightly extending toward more negative values for the observation period from November 1, 2008 to March 31, 2015 and the kurtosis indicates a relatively peaked distribution for both periods. In addition, it can be noted that the USD/EUR exchange rate is serially uncorrelated, as shown by the corresponding correlogram in Appendix 1 representing white noise (and stationarity).

The USD/EUR exchange rate daily returns displayed in Figure 3 complements the understanding of the volatility of the exchange rate. It clearly demonstrates the well-known phenomenon of volatility clustering in financial markets, i.e. the tendency for large returns (of

either sign) to follow large returns, and small returns (of either sign) to follow small returns. It can be also concluded that volatility changes over time (i.e. heteroskedastic in nature) and tends to be positively correlated with its level during the immediately preceding periods.

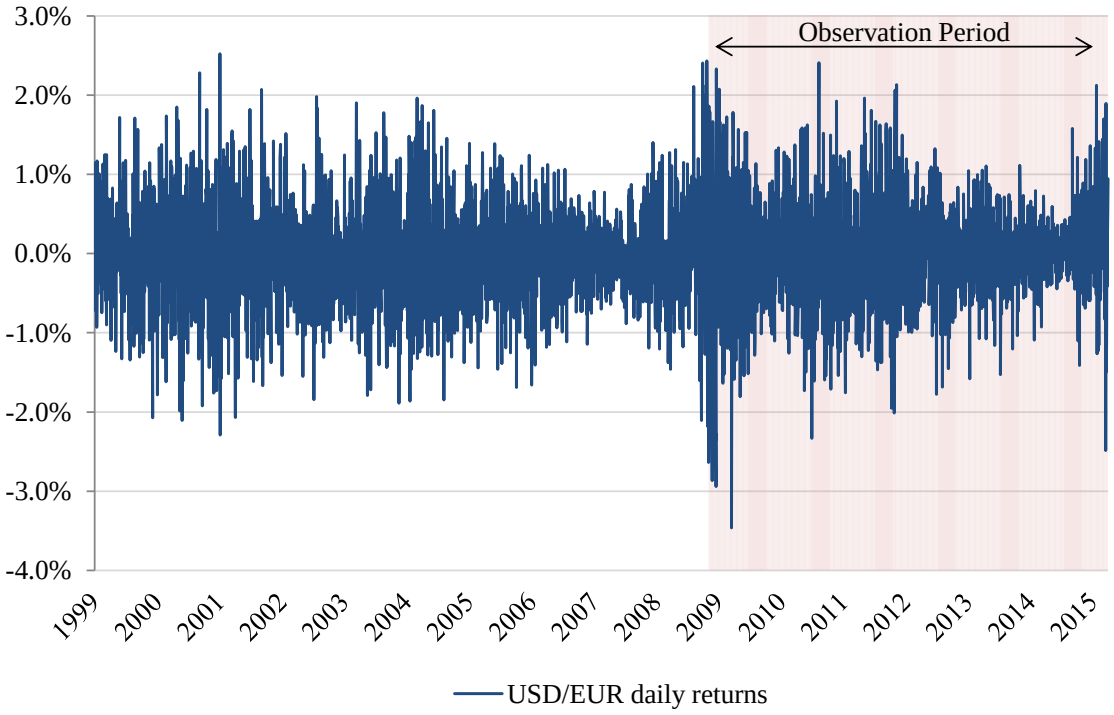

Figure 3. The USD/EUR exchange rate daily returns

Source: Compiled by the author on the basis of exchange rate data observed from Bloomberg

The Key Announcement Dates

The complete sample includes the QE announcements by the both central banks and consists of 32 events in total. Since the observable history of QE programmes is by far longer for the US (from November, 2008 to November, 2014), than that for the Eurozone starting from January, 2015, most of the events analysed in this thesis are related to the QE programmes implemented in the US – i.e. a total of 28 events. Two events are related to the QE programme in the Eurozone, and additionally two events related to the Federal Reserve's Maturity Extension Programme, are also analysed. The summary table containing the full set

of relevant events is provided in Appendix 2 (the appendix also outlines the respective URLs for the sources of the announcements).

The announcements consisted mainly of signals of possible future purchases, firm disclosures of planned purchases, including quantities and time-frames, and as well as statements of purchase slowdowns and a cutbacks. It is assumed that announcements which language refers to a looser monetary policy (e.g. the announcements that discuss launching or extending the QE programmes) would depreciate the national currency while the announcements that discuss slowing or limiting the purchases of these programmes, would have the opposite effect. To maintain continuity with the literature, this thesis follows Neely (2014) in classifying the events as "buy" events and "sell" events according to the announcement language. Based on this classification, there would be then 14 "buy" events and 14 "sell" events related to the Federal Reserve's QE programmes, and two "buy" events related to the recent QE programme of the European Central Bank, while these "buy" announcements of the European Central Bank can be in turn modelled as "sell" events for the US dollar. Since the Federal Reserve's Maturity Extension Programme is distinguished from the QE, as it did not expand the monetary base, the announcements of this programme are not classified as "buy" or "sell" events. However, as these announcements also discussed the asset purchases, one might expect that their effects would be more similar to QE "buy" announcements rather than "sell" announcements.

Although there are several other factors that influence the exchange rate on daily basis as well as in long term, Figure 4, representing the USD/EUR exchange rate and the QE episodes, including QE announcements, suggests some relationship between QE and the exchange rate. Furthermore, it seems that even when the QE was continued, i.e. the central bank (the Federal Reserve) was still implementing asset purchases, by increasing its balance sheet, the domestic currency (US dollar) rather tended to appreciate if the purchases were announced to be slowed. It also displays the robust appreciation of US dollar against euro at the time when the third round of QE in the US ended and similar programme was announced by the European Central Bank.

In addition, Figure 4 also includes the two dates related to Maturity Extension Programme ("Operation Twist") – the announcement of the programme and the extension of the programme as marked with green vertical lines. Interestingly, it seems that generally the US dollar rather appreciated than depreciated during the programme – in contrast to the QE

programmes. This may reflect the less aggressive nature of this programme compared to QE. Although it also comprised long-term Treasury purchases, it was less aggressive measure than QE since it did not expand the monetary base.

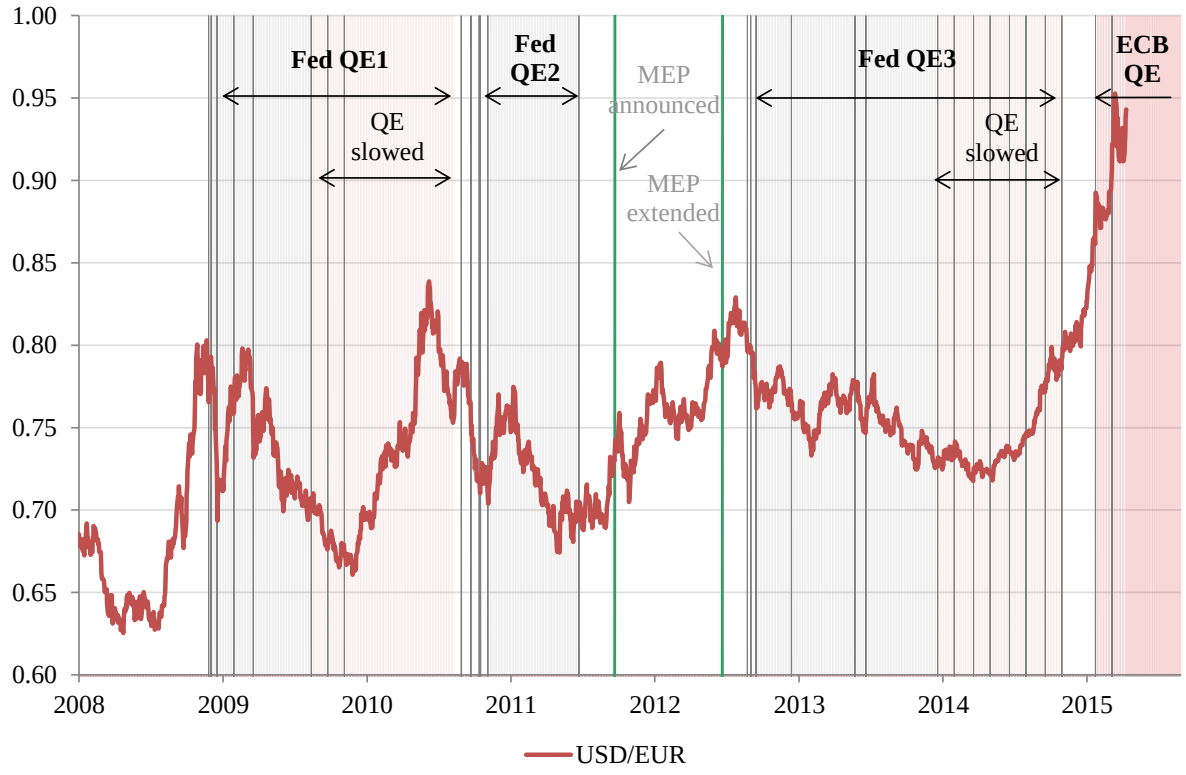

Figure 4. The USD/EUR exchange rate and the QE episodes

Note: The vertical grey lines correspond to days related to QE announcements; the vertical green lines represent the dates related to Maturity Extension Programme announcements.

Source: Compiled by the author on the basis of exchange rate data observed from Bloomberg and event data provided in Appendix 2

When looking at the historical distributions of USD/EUR exchange daily returns, it stands out that at least the three largest daily exchange rate returns have occurred on dates that can be related to QE1 announcements by the Federal Reserve. These are the days when US dollar has depreciated the most, even when observed over the whole USD/EUR history, since January 1, 1999 when the euro was introduced (see Figure 5).

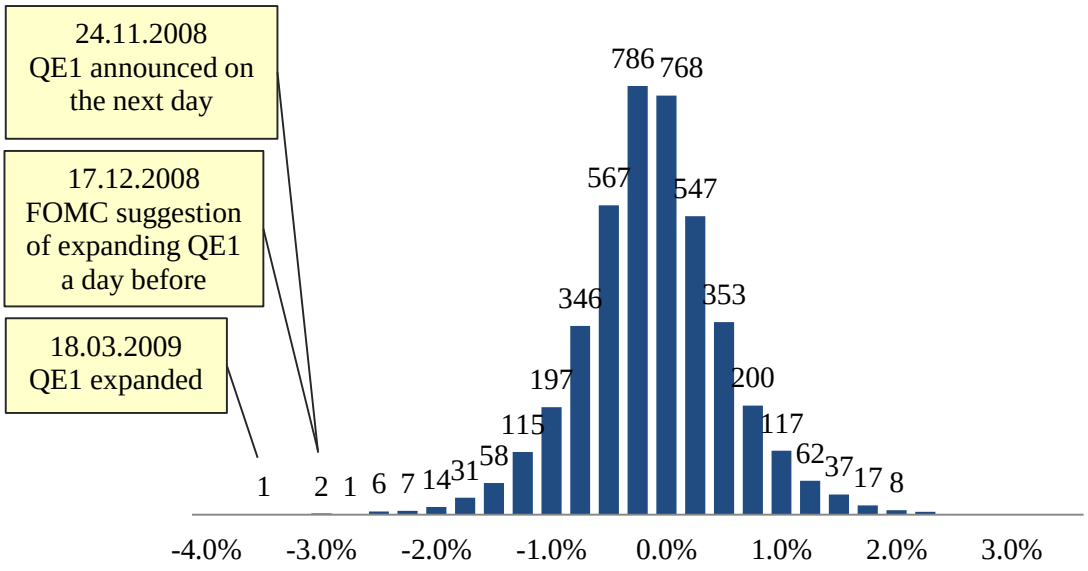

Figure 5. The distribution of USD/EUR exchange daily returns

Note: The frequency (No. of observations) is displayed above the columns.

Source: Compiled by the author on the basis of exchange rate data observed from Bloomberg and event data provided in Appendix 2

3.1.2. Methodology for Empirical Analysis

The previously discussed literature suggested that QE announcements can change market expectations of future asset purchases by the central banks and, consistent with the efficient market hypothesis, immediately affect financial markets. Due to its suitability for fast moving financial variables that are commonly thought to incorporate all public information, the event-study approach was used in most cases. For instance, Neely (2014) went even further and stated that while markets may have had initially under- or overestimated the policies' impact, the efficient market hypothesis implies that the initial impact is the best point to estimate the long-run effect.

This thesis concentrates on the QE programmes of the Federal Reserve and the European Central Bank and uses the widely used event-study methodology to examine the impact of QE on the USD/EUR exchange rate. While the first part of the analysis is based on the most common type of event study that examines the exchange rate behaviour around official communications regarding QE, the second part of the analysis employs generalised autoregressive conditionally heteroskedastic (GARCH) models in order to look at QE

announcements' effects more formally as well as to study the effect on the exchange rate volatility.

The approach taken in this thesis is similar to those of earlier studies that examined the QE impact on the financial market (either on asset prices or exchange rates–often the same event study was used for both) in that it uses communications by central banks and identifies the "news" about their QE programmes of asset purchases. Likewise, in Neely (2014) and Glick and Leduc (2012), the effects of the announcements are observed as the effects of separate events as well as the effects of event clusters. The clusters are formed for each QE programme based on the classification of "buy" and "sell" events discussed in the previous section.

However, there are some important assumptions that underlie the validity of the event-study approach for an assessment of the effects of QE. First, it assumes that the selected event set includes all announcements that have affected expectations about the total future volume of relevant asset purchases under QE. Second, the expectations about these purchases have not been affected by anything other than these announcements. Third, one can measure responses in windows wide enough to capture long-running effects but short enough that the net cumulative effect of other news during the event windows is negligible. Fourth, markets are efficient in the sense that all the effects on the exchange rate occur when market participants update their expectations and not when actual purchases take place.

This thesis attempts to satisfy the first assumption by selecting a large set of announcements, including not only those announcements that provide firm disclosures of planned activities/purchases, but also suggestions and hints for possible future actions. However, the possibility that, to some extent, markets alter their QE expectations in response to other news (such as macro news) remains. Selecting the window length is challenging. It involves a trade-off between allowing sufficient time for revised expectations to become fully incorporated into exchange rates and keeping the window narrow enough to make it unlikely to contain the release of other important information. Consistent with Neely (2014), Meaning and Zhu (2011), and Joyce *et al.* (2011a), this thesis considers both one- and two-day event windows to examine the exchange rate behaviour around official communications regarding QE. Although some event studies often examine intraday price changes in order to avoid the pollution of measured responses by extraneous information, the author considers a wider window more suitable in the current context. While it is practically impossible to draw a

response window narrow enough to include only the effects of QE, given the novelty of the QE and the diversity of beliefs about the mechanisms by which it operates, changes may have been absorbed more slowly than for typical monetary policy shocks, for instance, those related to the change in policy rate (Joyce *et al.,* 2011a). Moreover, unexpected or unusual news often produces protracted adjustment periods (Gagnon *et al.*, 2011b; Neely, 2014).

An Analysis Based on the GARCH Model

The usage of the GARCH class of models proposed by Bollerslev (1986) was motivated by the fact that it allows an alternative and more formal method of examining the QE announcements' effects and additionally, of studying the effect on exchange rate volatility. Another motivation for using the GARCH model is the heteroskedastic nature of the returns of the USD/EUR time series. As the volatility of USD/EUR changes over time, it makes sense to consider a model that does not assume that the variance is constant and which describes how the variance of the errors evolves.

The GARCH class models are the most common tools when modelling the volatility of exchange rates. The GARCH models are also widely used to study the effects of three central bank interventions on the exchange rate (Neely, 2005). Since QE can be viewed as being similar to intervention, the approach using GARCH models in this thesis also draws parallels with those taken in studies that examined the effects of foreign exchange rate intervention (e.g., Chang and Taylor (1998), Dominguez (1998), Aguilar and Nydalh (2000), Edison (2006), and Watanabe and Harada (2006)).

The general structure of a GARCH model includes the mean equation (see equation 1), the variance equation (see equation 3) and the equation that connects the two (equation 2):

$$y_t = \mu_0 + \varepsilon_t \tag{1}$$

$$\varepsilon_t = \nu_t \sigma_t \tag{2}$$

$$\sigma^2{}_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2 \tag{3}$$

where

y_t – return of an asset,

μ_0 – conditional mean,

ε_t – random shock, error term,

ν_t – white-noise process with zero mean and unit variance,

σ_t – conditional standard deviation of the error term,

$\sigma^2{}_t$ – conditional variance of the error term,

α_0 – constant term,

$\sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2$ – ARCH term i.e. information about volatility from the previous period,

$\sum_{i=1}^{p} \beta_i \sigma_{t-i}^2$ – GARCH term i.e. last period's forecast variance.

The studies of intervention use GARCH models in which intervention and other variables can influence exchange rate conditional variance contemporaneously, while such specifications also frequently include lagged values of intervention and/or dummy variables for weekends and holidays as explanatory variables (Neely, 2005). For instance, Watanabe and Harada (2006), examined the effects of the Bank of Japan's intervention on the behaviour of the yen/USD exchange estimating GARCH(1,1). In addition to explanatory variables of intervention, which were the Bank of Japan's and Federal Reserve's net purchases of dollars, they also included into the conditional mean equation the spread between the Japanese and the US overnight interest rates as explanatory variable. Aguilar, Nydalh (2000) also include a dummy variable for the days when the governor or the deputy governors held a speech – if the speech was aimed to signal a tightening of monetary policy, then the dummy variable took value 1; if the aim was to signal a more expansive monetary policy, -1; and 0 in the case the speech was neutral.

Similar to Aguilar, Nydalh (2000), the GARCH model in this thesis employs the (0, 1) dummy variables for the days related to the QE announcements. At first, the QE announcements are observed as single events (or, single "interventions"), and afterwards, QE will be defined as a series of events according to the clusters according to the classification discussed in the previous subchapter. Initially, there will be one dummy variable for each QE announcement and additionally those for the Federal Reserve's Maturity Extension Programme – therefore, a total of 32 dummy variables. The event clusters are formed for each QE programme while the "buy" and "sell" events and the Maturity Extension Programme events will be grouped separately. Thus, there will be eight dummy variables to describe each cluster. After that, the announcements are grouped once more so that event clusters are

formed for each central bank (the "buy" and "sell" events and the Maturity Extension Programme events will be grouped separately) – which results in four event clusters.

Additionally, controlling for financial turmoil and its impact on market sentiment, the daily logarithmic returns of the Chicago Board Options Exchange Volatility Index (VIX), which measures the implied volatility of S&P 500 index options, is included as explanatory variable for the conditional mean equation. Often referred to as the "fear index" or the "fear gauge", the VIX is considered as one of the best indicators reflecting the general market sentiment. Similarly to Watanabe, Harada (2006), current thesis also attempted to include the spread between the overnight interest rates (the spread between the overnight interest rates of the Eurozone and the US) as explanatory variable, but as it appeared statistically insignificant, it is not used in the estimated model.

To test the statistical significance of the QE announcements, and their effect on exchange rate level as well as on volatility, this thesis considers three GARCH models. The first one is used to analyse the effects of all announcements as for each separate event (the results are almost identical to entering these variables in separate regressions, since the announcement days from the two central banks do not overlap). The other two models are used to estimate the effects of the previously described event clusters. Using different models will also contribute to the robustness of the results.

Therefore, the structure of the GARCH models that are estimated in this thesis is expressed as follows:

$$y_t = \mu_0 + \sum_{i=1}^{k} \gamma_i D_i + \delta_i V_i + \varepsilon_t \tag{4}$$

$$\varepsilon_t = \nu_t \sigma_t \tag{5}$$

$$\sigma^2{}_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2 + \sum_{i=1}^{k} \lambda_i D_i \tag{6}$$

where

D_i – dummy variables related to QE announcements or announcement clusters,

V_i – the logarithmic returns of the VIX.

Similarly to Watanabe, Harada (2006), the right-hand side of the mean equation does not contain any lagged exchange rate returns because the return for the USD/EUR exchange rate was found to be serially uncorrelated.

The initial selection of a particular model specification is based on the Akaike and Schwarz's Bayesian information criteria (see Tables 7-9 in Appendix 7 for selection for all the three models). Accordingly, the first model used to estimate the effects of all announcements separate events will be GARCH(0,1) model. The usage of this model is also supported by the highly statistically significant coefficient of the lagged squared residual in the conditional variance equation (see Appendix 8) and the evidence of no autocorrelation and no conditional heteroskedasticity (ARCH effects) left in the residuals (see the Appendices 9 and 10 respectively). It also appears that including the VIX component in the mean equation is justified as it comes highly significant (statistically significant at 1% confidence level), thus improving the quality and explanatory power of the model.

A different model specification is used for the other two models that estimate the effects of event clusters since for those, GARCH(0,2) and GARCH(1,1) accordingly, seem somewhat a better fit based on the Akaike and Schwarz's Bayesian information criteria (see Appendix 7). As with the first model, the usage of these models is supported by the highly statistically significant coefficients on both the lagged squared residuals and lagged conditional variance terms in the conditional variance equation, as well as the evidence of no autocorrelation and no conditional heteroskedasticity. The VIX component in the mean equation remains highly significant.

3.2. Empirical Results

This section first discusses the nominal USD/EUR changes in 1-day and 2-day windows around the 30 QE events and the two events that were related to the Maturity Extension Programme. Then, these findings are compared to the estimates of the GARCH models. The GARCH models are used to estimate the effects of the QE events on the level as well as on the volatility of the USD/EUR exchange rate.

The results of the event study are organised as follows: the nominal USD/EUR changes in 1-day and 2-day windows around the 30 QE events and the two events that were

related to the Maturity Extension Programme are provided in Appendices 3-6. Appendix 3 reports the results for Federal Reserve's "buy" announcements (i.e. the announcements that contained firm disclosures of planned purchases, extensions of the programmes and suggestions of possible future purchases) for the three Federal Reserve's QE programmes (QE1, QE2, QE3). Accordingly, Appendix 4 reports the results for the Federal Reserve's "sell" announcements. Appendix 5 reports the results for the European Central Bank's QE "buy" announcements (– these announcements should affect the USD/EUR exchange rate in the same direction as the Federal Reserve's "sell" announcements). Appendix 6 reports the results for the announcements that were related to the Maturity Extension Programme by the Federal Reserve. To assess the relative size of the reported changes, the appendices also provide comparable values (in parenthesis) that denote the proportion of daily changes during the observation period that were larger in absolute value than the change on the particular event day.

The output data for the GARCH models that are used to estimate the significance of the QE announcements and their effect on the USD/EUR level as well as on the volatility, is provided in Appendices 8-12. The Appendix 8 provides the output for the GARCH model that considers the effect of each announcement separately, and the Appendices 11-12 provide the output for GARCH models that are used to estimate the effect of event clusters.

3.2.1. The USD/EUR Reaction Around the Key Events

When observing the nominal USD/EUR changes in 1-day and 2-day windows (see Appendix 3), it is found that the largest exchange rate fluctuations appeared around the announcements related to the Federal Reserve's QE1 programme. The findings are robust to that in general, the US dollar depreciated against the euro over the 5 QE1 "buy" announcements with a total effect of 6.0–9.7% depending on which window size is considered most accurate[4]. In comparison, the 5 "buy" announcements of the later, QE2 programme seem

[4] There is one exceptional date on which the dollar did not depreciate – December 1, 2008, when Federal Reserve's Chairman Ben Bernanke held a speech on the Federal Reserve policies during the crisis. Although Bernanke suggested a further loosening the monetary policy by stating that Federal Reserve could start buying the longer-term, dollar instead appreciated on that day (and on the next day). One explanation for this could be

to have much smaller effects. Although the dollar tended to depreciate on these days, the sum effect is relatively modest, 2.3–4.2% depending on the window size. The result is very similar for the QE3 "buy" announcements – the depreciation of the dollar is evidenced on all the announcement days, but the overall effect remains between 2.3–3.9%.

In contrast, there does not seem to be a similar robust relationship between the "sell" announcements of the QE1 and the USD/EUR exchange rate (see Appendix 4). Instead, the exchange rate rather changes in the opposite direction to what would be expected. The exchange rate reaction to the QE2 and QE3 "sell" events is similarly rather modest, but the direction of the movements is what would be expected – the dollar mostly appreciated against the euro.

The few QE announcements regarding the recent QE programme of the European Central Bank, seem to have had again stronger impact on the USD/EUR exchange rate (see Appendix 5). The exchange rate returns are relatively large in both, 1-day and 2-day windows while the euro was depreciating/the dollar was appreciating, as would be expected. The effect was particularly strong on the announcement day of the programme (2.1%) while the announcement of starting with the purchases also contributed to the overall effect of 2.6-2.9%.

Finally, it can be noted that compared to QE programmes, the effect of Maturity Extension Programme is rather unclear. However, the announcement of the programme seems to have supported the appreciation of the dollar (see Appendix 6).

Based on the previous findings, the one of the main conclusions would be that the QE announcements had an impact on the level of the USD/EUR exchange rate, but with most of the effect produced by the "buy" announcements. This conclusion seems consistent with what would be expected. Since the "buy" announcements consisted also the information of the volumes of the planned purchases, including the time-frames, it would be reasonable expect that the announcements of slowing down the pace of purchases or concluding the programmes contained less "news" for the market.

The second conclusion is that the first programme of the QE in the US had far larger effects than the following programmes. A part of reason could be that over time, markets

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the flight-to-safety phenomenon, especially during the peak crisis and the general extremely high volatility of financial markets.

became familiar with the central bank new policies and incentives for asset purchases, and thus, in later QE episodes, markets would be able to anticipate the some of the actions by the central bank and alter their QE expectations in response to macro news. At the same time, it is also possible that the magnitude of the observed fluctuations is related to the general market volatility, meaning that, possibly the large magnitude of the fluctuations in exchange rate did not depend (only) on the content of the "news", and happened to be large as the markets at that time were extremely volatile.

The following section will analyse GARCH models to consider the robustness of the previous findings and additionally, estimate the effects of QE announcements on the exchange rate volatility.

3.2.2. The Effects of the Federal Reserve's QE "Buy" Announcements

The GARCH (0,1) model that is used to estimate the effects of each announcement as a separate event, confirms the significance of the effects of six Federal Reserve "buy" announcements on the level of USD/EUR exchange rate and suggests that there were five announcements that had a statistically significant impact on the exchange rate (see Table 3). Although statistically significant announcements were found in all of the Federal Reserve's QE programmes, the estimated coefficients of the dummy variables (announcements) indicated that the announcements of the QE1 programme had the largest impact. This result is also supported by the GARCH (0,2) model that estimates the effects of the event clusters for each programme. These conclusions are similar to those that were previously made based on the observation of the nominal USD/EUR changes in one-day and two-day windows.

An interesting result regarding the initial round of QE in the US is that the effects of the announcements of expanding the QE programme were highly significant, while the effect of the announcement of the initial launching the programme was not. One possible explanation could be that starting with such a programme did not come as a surprise to the market (on the day the announcement was launched). This argument is also supported by the large depreciation of the dollar on the day before the announcement (see Figure 3). At the same time, it also might reflect the difference in the announced purchase volumes of the programme as the expansion of the QE1 boosted its initial size almost three times.

It also appears that the early hints and signals by the chairman of the Federal Reserve or the FOMC suggesting looser monetary policy were very important and credible for the market, and in some cases, even more important than the following firm disclosures on actual purchases.

As would be expected, the signs of the statistically significant coefficients confirm that, in general, the dollar was depreciating against the euro as a result of the Federal Reserve's "buy" announcements. There is only one announcement date that indicates a slight appreciation of the dollar, but the effect is rather small and not significant at the 1% or 5% confidence levels[5].

Additionally, it was found that several of the Federal Reserve's "buy" announcements had a statistically significant effect on the volatility of the USD/EUR exchange rate, although the coefficients are very small. In all cases, the effect was a reduction in volatility of the exchange rate, possibly indicating that these programmes provided a calming effect on the market by helping to cool down the concerns regarding the risks and general uncertainty.

Based on the GARCH (1,1) model that estimates the effect of all the "buy" announcements of the Federal Reserve as the effect of one variable, it can be concluded that the overall effect of these announcements was statistically highly significant (at the 1% confidence level) for the level of USD/EUR leading to the depreciation of the dollar. Although the GARCH (0,1) and GARCH (0,2) models provided some evidence for the effects on the volatility for a few episodes, the GARCH (1,1) model does not support the overall effect of these announcements on the exchange rate volatility.

Table 3. The Effects of the Federal Reserve's "Buy" Events

Programme	Date	Event	Impact on USD/EUR Level	Impact on Volatility
QE1	25.11.2008	QE announced	0.8296	0.0053
	01.12.2008	Bernanke's suggestion of expanding QE	-0.5167	-0.0035***
	16.12.2008	FOMC suggestion of expanding QE	-2.6263***	-0.0035
	28.01.2009	Fed stands ready to expand QE	0.7174	0.0001
	18.03.2009	QE expanded	-2.5574***	0.0040

[5] All conclusions are based on coefficents that are statistically significant.

		The Effect of the QE1 "Buy" Cluster	**-0.7928*** **	**0.0008**
QE2	27.08.2010	Bernanke hints at QE2	0.2532	-0.0031
	21.09.2010	FOMC emphasises low inflation, hints QE2	-1.4026***	-0.0026
	12.10.2010	FOMC hints at QE2	-0.3022	-0.0033***
	15.10.2010	Bernanke: Fed stands ready to ease further	0.4931*	-0.0033**
	03.11.2010	QE2 announced	-0.3280	-0.0033***
		The Effect of the QE2 "Buy" Cluster	**-0.2865**	**0.0005**
QE3	22.08.2012	FOMC hints at additional easing	-0.5036	-0.0033
	31.08.2012	Bernanke hints at QE3	-0.3565***	-0.0032***
	13.09.2012	QE3 announced	-0.7549**	-0.0014
	12.12.2012	QE3 expanded	-0.3739	-0.0025
		The Effect of the QE3 "Buy" Cluster	**-0.5171*** **	**-0.0023*** **
The Overall Effect of the Fed "Buy" Events			**-0.5048*** **	**0.0000**

Note: The impact on USD/EUR level and volatility is measured by the estimated coefficients of the dummy variables (events) which are represented in percentage points. ***, ** and * indicate statistical significance at the 1%, 5% and 10% confidence level, respectively. Negative coefficients indicate a negative impact on the USD/EUR level/volatility.
Source: Appendices 8,11,12

To compare with the results of the previous analysis based on the observations of the nominal USD/EUR changes in one-day and two-day windows, the main conclusions are similar in that the QE "buy" announcements affected the USD/EUR exchange rate and led to the depreciation of the dollar with most of the effect coming from the QE1 announcements. These findings are broadly consistent with those of previous studies that estimate the effects of the Federal Reserve's QE1 and QE2 announcements on bond yields and/or exchange rates. These studies similarly found large and significant effects of QE1 and rather small and less significant effects of QE2 (e.g., Krishnamurthy and Vissing-Jorgensen, 2011; Meaning and Zhu, 2011; Glick and Leduc, 2012; 2013; Neely, 2014). The additional evidence in the current thesis is that QE3 was again more effective than QE2. These results somewhat illustrate the scale of the three programmes. The QE1 and QE3 were comparable in size and approximately three times larger than QE2, which may be also one reason that the effects of QE2 were generally smaller than the other two programmes.

3.2.3. The Effects of the Federal Reserve's QE "Sell" Events

The GARCH (0,1) model that is used to estimate the effect of each announcement as a separate event suggests that four "sell" announcements had statistically significant effects on

the level of USD/EUR exchange rate and five "sell" announcements had statistically significant effects on the volatility (see Table 4).

As already noted in the previous analysis, the "sell" announcements do not seem to have had much effect on the USD/EUR. It is affirmed that the announcements regarding the slowdowns of purchases of QE1 instead led to a slight depreciation of the dollar, which is in the opposite direction of what would be expected from "sell" announcements. The reason could be that these announcements did not consist of much new information on the monetary policy (as the size of the programme was already stated in the "buy" announcements), while it can be assumed that the ending of the programme was still negative for the market and perceived as too early since the pace of recovery in output and employment was still slow. This is also supported by the fact that in the same month when the QE1 ended, the Federal Reserve indicated a need for another round of QE and announced it a few months later.

The other two statistically significant announcements concerning the tapering of QE2 and QE3 have led to an appreciation of the dollar, which would be an expected reaction in normal conditions. The effect on volatility is again very small and negative.

According to the GARCH (0,2) model that estimates the effects of the event clusters, including the effects of the "sell" clusters of each programme, only the QE2 (which is actually a single event) seems to be statistically significant, resulting in an appreciation of the dollar.

According to the GARCH (1,1) model, the overall effect of the Federal Reserve's "sell" announcements was found to be statistically insignificant for both the level and volatility of the USD/EUR exchange rate.

Table 4. The Effects of the Federal Reserve's "Sell" Events

Programme	Date	Event	Impact on USD/EUR Level	Impact on Volatility
QE1	12.08.2009	QE1 slowed	-0.4276***	-0.0029
	23.09.2009	QE1 slowed	0.2714	-0.0033***
	04.11.2009	QE1 downsized	-0.2987*	-0.0023
		The Effect of the QE1 "Sell" Cluster	**-0.1822**	**-0.0017**
QE2	22.06.2011	QE2 finishes	0.5396	-0.0033***
		The Effect of the QE2 "Sell" Cluster	**0.5285*** **	**-0.0034*** **
QE3	22.05.2013	Bernanke hints at the reduction of QE3	-0.2014	-0.0015
	19.06.2013	Bernanke hints at the reduction of QE3	0.3291	-0.0017
	18.12.2013	Tapering of QE3 announced	0.6041***	-0.0019

29.01.2014	QE3 tapered	0.2678	-0.0007
19.03.2014	QE3 tapered	0.5485***	-0.0032***
30.04.2014	QE3 tapered	-0.1512	-0.0032***
18.06.2014	QE3 tapered	-0.0540	-0.0033*
30.07.2014	QE3 tapered	-0.3210	-0.0003
17.09.2014	QE3 tapered	0.2510	-0.0008
29.10.2014	QE3 concluded	0.4634	-0.0030
	The Effect of the QE3 "Sell" Cluster	**0.1703**	**-0.0010**
	The Overall Effect of the Fed "Sell" Events	**0.1007**	**-0.0001**

Note: The impact on USD/EUR level and volatility is measured by the estimated coefficients of the dummy variables (events) which are represented in percentage points. ***, ** and * indicate statistical significance at the 1%, 5% and 10% confidence level, respectively. Negative coefficients indicate a negative impact on the USD/EUR level/volatility.
Source: Appendices 8,11,12

Consistent with the previous results of the empirical analysis, the main conclusion is that the "sell" announcements had only a marginal effect on the USD/EUR exchange rate, while the evidence of these effects is sparser. These results are also consistent with Neely's (2014) study who similarly studied the effects of the QE1 "sell" announcements and found that the three "sell" events did not strongly or consistently affect the USD exchange rate against major currencies, either the US or foreign bond yields.

Nevertheless, these results are not surprising when considering that the information regarding the duration of the QE programmes as well as the volumes of the planned purchases were already in place, and there was not much new information left in the "sell" announcements.

3.2.4. The Effects of the European Central Bank's QE "Buy" Events

The history of QE in Europe is relatively short; therefore, there are only two announcements included in the analysis. However, it was found that the effect of launching the programme on the USD/EUR was relatively large–comparable to the Federal Reserve's most important "buy" announcements during QE1 (but with a reaction in the opposite direction from expectations)–and highly statistically significant (see Table 5). This finding was also confirmed by the other models, GARCH (0,2) and GARCH (1,1). When accepting the significance at the 10% confidence level, GARCH (1,1) also suggested a slight positive effect on the USD/EUR volatility.

Table 5. The Effects of the European Central Bank's "Buy" Events

Programme	Date	Event	Impact on USD/EUR Level	Impact on Volatility
EAPP	22.01.2015	ECB announces QE	1.9630***	-0.0016
	05.03.2015	Draghi: Purchases start on March 9	1.0028	-0.0016
		The Effect of the ECB "Buy" Cluster	**1.4805*** **	**0.0019**
The Overall Effect of the ECB "Buy" Events			**1.5575*** **	**0.0018***

Note: The impact on USD/EUR level and volatility is measured by the estimated coefficients of the dummy variables (events) which are represented in percentage points. ***, ** and * indicate statistical significance at the 1%, 5% and 10% confidence level, respectively. Negative coefficients indicate a negative impact on the USD/EUR level/volatility.
Source: Appendices 8,11,12

The conclusions based on the GARCH models are largely in line with those of the previous analysis based on the observations of the nominal USD/EUR daily changes. Since it could be expected that over time markets become more familiar with the central bank's new policies and could thus anticipate the respective measures and price them into their expectations before the decisions of the central bank are announced, the finding of such a strong effect in the case of the recent QE announcement by the European Central Bank is interesting. It shows that despite the long-lasting speculations, the announcement still largely surprised the market allowing the decision makers of the central bank to more easily justify their unconventional policies and show them as successful.

3.2.5. The Effects of the Federal Reserve's Maturity Extension Programme Events

According to the GARCH (0,1) model, the initial announcement of the Maturity Extension Programme had a statistically significant effect on the level as well as on the volatility of the USD/EUR exchange rate. At the same time, the effect is different from that of the Federal Reserve's QE "buy" announcements since it did not trigger the depreciation of the dollar. However, the effect on volatility is similar–the announcement of the programme slightly helped to decrease the volatility. This finding is confirmed by the GARCH (0,2) model. However, in GARCH (1,1), the effect is no longer statistically significant.

Table 6. The Effects of the Federal Reserve's Maturity Extension Programme Events

Programme	Date	Event	Impact on USD/EUR Level	Impact on Volatility
MEP	21.09.2011	Maturity Extension Programme announced	0.4884**	-0.0032***
	20.06.2012	Maturity Extension Programme extended	0.5047	-0.0025
		The Effect of the MEP Cluster	**0.4892*** **	**-0.0033*** **
The Overall Effect of the MEP Events			**0.4919**	**0.0005**

Note: The impact on USD/EUR level and volatility is measured by the estimated coefficients of the dummy variables (events) which are represented in percentage points. ***, ** and * indicate statistical significance at the 1%, 5% and 10% confidence level, respectively. Negative coefficients indicate a negative impact on the USD/EUR level/volatility.
Source: Appendices 8,11,12

It can be concluded that the Federal Reserve's announcements of the Maturity Extension Programme had different and much smaller effects than the "buy" announcements of QE. The opposite movement in USD/EUR might be because the markets had been expecting QE3 rather than such programme (as the Maturity Extension Programme) that involved no change in the monetary base, and as the announced programme was less stimulatory than expected, the dollar instead appreciated. By all means, this finding reflects the less aggressive nature of this programme compared to QE and justifies the distinction from the QE programmes.

3.2.6. Concluding Remarks and Suggestions

The results of the empirical analysis of this thesis suggest that the QE announcements by the Federal Reserve and the European Central Bank had a significant impact on the USD/EUR exchange rate. The largest effects on the USD/EUR level were related to the Federal Reserve's QE1 programme and the initial announcement of the European Central Bank's QE programme. The "buy" announcements of the Federal Reserve generally depreciated the dollar against the euro while the European Central Bank's QE announcements had a strong opposite effect. It was also found that the Federal Reserve's "sell" announcements, in particular those related to the QE2 and QE3, mostly supported the appreciation of the dollar although the effect was relatively small. However, according to the estimated GARCH models, not all the effects were found statistically significant suggesting that the actual impact resulting from particular QE announcements may have been generally

smaller than the nominal USD/EUR changes around these announcements would indicate, especially during the high-volatility period in late 2008 and 2009.

The estimates of the GARCH models suggest that the Federal Reserve's announcements had mostly a negative effect on the volatility of the USD/EUR exchange rate, although the coefficients of the dummy-variables indicate that the effect was very small. The negative impact on volatility indicates that the central bank communications somewhat helped to reduce uncertainty and thus provided a calming effect on the market.

Regarding the Federal Reserve's announcement of the Maturity Extension Programme, there was a modest but statistically significant effect with an opposite direction to the Federal Reserve's "buy" announcements. The opposite movement in USD/EUR might be because the markets were expecting stronger measures to be announced. The reaction of the exchange rate seems to justify the distinction of the Maturity Extension Programme from the QE programmes.

In addition, an interesting finding regarding the QE announcements of the Federal Reserve, was that the announcements that provided hints for looser monetary policy were in some cases even more important than the following announcements that provided firm disclosures on actual purchases.

In more general, the results of this thesis suggest that central banks are not toothless when policy rates approach the zero lower bound. The depreciation of domestic currency as a response to the QE announcements probably stimulates the economy through export channels. Therefore, the findings of the thesis support the idea that QE stimulated the US economy through lower value of the dollar. As it was found that the recent European Central Bank's QE announcement led to a strong depreciation in euro, it is likely that similar positive effects occur to the economy of the Eurozone as well.

However, the results of do not provide information on the longevity of these effects. They only draw a limited insight of the effects of the QE effects of the two central banks with a focus on the USD/EUR exchange rate. Therefore, a similar research should be carried out including more currency pairs and perhaps larger event-windows and complementary research methods.

The empirical approach taken in this thesis has some shortcomings related to the simplifying assumptions that underlie the validity of the event-study approach. For instance, the assumption that all changes in expectations about the QE policies occur during the

selected event windows may not be plausible since it relies only on the central banks' announcements. There may have been other information, such as macro news or even rumours that influenced the market expectations before the decisions of the central bank were announced. The QE1 announcement on November 25, 2008 could be one example. The depreciation of the dollar was modest on that day and statistically insignificant based on the GARCH(0,1) model. At the same time, a large depreciation of the dollar was observed on the day before the announcement. Therefore, there is a risk that the market expectations were formed before the announcement and the model underestimates the effect of the announcement. The same risk should be considered when estimating the effects of the announcements of the later QE programmes since markets become more familiar with the central bank's new policies and would be more likely to alter their QE expectations in response to macro news. At the same time, there is also a risk that there was other news on the particular announcement days that significantly affected the exchange rate.

CONCLUSIONS

The master thesis studied the effects of QE on the basis of two leading economies: the US and the Eurozone. The US Federal Reserve was the first among the four major central banks to implement QE right after the 2007-2008 financial crisis, and the European Central Bank was the last to do so, as it launched its QE programme approximately six years later. The objective of this thesis was to estimate the effects of QE programmes on the USD/EUR exchange rate.

The following research questions were set in the thesis:

- How have the Federal Reserve's and the European Central Bank's QE programmes affected the level and volatility of the USD/EUR exchange rate?
- How do the effects differ across the different programmes?

The theoretical part of the thesis introduced the essential concepts of QE, and discussed the forms of QE as practices employed by the major central banks. It also identified a number of potential channels through which QE can affect the economy and provided an overview of the effects of QE based on existing literature.

In order to answer the research questions, quantitative method was used. More specifically, event study techniques and GARCH models were combined. The first part of the analysis was based on the most common type of event study that examined the exchange rate behaviour around official communications regarding QE. The second part of the analysis employed GARCH models in order to look at effects of QE events more formally and estimate the effect on the exchange rate volatility. The effects of the QE events were estimated for the separate events as well as for the event clusters. In order to form event clusters, the communications regarding QE were classified as "buy" events and "sell" events according to the communication language.

The results of the empirical analysis of this thesis suggest that the QE announcements by the Federal Reserve and the European Central Bank had a significant impact on the USD/EUR exchange rate. The largest effects on the USD/EUR level were related to the

Federal Reserve's QE1 programme and the initial announcement of the European Central Bank's QE programme. The "buy" announcements of the Federal Reserve generally depreciated the dollar against the euro while the European Central Bank's QE announcements had a strong opposite effect. It was also found that the Federal Reserve's "sell" announcements, in particular those related to the QE2 and QE3, mostly supported the appreciation of the dollar although the effect was relatively small. The estimates of the GARCH models suggest that the Federal Reserve's announcements had mostly a negative effect on the volatility of the USD/EUR exchange rate, although the coefficients of the dummy-variables indicate that the effect was very small. The negative impact on volatility indicates that the central bank communications somewhat helped to reduce uncertainty and thus provided a calming effect on the market.

In addition, an interesting finding regarding the QE announcements of the Federal Reserve, was that the announcements that provided hints for looser monetary policy were in some cases even more important than the following announcements that provided firm disclosures on actual purchases.

Having a vital and almost immediate influence on international trade, the balance of payments, and the overall economic performance, the exchange rate is one of the key linkages through which QE can affect the broader economy. Thus, the results of this thesis support the idea that QE stimulated the US economy through export channels and might do the same for the Eurozone as well.

However, it should be noted that the empirical approach taken in this thesis also has some shortcomings related to the simplifying assumptions that underlie the validity of the event-study approach. For instance, the assumption that all changes in expectations about the QE policies occur during the selected event windows may not be plausible since it relies only on the central banks' announcements. There may have been other information, such as macro news or even rumours that influenced market expectations before the decisions of the central bank were announced. Therefore, there is a risk that market expectations were formed before the announcement and the event study underestimates the effect of the announcement. The same risk is asserted when estimating the effects of the announcements of the later QE programmes. It is likely that markets have become more familiar with the central bank's new policies and were more likely to alter their QE expectations in response to macro news.

Additionally, there is also a risk that there was other news on the particular announcement days that significantly affected the exchange rate.

The results of the current thesis do not provide information on the longevity of these effects. They only provide a limited insight into the effects of QE of the two central banks with a focus on the USD/EUR exchange rate. Therefore, a similar research could be considered including more currency pairs and perhaps larger event-windows and complementary research methods.

KOKKUVÕTE

KVANTITATIIVNE LÕDVENDAMINE JA SELLE MÕJU USD/EUR VALUUTAKURSILE

Merili Palu

2007.-2008. aasta ülemaailmne finantskriis ja sellele järgnenud majandussurutis on oluliselt muutunud kaasaegse rahapoliitika põhimõtteid ja elluviimist. Viimase kuue aasta jooksul on suuremad keskpangad võtnud kasutusele mitmeid mittekonventsionaalseid rahapoliitika meetmeid. Mittekonventsionaalse rahapoliitika üheks äärmuslikumaks vormiks on kvantitatiivne lõdvendamine, mis võeti keskpankade poolt kasutusele pärast seda, kui keskpankade kehtestatud intressimäärad olid viidud nulli lähedale ning traditsioonilise rahapoliitikaga ei olnud enam võimalik majandust elavdada. Majanduskasvu stimuleerimine ning inflatsioonieesmärgi saavutamine vähetuntud ebastandardsete meetmetega on käesoleval ajal keskpankadele üks suurimaid väljakutseid ning arenev uurimisvaldkond.

Magistritöö uurimisprobleem tulenes sellest, et lühikese ajalooga kvantitatiivse lõdvendamise poliitika mõjude osas on palju ebaselgust. Viimaste aastate jooksul on olnud põhiliseks küsimuseks kas kvantitatiivne lõdvendamine on piisavalt tõhus, et avaldada olulist mõju reaalmajandusele. Teema on käesoleval ajal eriti aktuaalne Euroopas seoses sellega, et Euroopa Keskpank on äsja alustanud oma esimese kvantitatiivse lõdvendamise programmiga.

Käesolevas magistritöös käsitles autor USA Föderaalreservi ja Euroopa Keskpanga kvantitatiivse lõdvendamise programmide mõju USD/EUR valuutakursile. Avaldades otsest mõju rahvusvahelisele kaubandusele, maksebilansile ja seeläbi üldisemale majanduslikule jõudlusele, annab valuutakurss aimu ka sellest, kas ja kui olulisel määral on kvantitatiivne lõdvendamine suuteline avaldama mõju majandusele laiemalt.

Magistritöös püstitati alljärgnevad uurimisküsimused:

- Kuidas on USA Föderaalreservi ja Euroopa Keskpanga kvantitatiivse lõdvendamise programmid avaldanud mõju USD/EUR valuutakursi tasemele ja volatiilsusele?
- Kas ja kuidas erineb kvantitatiivse lõdvendamise mõju erinevate programmide lõikes?

Uurimisprobleemi lahendamiseks rakendati kvantitatiivseid uurimismeetodeid, milleks oli uudiste analüüs ning üldistatud autoregressiivsete tinglikult heteroskedastiliste (ing.k. *General Autoregressive Conditional Heteroscedastisity*) (GARCH) mudelite koostamine ja hindamine.

Empiirilise analüüsi tulemustest selgus, et mõlema keskpanga kvantitatiivse lõdvendamise programmid on avaldanud statistiliselt olulist mõju USD/EUR valuutakursile. Kõige suuremat mõju täheldati uudiste puhul, mis olid seotud Föderaalreservi esimese kvantitatiivse lõdvendamise programmiga ning Euroopa Keskpanga hiljuti välja kuulutatud kvantitatiivse lõdvendamise programmiga. Föderaalreservi poolne kommunikatsioon, mis käsitles lõdvemat rahapoliitikat mõjutas USD/EUR kurssi negatiivselt, mille tulemusena dollar euro vastu nõrgenes. Euroopa Keskpanga kvantitatiivse lõdvendamise programmil oli vastupidine efekt. GARCH mudelite hinnangud näitavad ühtlasi, et mitmed Föderaalreservi programmidega seotud uudised omasid väikest, kuid statistiliselt olulist negatiivset efekti valuutakursi volatiilsusele, mis viitab sellele, et keskpanga kommunikatsioon aitas mõnevõrra vähendada turul valitsevat ebakindlust. Kokkuvõttes toetavad magistritöö tulemused ideed, et kvantitatiivne lõdvendamine avaldas Ameerika Ühendriikide majandusele elavdavat mõju toetades riigi eksporti läbi odavnenud valuuta. Arvestades, et efekt valuutakursile tuvastati ka seoses Euroopa Keskpanga kvantitatiivse lõdvendamise programmiga võib sarnane positiivne efekt avalduda ka Euroala majandusele. Leitud tulemuste põhjal ei saa siiski järeldada kui pikaajaline võiks olla nõrgenenud valuutast tulenev positiivne mõju. Antud tulemused pakuvad vaid piiratud ülevaadet kvantitatiivse lõdvendamise mõjudest, fookusega USD/EUR valuutakursile. Seetõttu oleks otstarbekas kaaluda edasisi uuringuid, mis kaasaks analüüsi ka teisi valuutapaare.

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APPENDICES

Appendix 1. Correlogram of the USD/EUR Daily Returns

Sample: 11/03/2008 3/31/2015
Included observations: 1672

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.010	-0.010	0.1780	0.673
		2	0.008	0.007	0.2725	0.873
		3	-0.028	-0.028	1.6150	0.656
		4	-0.015	-0.015	1.9739	0.741
		5	0.017	0.017	2.4384	0.786
		6	0.044	0.043	5.6387	0.465
		7	0.033	0.033	7.4841	0.380
		8	-0.015	-0.014	7.8711	0.446
		9	-0.028	-0.026	9.2231	0.417
		10	0.009	0.012	9.3692	0.497
		11	0.030	0.030	10.885	0.453
		12	-0.021	-0.025	11.610	0.478
		13	0.031	0.028	13.257	0.428
		14	-0.015	-0.011	13.615	0.479
		15	0.007	0.009	13.696	0.549
		16	-0.001	0.000	13.698	0.621
		17	0.040	0.037	16.353	0.499
		18	-0.020	-0.021	17.054	0.519
		19	-0.032	-0.033	18.819	0.468
		20	-0.021	-0.020	19.563	0.486
		21	0.025	0.025	20.607	0.483
		22	-0.007	-0.009	20.694	0.540
		23	-0.027	-0.033	21.972	0.522
		24	-0.011	-0.012	22.182	0.568
		25	-0.029	-0.020	23.581	0.544
		26	-0.050	-0.050	27.771	0.370
		27	0.025	0.021	28.874	0.367
		28	0.002	-0.002	28.884	0.418
		29	0.018	0.022	29.463	0.441
		30	-0.004	0.000	29.485	0.492
		31	0.025	0.031	30.565	0.488
		32	-0.016	-0.012	30.975	0.518
		33	-0.026	-0.024	32.154	0.509
		34	-0.012	-0.018	32.403	0.546
		35	0.020	0.020	33.088	0.561
		36	0.003	0.007	33.107	0.607

Appendix 2. The Key Events

Date	Programme	Event	Brief description	Source
25.11.2008	QE1	FOMC statement	QE1 announced: Fed will purchase $100billion in GSE debt and $500 billion in MBS	www.federalreserve.gov/newsevents/press/monetary/20081125b.htm
01.12.2008	QE1	Bernanke's speech	First suggestion of extending QE to Treasuries	www.federalreserve.gov/newsevents/speech/bernanke20081201a.htm
16.12.2008	QE1	FOMC statement	First suggestion of extending QE to Treasuries by FOMC	www.federalreserve.gov/newsevents/press/monetary/20081216b.htm
28.01.2009	QE1	FOMC statement	Fed stands ready to expand QE and buy Treasuries	www.federalreserve.gov/newsevents/press/monetary/20090128a.htm
18.03.2009	QE1	FOMC statement	QE1 expanded: Fed will purchase $300 billion in long-term Treasuries and an additional $750 and $100 billion in MBS and GSE debt, respectively	www.federalreserve.gov/newsevents/press/monetary/20090318a.htm
12.08.2009	QE1	FOMC statement	QE1 slowed: All purchases will finish by the end of October	www.federalreserve.gov/newsevents/press/monetary/20090812a.htm
23.09.2009	QE1	FOMC statement	QE slowed: Agency debt and MBS purchases will finish at the end of Q1 2010	www.federalreserve.gov/newsevents/press/monetary/20090923a.htm
04.11.2009	QE1	FOMC statement	QE downsized: Agency debt purchases will finish at $175 billion	www.federalreserve.gov/newsevents/press/monetary/20091104a.htm
27.08.2010	QE2	Bernanke's speech	Bernanke suggests role for QE2 "should further action prove necessary"	www.federalreserve.gov/newsevents/speech/bernanke20100827a.htm
21.09.2010	QE2	FOMC statement	FOMC emphasises low inflation, which "is likely to remain subdued for some time before rising to levels the Committee considers consistent with its mandate"	www.federalreserve.gov/newsevents/press/monetary/20100921a.htm
12.10.2010	QE2	FOMC minutes	FOMC members' "sense" is that "(additional) accommodation may be appropriate before long"	www.federalreserve.gov/monetarypolicy/fomcminutes20100921.htm
15.10.2010	QE2	Bernanke's speech	Bernanke reiterates that Fed stands ready to further ease policy	www.federalreserve.gov/newsevents/speech/bernanke20101015a.htm
03.11.2010	QE2	FOMC statement	QE2 announced: Fed will purchase $600 billion in Treasuries	www.federalreserve.gov/newsevents/press/monetary/20100921a.htm

Appendix 2 Continued

22.06.2011	QE2	FOMC statement	QE2 finishes: Treasury purchases will wrap up at the end of month, as scheduled; principal payments will continue to be reinvested	www.federalreserve.gov/newsevents/press/monetary/20101103a.htm
21.09.2011	Maturity Extension Programme	FOMC statement	Maturity Extension Programme ("OperationTwist") announced: The Fed will purchase $400 billion of Treasuries with remaining maturities of 6 to 30 years and sell an equal amount with remaining maturities of 3 years or less	www.federalreserve.gov/newsevents/press/monetary/20110921a.htm
20.06.2012	Maturity Extension Programme	FOMC statement	Maturity Extension Programme extended: The Fed will continue to purchase long-term securities and sell short-term securities through the end of 2012. Purchases/sales will continue at the current pace, about $45 billion/month	www.federalreserve.gov/newsevents/press/monetary/20120620a.htm
22.08.2012	QE3	FOMC minutes	FOMC members "judged that additional monetary accommodation would likely be warranted fairly soon…"	www.federalreserve.gov/monetarypolicy/fomcminutes20120801.htm
31.08.2012	QE3	Bernanke's speech	Fed Chairman Ben Bernanke hints at QE3	www.federalreserve.gov/newsevents/speech/bernanke20120831a.htm
13.09.2012	QE3	FOMC statement	QE3 announced: The Fed will purchase $40 billion of MBS per month as long as"the outlook for the labour market does not improve substantially… in the context of price stability."	www.federalreserve.gov/newsevents/press/monetary/20120913a.htm
12.12.2012	QE3	FOMC statement	QE3 expanded: The Fed will continue to purchase $45 billion of long-term Treasuries per month but will no longer sterilise purchases through the sale of short-term Treasuries	www.federalreserve.gov/newsevents/press/monetary/20121212a.htm
22.05.2013	QE3	Bernanke's testimony to Congress	Fed Chairman Ben Bernanke hints at the reduction of pace of purchase. "If we see continued improvement and we have confidence that that is going to be sustained, then in the next few meetings, we could take a step down in our pace of purchases,"	www.ft.com/intl/cms/s/0/35b7c810-c2e8-11e2-bbbd-00144feab7de.html#axzz3YWxgkpa2
19.06.2013	QE3	Bernanke's Press Conference	Bernanke said "If the incoming data are broadly consistent with this forecast, the Committee currently anticipates that it would be appropriate to moderate the monthly pace of purchases later this year."	www.federalreserve.gov/mediacenter/files/FOMCpresconf20130619.pdf

Appendix 2 Continued

18.12.2013	QE3	FOMC statement	"Tapering" of QE3 announced. "If incoming information broadly supports the Committee's expectation of ongoing improvement in labour market conditions and inflation moving back toward its longer-run objective, the Committee will likely reduce the pace of asset purchases in further measured steps at future meetings"	www.federalreserve.gov/newsevents/press/monetary/20131218a.htm
29.01.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140129a.htm
19.03.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140319a.htm
30.04.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140430a.htm
18.06.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140618a.htm
30.07.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140730a.htm
17.09.2014	QE3	FOMC statement	QE3 tapered by $10 billion per month	www.federalreserve.gov/newsevents/press/monetary/20140917a.htm
29.10.2014	QE3	FOMC statement	QE3 concluded "since the economic activity is expanding at a moderate pace and labour market conditions improved further". The existing policy of reinvesting principal payments from agency debt and agency MBS in agency MBS and of rolling over maturing Treasury securities maintained. "Keeping the holdings of longer-term securities at sizable levels, should help maintain accommodative financial conditions"	www.federalreserve.gov/newsevents/press/monetary/20141029a.htm
22.01.2015	EAPP	ECB statement	ECB announces QE (i.e. the "Expanded Asset Purchase Programme")	www.ecb.europa.eu/press/pr/date/2015/html/pr150122_1.en.html
05.03.2015	EAPP	Mario Draghi's speech	President Mario Draghi said the first bond purchases under QE would start on March 9, 2015	www.ecb.europa.eu/press/pressconf/2015/html/is150305.en.html

Appendix 3. The USD/EUR Returns and the Federal Reserve's "Buy" Events

Programme	Date	Event	1-Day Return	2-Day Return
	25.11.2008	QE announced	-0.86	-3.73
			(0.16)	(0.00)
	01.12.2008	Bernanke's suggestion of expanding QE	0.63	2.30
			(0.28)	(0.03)
	16.12.2008	FOMC suggestion of expanding QE	-2.27	-4.63
			(0.01)	(0.00)
QE1	28.01.2009	Fed stands ready to expand QE	-0.05	0.17
			(0.92)	(0.80)
	18.03.2009	QE expanded	-3.47	-3.84
			(0.00)	(0.00)
		Fed QE1 "Buy" Sum	**-6.01**	**-9.72**
		Fed QE1 "Buy" Average	-1.20	-1.94
			(0.08)	(0.04)
	27.08.2010	Bernanke hints at QE2	-0.37	-0.82
			(0.49)	(0.29)
	21.09.2010	FOMC emphasises low inflation, hint for QE2	-1.54	-1.63
			(0.03)	(0.08)
	12.10.2010	FOMC hints at QE2	-0.35	0.10
			(0.50)	(0.88)
QE2	15.10.2010	Bernanke: Fed stands ready to ease further	0.76	-0.11
			(0.20)	(0.86)
	03.11.2010	QE2 announced	-0.75	-1.76
			(0.21)	(0.07)
		Fed QE2 "Buy" Sum	**-2.25**	**-4.21**
		Fed QE2 "Buy" Average	-0.45	-0.84
			(0.41)	(0.28)
	22.08.2012	FOMC hints at additional easing	-0.45	-1.47
			(0.41)	(0.10)
	31.08.2012	Bernanke hints at QE3	-0.58	-0.39
			(0.31)	(0.60)
	13.09.2012	QE3 announced	-0.70	-1.05
QE3			(0.24)	(0.21)
	12.12.2012	QE3 expanded	-0.53	-1.02
			(0.35)	(0.22)
		Fed QE3 "Buy" Sum	**-2.26**	**-3.94**
		Fed QE3 "Buy" Average	-0.57	-0.98
			(0.32)	(0.24)

Note: Returns are log changes between closing rates for 1- and 2-day windows in percentage points. Negative changes indicate depreciation of the dollar against the euro. The values in parentheses denote the proportion of 1-and 2-day changes from November 2008 to March 2015 that were larger in absolute value than the change on the reported event.
Source: Compiled by the author

Appendix 4. The USD/EUR Returns and the Federal Reserve's "Sell" Events

Programme	Date	Event	1-Day Return	2-Day Return
QE1	12.08.2009	QE1 slowed	-0.28	-0.34
			(0.60)	(0.64)
	23.09.2009	QE1 slowed	0.37	-0.37
			(0.49)	(0.62)
	04.11.2009	QE1 downsized	-0.93	-0.58
			(0.14)	(0.44)
		Fed QE1 "Sell" Sum	**-0.83**	**-1.29**
		Fed QE1 "Sell" Average	-0.28	-0.43
			(0.60)	(0.56)
QE2	22.06.2011	QE2 finishes	0.38	-0.37
			(0.47)	(0.62)
QE3	22.05.2013	Bernanke hints at the reduction of QE3	0.37	0.19
			(0.48)	(0.79)
	19.06.2013	Bernanke hints at the reduction of QE3	0.73	0.54
			(0.22)	(0.47)
	18.12.2013	Tapering of QE3 announced	0.60	0.55
			(0.29)	(0.46)
	29.01.2014	QE3 tapered	0.06	0.07
			(0.90)	(0.91)
	19.03.2014	QE3 tapered	0.73	0.64
			(0.22)	(0.39)
	30.04.2014	QE3 tapered	-0.40	-0.12
			(0.46)	(0.86)
	18.06.2014	QE3 tapered	-0.35	-0.15
			(0.50)	(0.82)
	30.07.2014	QE3 tapered	0.09	0.32
			(0.86)	(0.66)
	17.09.2014	QE3 tapered	0.74	0.58
			(0.22)	(0.44)
	29.10.2014	QE3 concluded	0.80	0.52
			(0.18)	(0.48)
		Fed QE3 "Sell" Sum	**3.75**	**2.78**
		Fed QE3 "Sell" Average	0.34	0.25
			(0.51)	(0.72)

Note: Returns are log changes between closing rates for 1- and 2-day windows in percentage points. Negative changes indicate depreciation of the dollar against the euro. The values in parentheses denote the proportion of 1-and 2-day changes from November 2008 to March 2015 that were larger in absolute value than the change on the reported event.
Source: Compiled by the author

Appendix 5. The USD/EUR Returns and the European Central Bank's "Buy" Events

Programme	Date	Event	1-Day Return	2-Day Return
	22.01.2015	ECB announces QE	2.12	1.61
			(0.01)	(0.08)
	05.03.2015	Draghi: Purchases start on March 9	0.43	1.31
EAPP			(0.42)	(0.14)
		ECB QE "Buy" Sum	**2.56**	**2.92**
		ECB QE "Buy" Average	1.28	1.46
			(0.06)	(0.11)

Note: Returns are log changes between closing rates for 1- and 2-day windows in percentage points. Negative changes indicate depreciation of the dollar against the euro. The values in parentheses denote the proportion of 1-and 2-day changes from November 2008 to March 2015 that were larger in absolute value than the change on the reported event.
Source: Compiled by the author

Appendix 6. The USD/EUR Returns and the Maturity Extension Programme Events

Programme	Date	Event	1-Day Return	2-Day Return
	21.09.2011	Maturity Extension Programme announced	0.95	0.83
			(0.14)	(0.29)
	20.06.2012	Maturity Extension Programme extended	-0.17	-1.04
MEP			(0.73)	(0.22)
		MEP Sum	**0.77**	**-0.21**
		MEP Average	0.39	-0.10
			(0.47)	(0.88)

Note: Returns are log changes between closing rates for 1- and 2-day windows in percentage points. Negative changes indicate depreciation of the dollar against the euro. The values in parentheses denote the proportion of 1-and 2-day changes from November 2008 to March 2015 that were larger in absolute value than the change on the reported event.
Source: Compiled by the author

Appendix 7. Akaike and Schwarz Info Criteria of the GARCH Models

Table 7. The Info Criteria of the Models Estimating All Announcements

Model	Akaike Info Criterion	Schwarz Info Criterion
GARCH(0,1)	**-7.38285**	**-7.16235**
GARCH(0,2)	-7.36491	-7.14117
GARCH(1,1)	-7.32022	-7.09648
GARCH(1,2)	-7.34643	-7.11944
GARCH(2,1)	-7.30414	-7.07715
GARCH(2,2)	-7.30862	-7.07839

Note: The Akaike and Schwarz's information criteria are smallest for GARCH(0,1) model as marked in bold.
Source: Compiled by the author

Table 8. The Info Criteria of the Models Estimating Eight Announcement Clusters

Model	Akaike Info Criterion	Schwarz Info Criterion
GARCH(0,1)	-7.36530	-7.30045
GARCH(0,2)	**-7.38333**	**-7.31523**
GARCH(1,1)	-7.29338	-7.22528
GARCH(1,2)	-7.32052	-7.24919
GARCH(2,1)	-7.32419	-7.25286
GARCH(2,2)	-7.34308	-7.26849

Note: The Akaike and Schwarz's information criteria are smallest for GARCH(0,2) model as marked in bold.
Source: Compiled by the author

Table 9. The Info Criteria of the Models Estimating Four Announcement Clusters

Model	Akaike Info Criterion	Schwarz Info Criterion
GARCH(0,1)	-7.37894	-7.34003
GARCH(0,2)	-7.40400	-7.36184
GARCH(1,1)	**-7.50479**	**-7.46263**
GARCH(1,2)	-7.29765	-7.25225
GARCH(2,1)	-7.31703	-7.27163
GARCH(2,2)	-7.32969	-7.28105

Note: The Akaike and Schwarz's information criteria are smallest for GARCH(1,1) model as marked in bold.
Source: Compiled by the author

Appendix 8. GARCH(0,1) Estimation Output

Dependent Variable: DLOG_USDEUR
Method: ML - ARCH
Sample: 11/03/2008 3/31/2015
Included observations: 1672
Failure to improve Likelihood after 161 iterations
Presample variance: backcast (parameter = 0.7)
GARCH = C(35) + C(36)*RESID(-1)^2 + C(37)*D01_12_2008 + C(38)
*D03_11_2010 + C(39)*D04_11_2009 + C(40)*D05_03_2015 +
C(41)*D12_08_2009 + C(42)*D12_10_2010 + C(43)*D12_12_2012
+ C(44)*D13_09_2012 + C(45)*D15_10_2010 + C(46)
*D16_12_2008 + C(47)*D17_09_2014 + C(48)*D18_03_2009 +
C(49)*D18_06_2014 + C(50)*D18_12_2013 + C(51)*D19_03_2014
+ C(52)*D19_06_2013 + C(53)*D20_06_2012_MEP + C(54)
*D21_09_2010 + C(55)*D21_09_2011_MEP + C(56)*D22_01_2015
+ C(57)*D22_05_2013 + C(58)*D22_06_2011 + C(59)
*D22_08_2012 + C(60)*D23_09_2009 + C(61)*D25_11_2008 +
C(62)*D27_08_2010 + C(63)*D28_01_2009 + C(64)*D29_01_2014
+ C(65)*D29_10_2014 + C(66)*D30_04_2014 + C(67)
*D30_07_2014 + C(68)*D31_08_2012

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	9.21E-05	0.000153	0.600125	0.5484
D01_12_2008	-0.005167	0.007219	-0.715731	0.4742
D03_11_2010	-0.003280	0.011187	-0.293222	0.7694
D04_11_2009	-0.002987	0.001696	-1.761230	0.0782
D05_03_2015	0.010028	0.059150	0.169536	0.8654
D12_08_2009	-0.004276	0.001616	-2.645606	0.0082
D12_10_2010	-0.003022	0.012511	-0.241572	0.8091
D12_12_2012	-0.003739	0.003020	-1.238036	0.2157
D13_09_2012	-0.007549	0.003594	-2.100317	0.0357
D15_10_2010	0.004931	0.002870	1.718308	0.0857
D16_12_2008	-0.026263	0.002699	-9.732016	0.0000
D17_09_2014	0.002510	0.088795	0.028272	0.9774
D18_03_2009	-0.025574	0.008852	-2.889173	0.0039
D18_06_2014	-0.000540	0.001100	-0.491222	0.6233
D18_12_2013	0.006041	0.002290	2.637741	0.0083
D19_03_2014	0.005485	0.002033	2.698352	0.0070
D19_06_2013	0.003291	0.031744	0.103676	0.9174
D20_06_2012_MEP	0.005047	0.089365	0.056471	0.9550
D21_09_2010	-0.014026	0.001785	-7.856521	0.0000
D21_09_2011_MEP	0.004884	0.002245	2.175540	0.0296
D22_01_2015	0.019630	0.002526	7.770110	0.0000
D22_05_2013	-0.002014	0.009808	-0.205292	0.8373
D22_06_2011	0.005396	0.003770	1.431564	0.1523
D22_08_2012	-0.005036	0.017647	-0.285362	0.7754
D23_09_2009	0.002714	0.014271	0.190168	0.8492
D25_11_2008	0.008296	0.038646	0.214668	0.8300
D27_08_2010	0.002532	0.016753	0.151159	0.8799
D28_01_2009	0.007174	0.033191	0.216137	0.8289
D29_01_2014	0.002678	0.007590	0.352857	0.7242
D29_10_2014	0.004634	0.060038	0.077183	0.9385
D30_04_2014	-0.001512	0.001136	-1.331683	0.1830
D30_07_2014	-0.003210	0.005585	-0.574754	0.5655
D31_08_2012	-0.003565	0.000543	-6.564314	0.0000
DLOG_VIX	0.032621	0.001979	16.48537	0.0000

Appendix 8 Continued

Variance Equation

C	3.32E-05	1.23E-06	26.91968	0.0000
RESID(-1)^2	0.126037	0.029525	4.268816	0.0000
D01_12_2008	-3.54E-05	1.80E-06	-19.70594	0.0000
D03_11_2010	-3.29E-05	1.87E-06	-17.54949	0.0000
D04_11_2009	-2.34E-05	1.75E-05	-1.338647	0.1807
D05_03_2015	-1.59E-05	0.004465	-0.003568	0.9972
D12_08_2009	-2.93E-05	0.000219	-0.134028	0.8934
D12_10_2010	-3.27E-05	1.86E-06	-17.59668	0.0000
D12_12_2012	-2.51E-05	3.05E-05	-0.823594	0.4102
D13_09_2012	-1.35E-05	0.000205	-0.066043	0.9473
D15_10_2010	-3.31E-05	1.59E-05	-2.082990	0.0373
D16_12_2008	-3.52E-05	0.000247	-0.142187	0.8869
D17_09_2014	-7.81E-06	0.020092	-0.000389	0.9997
D18_03_2009	3.98E-05	0.002594	0.015323	0.9878
D18_06_2014	-3.31E-05	1.94E-05	-1.707410	0.0877
D18_12_2013	-1.88E-05	3.37E-05	-0.556337	0.5780
D19_03_2014	-3.24E-05	1.98E-06	-16.32372	0.0000
D19_06_2013	-1.70E-05	0.002205	-0.007693	0.9939
D20_06_2012_MEP	-2.46E-05	0.003530	-0.006974	0.9944
D21_09_2010	-2.64E-05	6.38E-05	-0.414387	0.6786
D21_09_2011_MEP	-3.23E-05	1.99E-06	-16.28550	0.0000
D22_01_2015	-1.55E-05	4.00E-05	-0.388190	0.6979
D22_05_2013	-1.45E-05	0.001930	-0.007502	0.9940
D22_06_2011	-3.29E-05	1.85E-06	-17.78524	0.0000
D22_08_2012	-3.31E-05	3.09E-05	-1.072801	0.2834
D23_09_2009	-3.27E-05	1.87E-06	-17.48419	0.0000
D25_11_2008	5.30E-05	0.002970	0.017850	0.9858
D27_08_2010	-3.08E-05	0.000720	-0.042718	0.9659
D28_01_2009	1.10E-06	0.002997	0.000367	0.9997
D29_01_2014	-7.45E-06	0.002432	-0.003063	0.9976
D29_10_2014	-3.04E-05	0.003173	-0.009577	0.9924
D30_04_2014	-3.18E-05	1.20E-05	-2.644943	0.0082
D30_07_2014	-3.21E-06	9.28E-05	-0.034600	0.9724
D31_08_2012	-3.20E-05	1.94E-06	-16.52828	0.0000

R-squared	0.175630	Mean dependent var	0.000102
Adjusted R-squared	0.159022	S.D. dependent var	0.006575
S.E. of regression	0.006029	Akaike info criterion	-7.382852
Sum squared resid	0.059546	Schwarz criterion	-7.162349
Log likelihood	6240.065	Hannan-Quinn criter.	-7.301153
Durbin-Watson stat	2.036793		

Appendix 9. Correlogram of the Residuals of the GARCH(0,1) Model

Sample: 11/03/2008 3/31/2015
Included observations: 1672

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.034	-0.034	1.8849	0.170
		2	0.026	0.025	3.0375	0.219
		3	-0.026	-0.024	4.1790	0.243
		4	-0.060	-0.063	10.261	0.036
		5	-0.005	-0.008	10.308	0.067
		6	0.007	0.009	10.397	0.109
		7	0.036	0.034	12.561	0.084
		8	-0.005	-0.008	12.610	0.126
		9	-0.013	-0.015	12.876	0.168
		10	-0.011	-0.009	13.097	0.218
		11	0.014	0.018	13.415	0.267
		12	-0.003	-0.003	13.434	0.338
		13	0.042	0.038	16.360	0.230
		14	0.013	0.014	16.631	0.276
		15	0.009	0.011	16.779	0.332
		16	-0.021	-0.018	17.498	0.354
		17	0.008	0.012	17.602	0.414
		18	-0.005	-0.002	17.642	0.479
		19	-0.018	-0.019	18.164	0.512
		20	-0.013	-0.018	18.439	0.558
		21	0.005	0.006	18.486	0.618
		22	-0.002	-0.001	18.494	0.676
		23	-0.031	-0.032	20.098	0.636
		24	-0.015	-0.021	20.495	0.668
		25	-0.001	-0.000	20.497	0.720
		26	-0.046	-0.048	24.073	0.572
		27	0.003	-0.005	24.089	0.625
		28	-0.012	-0.015	24.333	0.664
		29	0.004	0.002	24.367	0.711
		30	-0.012	-0.014	24.599	0.744
		31	0.007	0.006	24.687	0.782
		32	-0.008	-0.008	24.787	0.815
		33	0.001	0.004	24.788	0.847
		34	0.002	0.001	24.792	0.876
		35	0.017	0.017	25.268	0.887
		36	-0.002	0.000	25.272	0.909

Appendix 10. ARCH-LM Test for the Residuals of the GARCH(0,1) Model

Heteroskedasticity Test: ARCH

F-statistic	0.047440	Prob. F(1,1669)	0.8276
Obs*R-squared	0.047495	Prob. Chi-Square(1)	0.8275

Test Equation:
Dependent Variable: WGT_RESID^2
Method: Least Squares
Date: 05/17/15 Time: 15:29
Sample (adjusted): 11/04/2008 3/31/2015
Included observations: 1671 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.968212	0.047760	20.27236	0.0000
WGT_RESID^2(-1)	-0.005331	0.024476	-0.217807	0.8276

R-squared	0.000028	Mean dependent var	0.963077
Adjusted R-squared	-0.000571	S.D. dependent var	1.697389
S.E. of regression	1.697873	Akaike info criterion	3.897826
Sum squared resid	4811.347	Schwarz criterion	3.904314
Log likelihood	-3254.633	Hannan-Quinn criter.	3.900230
F-statistic	0.047440	Durbin-Watson stat	1.980461
Prob(F-statistic)	0.827606		

Appendix 11. GARCH(0,2) Estimation Output

Dependent Variable: DLOG_USDEUR
Method: ML - ARCH (Marquardt) - Normal distribution
Sample: 11/03/2008 3/31/2015
Included observations: 1672
Convergence achieved after 16 iterations
Presample variance: backcast (parameter = 0.7)
GARCH = C(11) + C(12)*RESID(-1)^2 + C(13)*RESID(-2)^2 + C(14)
*QE1_BUY + C(15)*QE1_SELL + C(16)*QE2_BUY + C(17)
*QE2_SELL + C(18)*QE3_BUY + C(19)*QE3_SELL + C(20)
*EAPP + C(21)*MEP

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	8.72E-05	0.000162	0.536889	0.5913
QE1_BUY	-0.007928	0.001579	-5.020631	0.0000
QE1_SELL	-0.001822	0.002057	-0.885726	0.3758
QE2_BUY	-0.002865	0.002322	-1.234141	0.2172
QE2_SELL	0.005285	0.001811	2.919099	0.0035
QE3_BUY	-0.005171	0.001509	-3.427801	0.0006
QE3_SELL	0.001703	0.001109	1.534731	0.1248
EAPP	0.014805	0.004018	3.684812	0.0002
MEP	0.004892	0.001615	3.029906	0.0024
DLOG_VIX	0.031771	0.002095	15.16502	0.0000
Variance Equation				
C	3.26E-05	1.39E-06	23.50255	0.0000
RESID(-1)^2	0.142429	0.035081	4.060024	0.0000
RESID(-2)^2	0.055839	0.016071	3.474473	0.0005
QE1_BUY	8.27E-06	6.12E-06	1.351223	0.1766
QE1_SELL	-1.73E-05	2.58E-05	-0.668206	0.5040
QE2_BUY	5.44E-06	1.93E-05	0.281892	0.7780
QE2_SELL	-3.44E-05	4.93E-06	-6.979066	0.0000
QE3_BUY	-2.30E-05	7.83E-06	-2.933764	0.0033
QE3_SELL	-9.53E-06	1.00E-05	-0.949657	0.3423
EAPP	1.89E-05	6.77E-05	0.278700	0.7805
MEP	-3.27E-05	7.64E-07	-42.79492	0.0000

R-squared	0.136749	Mean dependent var	0.000102
Adjusted R-squared	0.132074	S.D. dependent var	0.006575
S.E. of regression	0.006125	Akaike info criterion	-7.383330
Sum squared resid	0.062355	Schwarz criterion	-7.315233
Log likelihood	6193.464	Hannan-Quinn criter.	-7.358099
Durbin-Watson stat	1.996754		

Appendix 12. GARCH(1,1) Estimation Output

Dependent Variable: DLOG_USDEUR
Method: ML - ARCH (Marquardt) - Normal distribution
Date: 05/19/15 Time: 23:05
Sample: 11/03/2008 3/31/2015
Included observations: 1672
Convergence achieved after 40 iterations
Presample variance: backcast (parameter = 0.7)
GARCH = C(7) + C(8)*RESID(-1)^2 + C(9)*GARCH(-1) + C(10)
*FED_BUY + C(11)*FED_SELL + C(12)*EAPP + C(13)*MEP

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.000112	0.000131	0.852389	0.3940
FED_BUY	-0.005048	0.001179	-4.282114	0.0000
FED_SELL	0.001007	0.000674	1.494232	0.1351
EAPP	0.015575	0.004050	3.845254	0.0001
MEP	0.004919	0.004444	1.106948	0.2683
DLOG_VIX	0.022598	0.001726	13.09146	0.0000
Variance Equation				
C	2.30E-07	8.57E-08	2.687868	0.0072
RESID(-1)^2	0.031871	0.006380	4.995344	0.0000
GARCH(-1)	0.959947	0.007055	136.0690	0.0000
FED_BUY	9.32E-08	1.39E-06	0.067230	0.9464
FED_SELL	-8.31E-07	1.21E-06	-0.685790	0.4928
EAPP	1.82E-05	9.60E-06	1.891299	0.0586
MEP	5.00E-06	4.29E-06	1.165837	0.2437

R-squared	0.124577	Mean dependent var	0.000102
Adjusted R-squared	0.121950	S.D. dependent var	0.006575
S.E. of regression	0.006161	Akaike info criterion	-7.504788
Sum squared resid	0.063234	Schwarz criterion	-7.462633
Log likelihood	6287.003	Hannan-Quinn criter.	-7.489169
Durbin-Watson stat	2.005627		