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Master of Science (M.Sc) in Banking and Finance

"The impact of QE on the economy and financial markets"

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Abstract

The main purpose of this thesis is to discuss and examine the impact of the quantitative easing, which was implemented during the global financial crisis of 2008, to the financial assets and the economy and find, if any, the economic and financial effects it has had in the implementing countries. We discuss the unconventional monetary policies of the large four central banks; Federal Reserve (FED), European Central Bank (ECB), Bank of England (BOE) and Bank of Japan (BOJ) with a special emphasis in the Federal Reserve's implementation policy in the United States of America.

The impact of QE on the economy and financial markets

The main purpose of this thesis is to discuss and examine the impact of quantitative easing, which was implemented by the central banks during the global financial crisis of 2008, to the financial assets and the economy.

The first chapter describes the theoretical context of the monetary policy, both conventional and unconventional. How central banks implement monetary policy and why there is need for unconventional measures such as the quantitative easing (QE). Furthermore, the transmission channels of QE are presented.

The second chapter discuss the the implementation of the QE during the financial crisis of 2008 by the four central banks; European Central Bank, Bank of England, Bank of Japan and Federal Reserve Bank. A special emphasis is given to Fed's QE policy. At the end of this chapter the effects of QE in the financial assets and the domestic and global economy are discussed.

The third chapter describes the methodology of the empirical study and presents the results.

Contents

Chapter 1: The theoretical context of monetary policy

1. Conventional and unconventional monetary policy

1.1 Conventional monetary policy

The main objective of a central bank is to maintain price stability in order to reach economic growth and full employment. The most common tools that a central bank uses in order to implement monetary policy and achieve these goals are

1. By performing open market operations
2. By changing the discount rate
3. By changing reserve requirements

Open market operations

The most commonly used tool of monetary policy is open market operations. Open market operations occur when a central bank sells or buys Treasury Bonds in order to impact the quantity of bank reserves and the level of interest rates .

Changing the discount rate.

When financial markets are impaired a central bank plays the role of the "lender of last resort". In the unlikely event of a bank run, banks can borrow money from the central bank until depositors become convinced that the bank will be in position to honor their withdrawals. The interest rate that banks pay to the central bank in order to borrow this money is the discount rate.

Changing Reserve Requirements.

Another tool of monetary policy is for the central bank to raise or lower the reserve requirement which is the percentage of each bank's deposits with the central bank. If a bank is required to hold a greater amount in reserves then it will have less money to lend out to households and firms. If banks are allow to have smaller amount in reserves, then they will have a greater amount to lend out to households and firms.

By setting the interest rate to a specific level a central bank can manage liquid conditions in the market and achieve its primary goals which are inflation and price stability. The size of the central's bank balance sheet is affected by external factors such as government deposits, public demand for capital. Under normal market conditions a central bank is not involved directly to the purchase of government bonds, corporate debt or any other form of financial instruments

This type of policy has proved to be an effective way of providing monetary stimulus to economies during market turmoil. So why is the need for unconventional measures? The reason for unconventional measures becomes evident in times of powerful economic shocks that have push nominal interest rates to zero. At this point, cutting policy rates further becomes mission impossible.

1.2 Unconventional monetary policy

Central banks switched to unconventional monetary policies when the possibility for further conventional monetary policies has been exhausted. The main purpose of a central bank, when implements QE, is to directly affecting the long term interest rates by purchasing assets and injecting money to the economy. In contrast to conventional monetary policy which targets the short term interest rates conventional monetary policy focuses on the long term interest rates.

Central banks seek to affect long term interest rates by expanding their balance sheets and so the quantity of money (Goodfriend, 2011) when implementing QE in contrast to conventional

monetary policy which focuses on setting the price of money. As a result, the balance sheet of all participants, from the central bank to the banking sector and to the non bank private sector is affected.

A central bank buys the long term assets mainly from the non bank private sector such as pension funds and insurance companies. By selling these long term asset to the central bank, the non bank private sector eliminate its holdings. The central bank rather than printing new money in order to pay, credits the accounts of the sellers of these assets. As a result, through quantitative easing the bank deposits of the non bank private sector increase. The central bank in order to finance these purchases, issues base money in the form of reserves which are held by other commercial banks.

Figure 1

how the balance sheet of non-bank private sector, central bank and private bank is affected by the QE

Non-bank private sector

Assets	Liabilities
- Long term assets + Deposits	

Central bank

Assets	Liabilities
+ Long term assets	+ Reserves

Private bank

Assets	Liabilities
+ Reserves	+ Deposits

1.3 The zero lower bound.

As discussed earlier, central banks conduct monetary policy by purchasing and selling short term debt securities in order to affect short term nominal interest rates by alternating the monetary base. However, this monetary policy is ineffective when interest rates are zero. This situation is described as Zero lower bound (ZLB) and it has received criticism about promoting economic growth (Smaghi,2009).

At the zero lower bound, money and bonds become close substitutes causing a liquidity trap to limit the capacity of a central bank to stimulate economic activity. Increasing the monetary base is not an effective stimulus on its own.

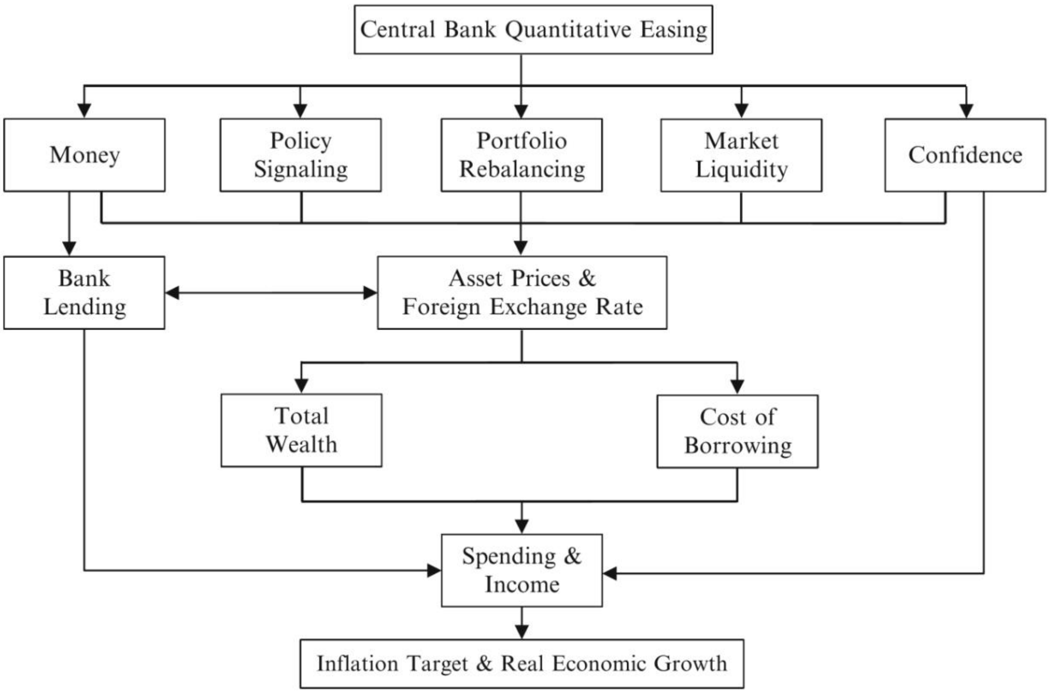
Recent studies have shown that quantitative easing can play a significant role in neutralizing the negative effects of the zero lower bound and preventing liquidity traps. Bhattarai, Eggertsson and Gafarov showed that when short term interest rates are up against the zero lower bound, QE can be effective to fight inflation and a negative output gap as it leads to the target lower real long-term interest rates.

1.4 To what degree does unconventional monetary policy differ from the conventional one?

Bean (2009) mentions that conventional monetary policy is pretty similar to the QE. The main difference between open market operations and the QE is the circumstances under the QE is implanted and its scale (Bean 2009). Furthermore, what Woodford recognizes as pure QE, the purchasing of short term assets by a central bank, is exactly the same with the open market operation. However, the distinct difference is that with QE causes a straight injection of a specified amount of money which is not influences its price through variations in the price base of money. A second difference from conventional monetary policy is that with QE central banks have to next level by purchasing not only short term government securities but a variety of assets. Bank of England and Federal reserve have purchased long term bonds, as well as corporate bonds and mortgage backed securities.

1.5 The Transmissions channels of Quantitative Easing

figure 1



Trasmission channel of QE. (source: Hausken and Ncube Quantitative Easing and Its Impact in the US, Japan, the UK and Europe)

1.5.1 Portfolio Rebalancing

The main channel through which QE affect the asset prices is through portfolio rebalancing. When a central bank purchases assets from the private sector, it "changes" the portfolio of the sellers of the assets. The first effect after the purchase is that it reduces the amount of the securities that the private sector is holding hence reducing supply. The second effect is that the private sector is left with cash in bank in form of deposits rather than securities. The combination of these two effects leads to the rise of the price being purchased and hence lower its yield. This trend was first observed by James Tobin and it is known as portfolio rebalance effect.

In order the portfolio rebalancing process to work the private sector must not be indifferent between holding money and bonds. If cash and bonds are considered as perfect substitutes then the process has no result and the portfolios remain in balance.

When the economy is at zero bound level the interest and credit risk between cash and one period bonds is zero. By these conditions any attempt by the central bank for expansionary monetary policy has no impact as the economy falls in liquidity trap. Woodford (2012) called this process as “pure QE” when the main goal is to inject money to the economy rather than lower the yields. A characteristic example of pure QE is the policy of the Central Bank of Japan between 2001 and 2006 which had as main goal the injection of money in the economy.

The above explains why the QE that was implemented by the FED targeted the purchase of long term bonds rather than those of short term. Cash and long term bonds are not likely to be considered as perfect substitutes allowing portfolio rebalancing and asset movements (Tobin 1969, Meltzer 1972).

1.5.2 Duration channel

Another channel through which QE may affect assets prices is through duration. In bonds, duration is a measure of price sensitivity and it can be considered as a measurement of interest rate risk. Central banks can affect asset prices by changing the aggregate amount of interest rate risk in the bond markets. When investors expect interest rates to rise and hence interest rate risk, they will demand a higher term premium in order to bear the risk.

When a central bank purchases long term securities such as bonds it actually alternates the aggregate amount of interest rate risk- duration risk by reducing it. This leads to reduction of compensation that private investors require, which in turn leads to reduction of duration risk. As a result, long term interest rates fall.

1.5.3 Signaling Channel

Another channel through which long term assets purchase may affect interest rates is signaling channel. When a central bank reveals its assessment for the economic outlook, it is signaling its expectations about its policy rates. By purchasing long term assets a central bank clearly indicates its commitment and objectives to a loosen monetary policy. This might help to maintain its credibility in the economy and keep inflation at the desired levels. Furthermore, when a central bank signals to the market that assets' expected future returns will be affected, purchases of long-term assets are likely to have an impact on today's asset prices and yields. Gangon et al (2010) propose that today's asset prices should reflect future asset prices otherwise investors could make profits from selling later assets bought today. Although it is expected all interest rates to be affected through the signaling channel, it is on the short and medium term the biggest impact (Krishnamurthy , 2011). Moreover Krishnamurthy et al., 2011 suggest that because quantitative easing announcements include information regarding future interest rates, market participants are likely to relate these quantitative easing announcement as a signal that interest rates will be kept low for a long period of time.

1.5.4 Liquidity Channel

Another channel that may affect interest rates, especially when markets are in turmoil, is the liquidity channel. When investors believe that they may not find buyers to sell the assets they hold, because of the bad financial situation, they might require a higher return to compensate them. When a central bank purchases long term assets, it is increasing the liquidity by increasing the trading volume of these specific assets. As a result, the central bank lowers the liquidity premia (Joyce, Breedon, 2011).

1.5.5 Inflation Channel

An expansionary monetary policy like the quantitative easing it increases inflation expectations and it is a way of affecting the interest rates (Cihak, 2009). Historically, when money supply is increased this leads to higher price levels. A higher level of inflation could enable to reach lower levels or real interest rates. However, the impact of this channel remains controversial among economists. On one hand, economists like Paul Kraugman, Scott Summer advocate that when nominal interest rates are in the zero lower bound but the economy is slow moving expected inflation could boost the economy. On the other hand, economists like Niall Ferguson and John Taylor suggest that inflation expectations arising from QE may increase the risks of currency debasement and inflation (Asness, 2010)

How assets prices boost the economy?

Tobin (1969) was the first to suggest the linkage between stock prices and real output. More specifically, he focused on the impact that stock prices have on the cost of capital and it measured by a ratio of the market value of a company's assets divided by the replacement cost of assets. When stock prices are high according to this ratio - the value of companies relative to their replacement cost of capital is also high. As a result, investment expenditure increases leading to a higher economic output because companies find it more easier to finance their investment expenditures.

Modigliani (1971) also studied the relationship between stock performance and GDP. His focus mainly on how assets prices impact consumption. Higher asset prices increase the wealth to the individual that hold these assets. Therefore increased assets prices is equal to increased income. Modigliani concluded that consumers will adjust their consumption levels upwards as their income is increased due to higher assets prices.

Bernake and Getrler (1989) study the impact of assets prices to the economy from a different approach, this of a a company's balance sheet. They suggest that how much money a company can borrow from the markets is highly dependent from the collateral they can provide. When stock prices increase the value of this collateral also increases, so it is more easier for the companies to raise capital for investment purposes which leads to an expansion in economic activity.

When asset prices increase, the net wealth of asset owners do so. These profits could stimulate spending by household and firms. Empirical analysis by Joyce et tal (2013) estimated that the 375 billion pounds of assets purchases boosted UK households' net wealth by 30%

Cost of capital.

Households and firms are accessing finance with relation to the risk free rates at maturity they want to borrow. So reduction in the yield curve is likely to mean reduction to interest rates that households and firms are facing. When funding costs are reduced, it will enable banks to lend to households and firms to loan at a reduced price.

Chapter 2: Uncoventional monetary policy by the Central Banks

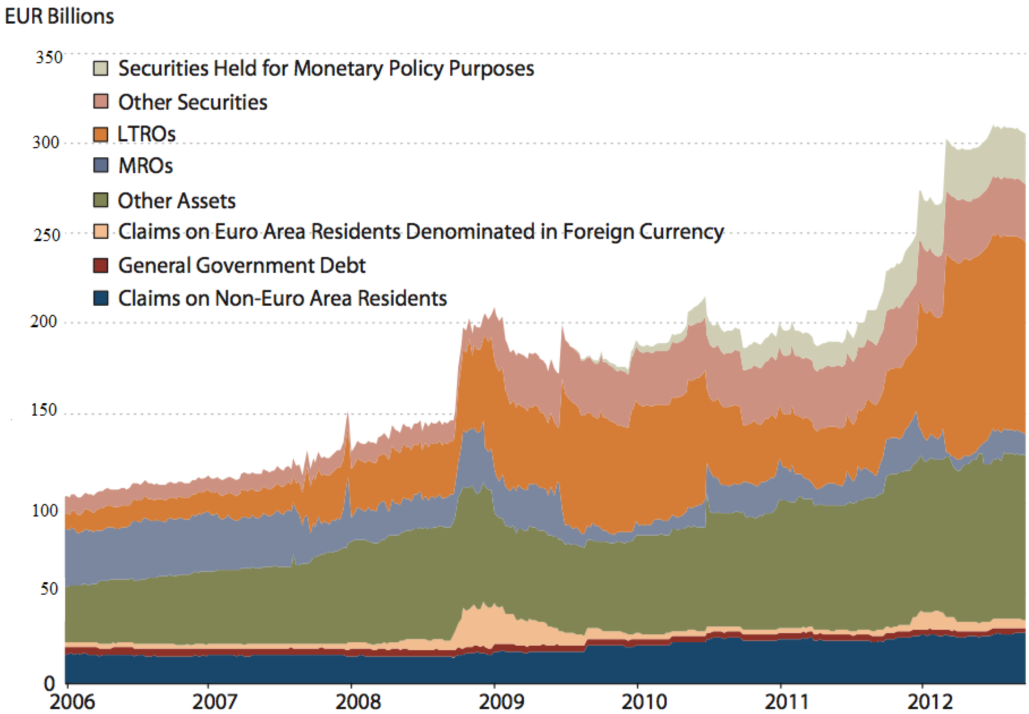
2.1 The case of European Central Bank (ECB)

Even though the European Central bank (ECB) started buying assets from commercial banks, as part of its non-conventional monetary policy, in March 2015 to support economic growth it had already started a series of measures before and after the collapse of Lehman brothers.

On August 2007 ECB poured 95 billion euros to the Eurozone banking system by allowing commercial banks to draw overnight the total capital they needed. This surprisingly high amount of capital that banks overdrawn was an indicator of the severe market conditions and it was a sign of lack of confidence between the market participants. The ultimate aim of this move by the ECB was to encourage commercial banks to provide the economy with liquidity (European Central Bank 2010)

From October 2008 until May 2009 ECB cut its policy rate from 4.25% to 1%. More specifically ECB increased market liquidity by main refinancing operations (MROs) and long term refinancing operations (LTROs).

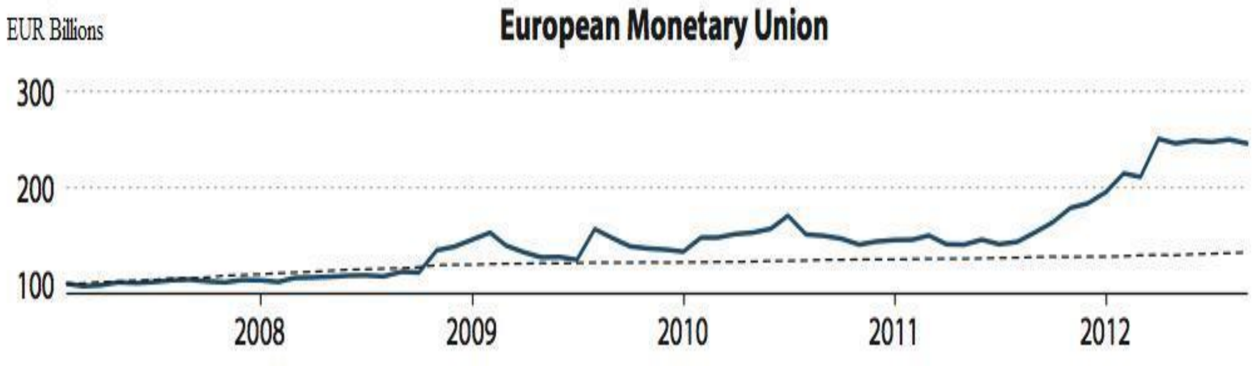
Figure 3



Types of assets purchases by the ECB (source: Fawley and Neely, 2013)

As a direct result of these two refinances operations not only the ECB balance sheet changed but also the monetary base.

Figure 4



ECB's monetary base (source: Fawley and Neely, 2013)

2.1.1 Programs implemented by the ECB

Covered bond purchase programs 1, 2, 3.

On 2 July 2009 and when the European debt crisis started to become evident, the ECB launched its first covered bond purchase program (CBPP1). The program ended, as planned, on 30 June 2010 when it reached a total amount of €60 billion.

In November 2011 the European Central Bank started to buy covered bonds, in its latest attempt to to revive lending in the Eurozone and stave off a vicious bout of economic stagnation.

On October 2014 the ECB started to buy covered bonds under a third covered bond purchase program (CBPP3).

The measure helped to enhance the functioning of the monetary policy transmission mechanism, to support financing conditions in the euro area, to facilitate credit provision to the real economy and to generate positive spillovers to other markets.

Asset-backed securities purchase program.

On November 2014 the ECB started the asset-backed securities purchase program (ABSPP). Main purpose of the ABSPP program was to help banks diversify their funding sources and to stimulate the issuance of new securities.

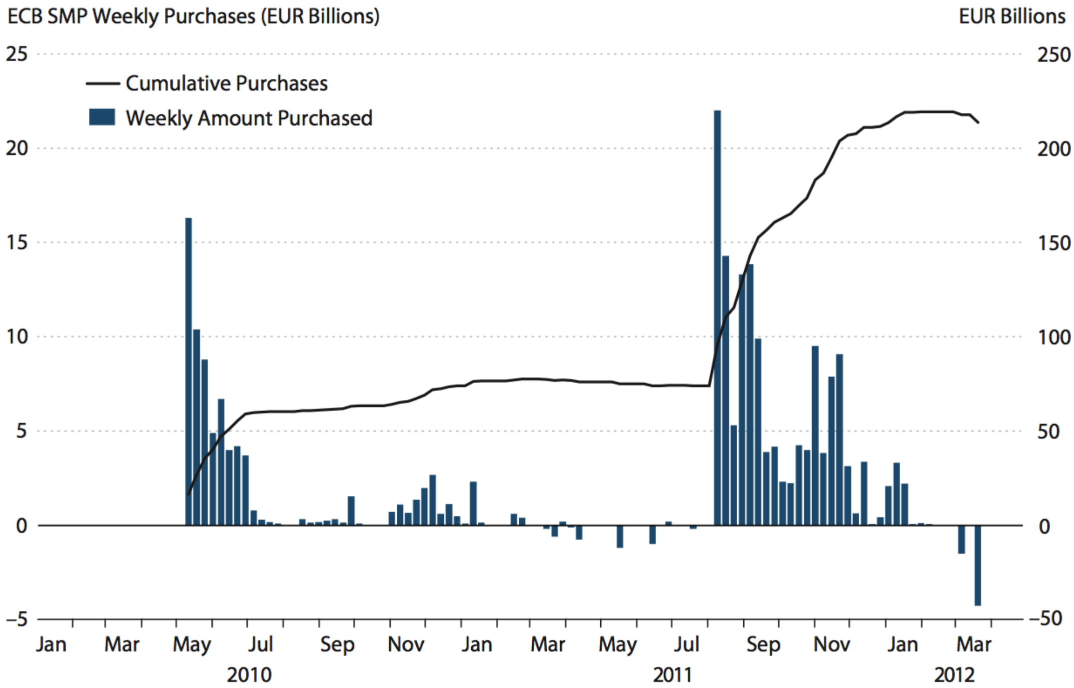
Corporate sector purchase program.

On June 2016 the ECB started to buy corporate bonds under the corporate sector purchase program (CSPP).

Public sector purchase program.

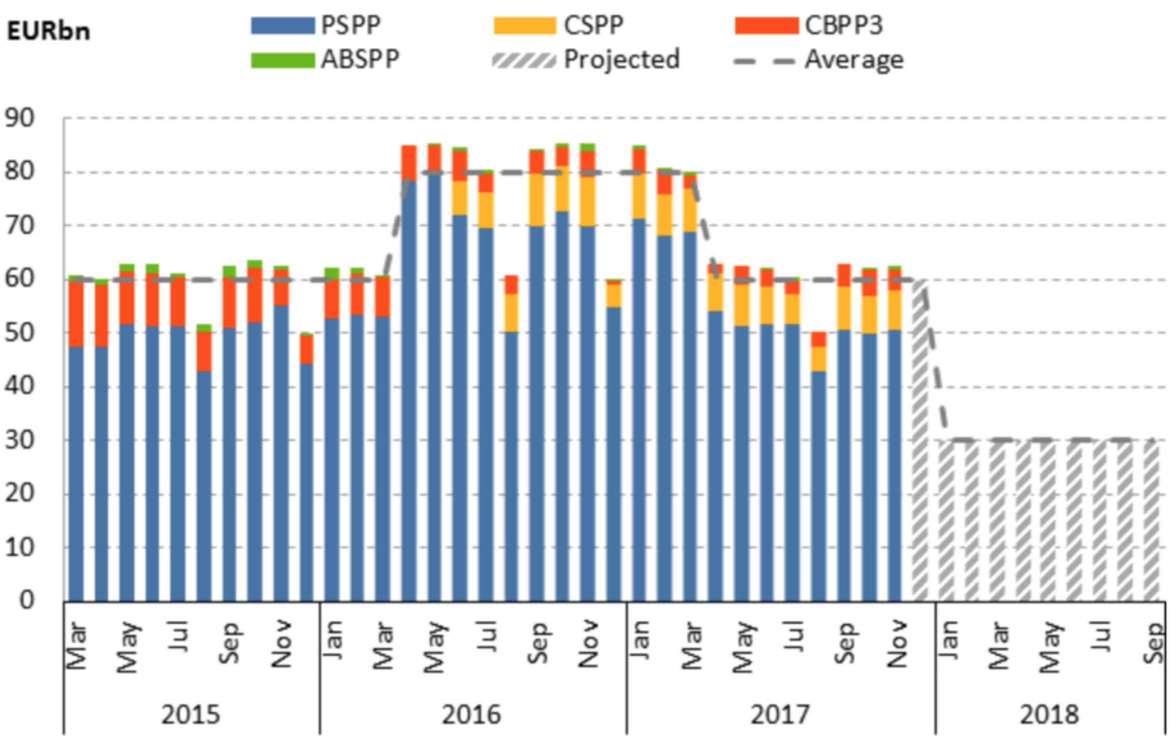
On March 2015 the ECB started to purchase public sector securities under the public sector purchase program (PSPP). The PSPP program included securities such as nominal and inflation linked central government bonds and bonds issued by regional and local governments and international organizations located in the Euro area.
The purchases of assets under the covered bond program between 2009 and 2011 amounted a total of 100 EUR billion (Fawley and Neely, 2013). Most of the purchases as it is indicated from the below figure were made in the spring of 2010.

Figure 5



Ecb Sovereign Debt purchases (source: Fawley and Neely, 2013)

Figure 6



ECB purchases categorized by program (source : www.ecb.eu)

2.1.2 ECB Forward guidance

Since July 2013, along with the asset purchases, the ECB has been providing the markets with forward guidance on the future path of ECB's monetary policy on the outlook for price stability. Forward guidance was an attempt of ECB not only to communicate how it assessed the current economic conditions and price stability but also to communicate its expectation about future interest rates.

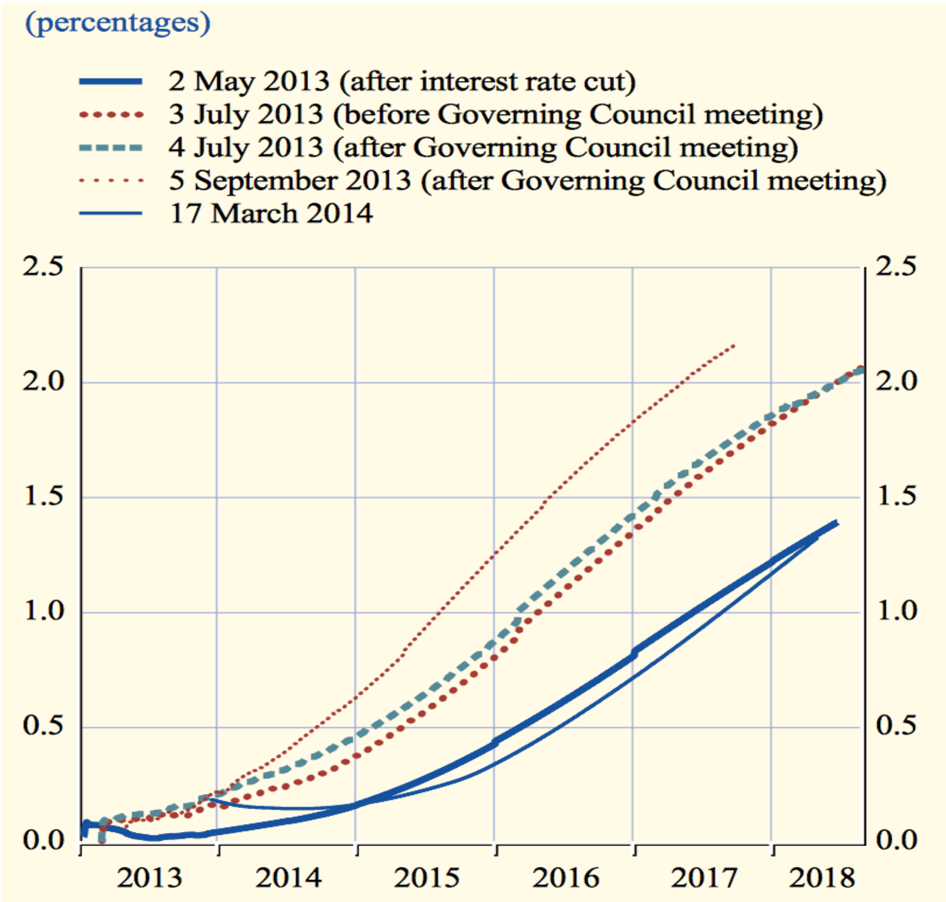
2.1.3 The impact of forward guidance

The impact of forward guidance can by measured by verifying any immediate market reaction which would drive a change in financial market expectations. A reaction in the markets can be expected if the forward guidance contains new information. But apart from

the market response side, the impact of forward guidance can be assessed by examining to which extent the market interest rates are in line with the central bank's monetary policy intentions.

The evidence suggests that after the ECB's announcement of 24th July 2013 regarding forward guidance markets reacted. More specifically, the announcement led to a more flattening money market curve and at the same time forward rates with maturities over six months declined by around five basis points. Furthermore, the following months the slope of the forward started to steepen as a sign of positive economic news.

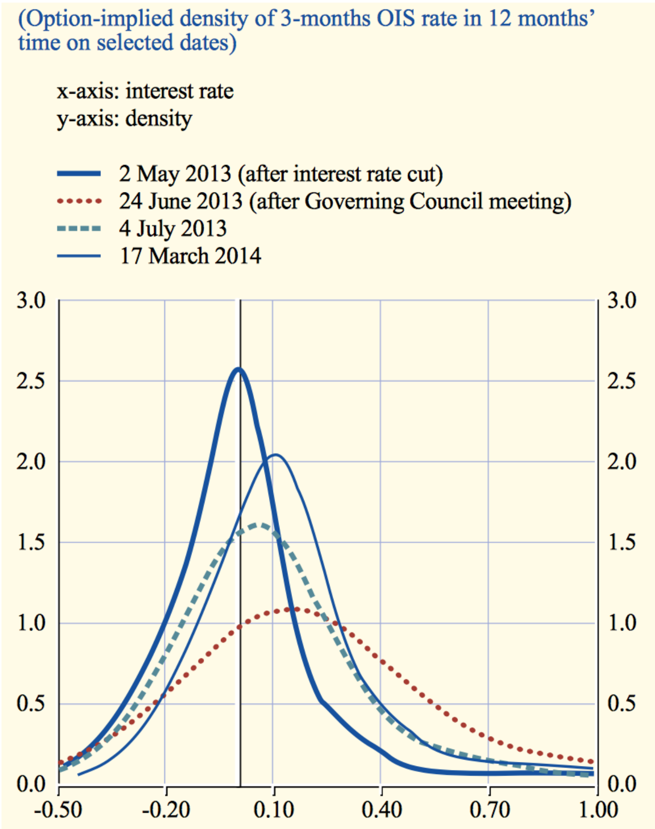
Figure 7



The impact of forward guidance(source: ECB monthly bulletin 2014)

Apart from the impact in the money market rates the forward guidance impacted also the uncertainty of the markets regarding the future of short term interest rates. Option implied density of the 3 month EURIBOR – a measure of predicting expectations regaring OIS- indicated that the dispersion of the short term expectations decreased during May and June 2013.

Figure 8



The impact of forward guidance, money market rates(source: ECB monthly bulletin 2014)

2.2 The case of Bank of Japan

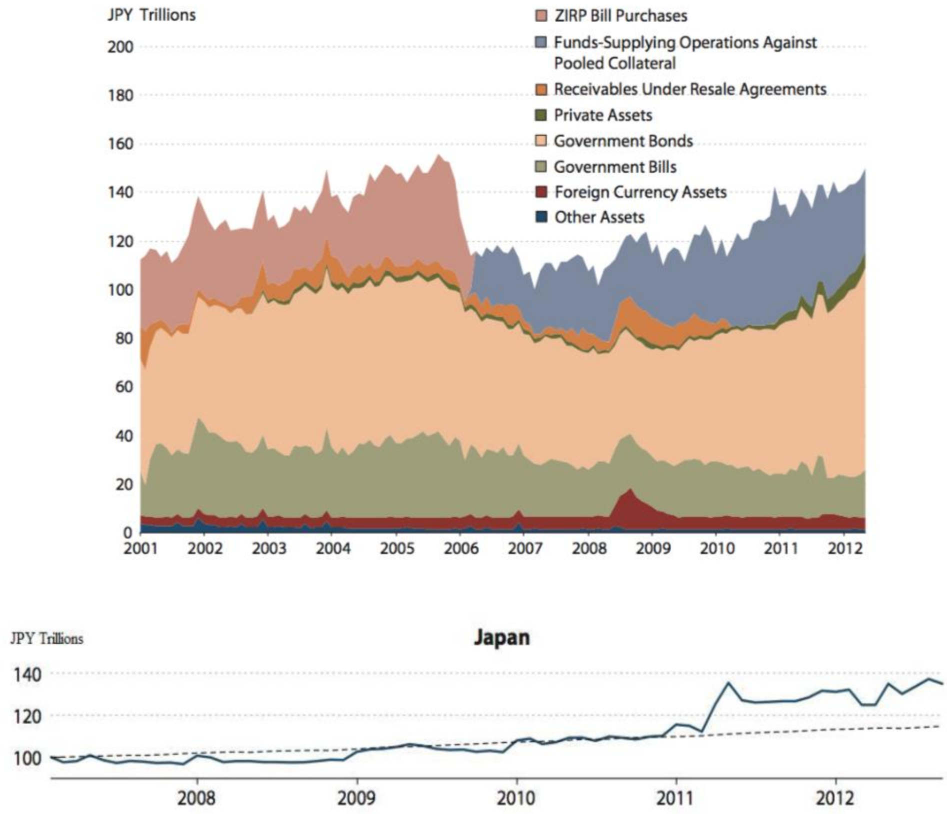
Japanese economy has a long experience with unconventionally monetary policy and quantitative easing which is dating back to 2001. The asset price bubble which collapsed in the early 1992s was characterized by rapid acceleration in prices of real estate and stock market. Following a period of zero interest rate policy (ZIRP) during 1999–2000, the Bank of Japan (BoJ) introduced quantitative easing in March 2001. Under this policy, the BoJ used purchases of Japanese Government Bonds (JGBs) as the main instrument to reach their operating target of current account balances (CAB) held by financial institutions at the BoJ (bank reserves).

The BOJ exited quantitative easing in March 2006, amid signs that the economy was emerging from deflation. Following the global financial crisis, the BoJ increased the pace of its JGB purchases and adopted a number of unconventional measures to promote financial stability. In October 2010, the BoJ introduced its Comprehensive Monetary Easing (CME) policy to respond to the re-emergence of deflation and a slowing recovery.

Even though the implementation of expansionary monetary policy the Japanese consumer price index (CPI) in October 2013 was roughly the same as in October 1993. While Japan's CPI has had its ups and downs over the past 20 years, the average inflation rate has been roughly zero. This uncommonly low inflation rate is viewed by some as harmful to economic performance. Shinzo Abe became prime minister of Japan in December 2012, promising to end Japan's long experience with very low inflation. In accordance with this promise, the Bank of

Japan (BOJ) recently adopted a 2 percent inflation target and embarked on a quantitative easing (QE) program designed to achieve this goal.

Figure 9



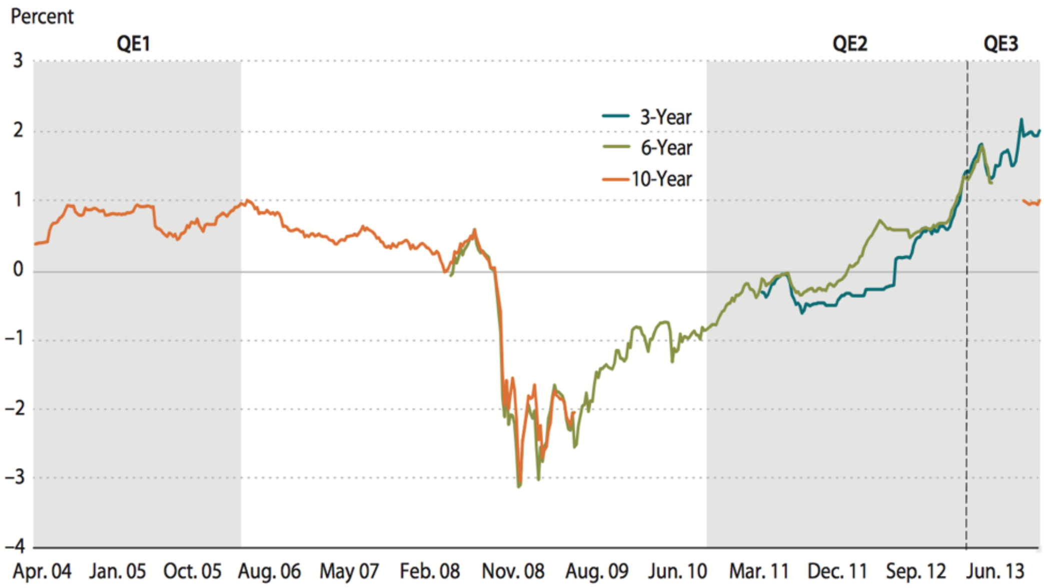
Assets purchases and monetary base BOJ (source: Fawley and Neely, 2013)

the impact of the QE policy is difficult to measure in the case of Japan. QE1 seemed to have little or no effect on the economy because of the zero percent inflation target and CPI saw very limited change as stated above. One possible explanation behind this narrow influence is that changes in the monetary base are not likely to affect inflation if the public expectation is that the program will be reversed shortly in the future (Andolfatto, 2014, Ugai, 2006).

However, since 2010 some evidence relating to inflation expectations indicate that the implementation of QE might affected the economy and help BOJ to achieve its target goal of inflation of 2%. The Japanese government issues inflation index bonds –bonds that pay interest id dependent on inflation. By comparing the yield on those bonds against to non inflation index bond a market forecast for future inflation can be derived. As shown in the below chart, inflation expectations have been moderate positively following the period untill the 2008 crisis. However, after the crisis of 2008 there was an impressive recovery in inflation expectations above the historical average.

More generally, it suggests that QE policies can have their desired effect on inflation if central banks are sufficiently committed to achieving their goal. Whether this will in fact eventually be the case in Japan remains to be seen.

Figure 10



Inflation expectations in Japan (source: Bloomberg)

2.2.1 How successful was the QE exit for Japanese economy

When central banks consider what is the best exit strategy and best transition to conventional monetary policies they might want to examine the case of Japan with ending the QE. Bank of Japan ended QE in 2006 and this decision did not have severe economic negative effects (Blinder, 2010). With overnight interest rate to zero percent, the BOE Japan took the decision to keep interest rates at ZLB and at the same time to increase market liquidity in order to reach the targeted inflation rate. Along with the inflation goals, market liquidity helped to stimulate the economy, even though it is difficult to understand which impacts were caused by the lowered interests rates and which from the capital injections in the economy((Ugai, 2006). The BOJ's balance sheet decreased from from ¥145 trillion to ¥116 trillion between March and July 2006. This decline reflected a ¥20 trillion decrease in funds-supplying operations as money markets were restored and institutions gradually stoped depending from the BoJ for funding. The most challenging task for the BOJ was the exit from the policy duration commitment and raising the interest rates. Under the policy duration commitment market participants expected funds from the BOJ at near zero rates for an extended period of time. So, before raising the interest rates BOJ needed to smoothly shorten the expectations of the market participants in order to avoid any dramatic shifts in the yield curve which could threaten the economic recovery. In order to fight this uncertainty the BOJ announced that it commits to maintain an accommodative stance attached to the consumer price index (CPI). Since one the main goals of monetary policy is to achieve price stability this commitment was reasonable and enhanced the credibility of BOJ to the market participants.

Japan's economic data (IMF,working paper 2010) suggest that it is possible to exit from a long period of QE without damaging financial markets, economic activity and without damaging inflation. After the QE was over the BOJ reduced its balance sheet and excess bank reserves within few months. There was no indication of high volatility in safe and risky assets. The only flunctuation in the Japanese government bonds was a yield rise of 35 basis point (IMF working paper, 2010) which is considered a normal raise by the market.

2.3 The case of Bank of England

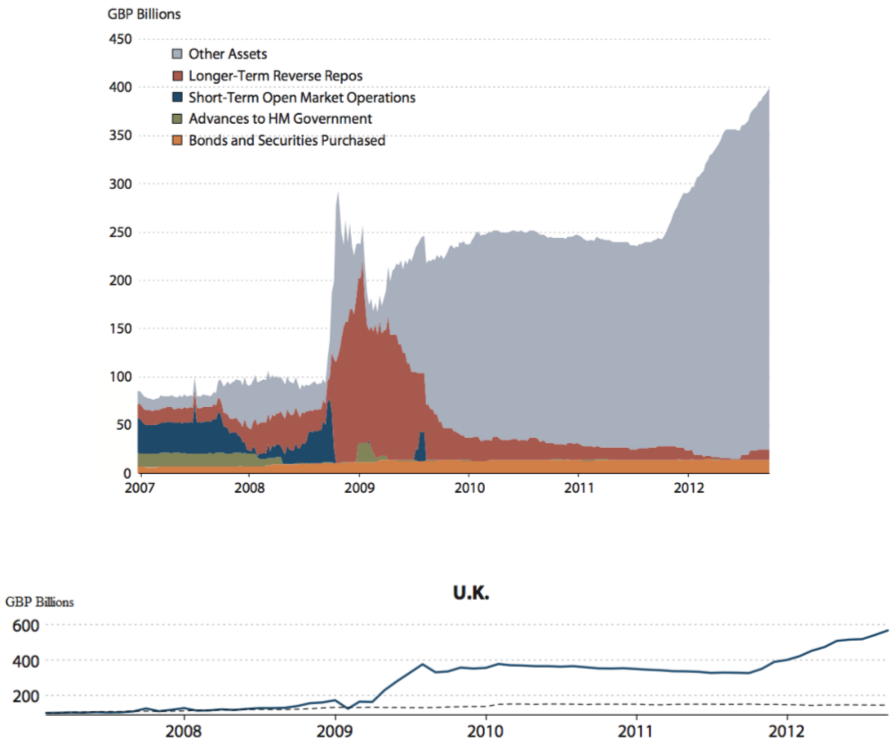
The Bank of England also responded after the global financial crisis of 2008 by implementing expansionary monetary policy. The first step came in January 2009 when BOE announced that it is lowering the bank rate rate at the level of 0.5%. Furthermore, it noted that without the implementation of unconventional monetary measures, the target for inflation of 2% was at risk. The Monetary Policy Committee when started the asset purchase facility (APF)program planned to achieve two goals i) the one was to ease credit conditions and ii) the other was to stimulate the market and the economy through QE.

The first assets purchases had a ceiling of £50 billion in private assets and corporate bonds, and to finance the purchases the BOE issued short term gilts which are low risk bonds issued by the British government. What is important to mention is that this action by the BOE was not considered as QE because it did not expand the monetary base. The results of the first measures were not those expected as the did not stimulate the financial activity as asset holdings peaked in the second quarter of 2009 at less than £3 billion, or only 6% of the £50 billion ceiling (Fawley & Neely, 2013).

It was evident that additional action had to be taken from the BOE. In March of 2009 the BOE announced a ceiling of £75 billion in purchases and the following November this ceiling was raised to £200 billion. At this stage, the bank decided not to use gilts as a trade off for assets and the assets purchases were financed with central bank reserves, expanding the monetary base and the BOE's balance

sheet. The below figure shows how the monetary base was expanded and how the balance sheet of BOE grown during the asset purchases.

Figure 12



Assets purchases and monetary base BOE (source: Fawley and Neely, 2013)

As seen from the figure above the monetary base in the UK increased almost four times.
2009 was the year in which the volume of purchases increased impressively. The following years this trend continued but the difference was that bond purchases were replaced by reserve repos, in this way the BOE increased its reserves compared to pre crisis (Fawley & Neely, 2013).

Despite these measures, the BOE in October 2009 decided to extend the once more time.
This time the QE target increased from the previous £200 billion to £275 amid concerns regarding the inflation target of 2%. When signs of decrease in UK GDP

appeared in the fourth quarter of 2011 and the first quarter of 2012 the BOE decided to increase once again the target to £375 billion. By the end of 2012 the BOE held £100 million in corporate bonds and the the enormous amount of £360 billion in gilts (Fawley and Neely, 2013).

When the fist round of QE was over the Bank of England published a study to examine the impact of QE on the UK bank lending. The findings were mixed regarding the bank lending and this was because smaller banks were seemed to be more sensitive against the major ones in the level of assets purchases. What is more, the study revealed that bank lending is positive correlated to how adequately capitalized the banks are. This finding explains the action by the BOE to trigger QE as the UK banks were not adequately capitalized (Joyce & Spaltro, 2014).

Another study by Jonathan Bridges and Ryland Thomas compares what would be the economic situation in UK given that no QE was implanted. They conclude that if the QE was not implemented then the GDP growth would not have been in positive levels. QE increased the assets prices resulting in lower yields while at the same time it helped to stimulate the economy and investment which helped boosting the GDP growth. (Bridges & Thomas, 2012).

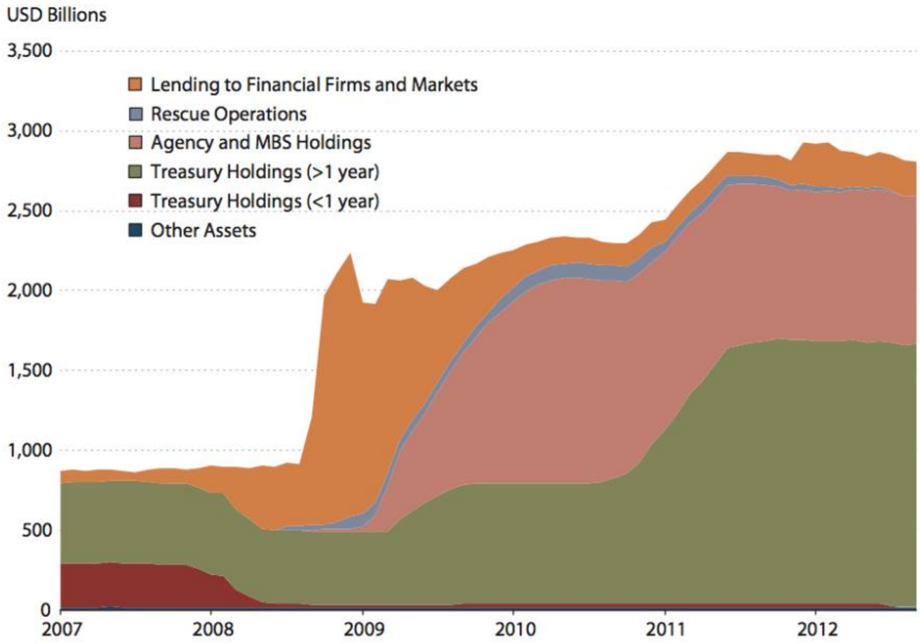
2.4 The case of Federal Reserve

In the United States the implementation of the unconventional monetary policies started to take place the fall of 2008. The housing bubble along with the bankruptcy of Lehman brothers were the two facts that threatened the stability of the whole financial system.
The Federal Reserve, at September, as a first step tried to increase liquidity to the financial markets not only in the US but also internationally. This was achieved by expanding its foreign exchange swaps lines with foreign central banks such as European Central Bank, Bank of England and the Swiss National Bank (Fawley and Neely 2013). The next step came on October with the creation of the Commercial Paper Funding Facility (CPFF). The purpose of the Commercial Paper Funding Facility (CPFF) was to provide liquidity to the U.S issuers of commercial papers, hence to increase the short term liquidity. The CPFF would work through a Special Purpose Vehicle (SPV) that would purchase eligible three-month unsecured and asset-backed commercial paper from eligible issuers. The CPFF program lent out totally 738 billion dollars before it was closed at 2010 and it was the first reaction from the FED in order to improve the credit conditions which were deteriorating.
As of today, the US economy has evidenced three different QE implantations. They are popular know as Q1, Q2 and Q3 based on their chronology.

2.4.1 Q1

The phase of Q1 started on late November. The Federal reserve announced purchases of housing agency debt and agency mortage-backed securities of up to 600 billion dollars. Of those 600 billion dollars, the 100 billion were government-sponsored entrerprise debt (GSE) and the rest 500 $ billions were mortage backed securities (MBS) issued by those GSEs (Fawley and Neely)

Figure 13



Fed's balance sheet of assets (source: Fawley and Neely, 2013)

The second step of the Q1 phase came on March 2009 when the Federal reserve announced that it will increase the purchases additionally for another 100$ billion of GSE debt and another 750$ billion of Mortage backed securities (MBS). Furthermore, it announced that it will purchase 300$ billion in Treasury securities. The total amount of these purchases summed up to 1.75 trillion dollars. This amount doubled the size of the U.S monetary base.

2.4.2 Q2

The second round of the federal reserve's monetary policy to stimulate the economy was initiated in the fourth quarter of 2010 in order to jump start the sluggish economic recovery. It lasted seven months from November 2010 to June

2011. When Q2 was launched the Fed announced that it would buy 600$ billion in US Treasuries bills, bonds and notes by March 2011. Main goal of the Q2 was to spur mild inflation by increasing the demand for goods and services. Fed's main concern was that a sluggish economy would create deflation, a economic situation in which the general price of goods and services in decreasing (like the Japan in the 90s). Q2 was widely expected by the financial markets and this is manifested by the fact that in a Reuters poll conducted October 2010, 16 out of 16 dealer participants expected that the Fed will ease monetary policy. As a result assets prices were already adjusted from October and did not wait the announcement until the November 3 FOMC meeting in order to change.

The Fed continued Q2 also the fall of 2011 fearing another recession. On September 2011 the Fed announced the implementation of a policy called Operation Twist in an attempt to reduce long term interest rates as it could not reduce short term anymore.

With Operation Twist the Federal Reserve sells short term government bonds and buys long dated Treasuries in an effort to decrease long term interest rates rates and therefore to boost economy. Although Operation Twist is also a form of monetary easing, it differs from QE because is balance neutral. Unlike with QE, Operation Twist does not expand the Fed's balance sheet making it a less aggressive form of monetary policy.

2.4.3 Q3

Despite the implementation of QE1 and QE2 the US economy remained stagnant. Before announcing the QE3 on September 2012, The Fed announced on June 2012 that it will extend Operation Twist by purchasing and selling assets of 267$ billion. On September 2012 the Fed announced the third round of quantitative easing. The main difference of the QE3 and QE1 and QE2 stemmed from the fact that QE3 did not targeted for a specific quantity of purchase of assets. Instead it would purchase 40$ billion of MBS per month until the labor market improved substantially as the Fed chairman mentioned.
During QE3 and specifically on December 2012 the FOCM announced a change in the Maturity Extension Program. It would continue to purchase securities with the pace of 45$million/per month but the purchase of these securities will not be twisted by selling short term securities but now would have the additional effect of expanding the monetary base.

2.4.4 QE4

QE4 was the fourth round of the quantitative easing implemented by the Fed. Starting on January 2013, It announced that it would buy 85$ billion in Treasuries from other member banks each month. Two significant changes were signaled under the fourth round of quantitative easing. As Fed chairman Ben Bernake mentioned the QE4 would continue until either two things happened i) unemployment rate dropped below 6.5% and ii) the core inflation rose above 2.5%. Until then, the Fed was focusing on inflation rather than on job creation.

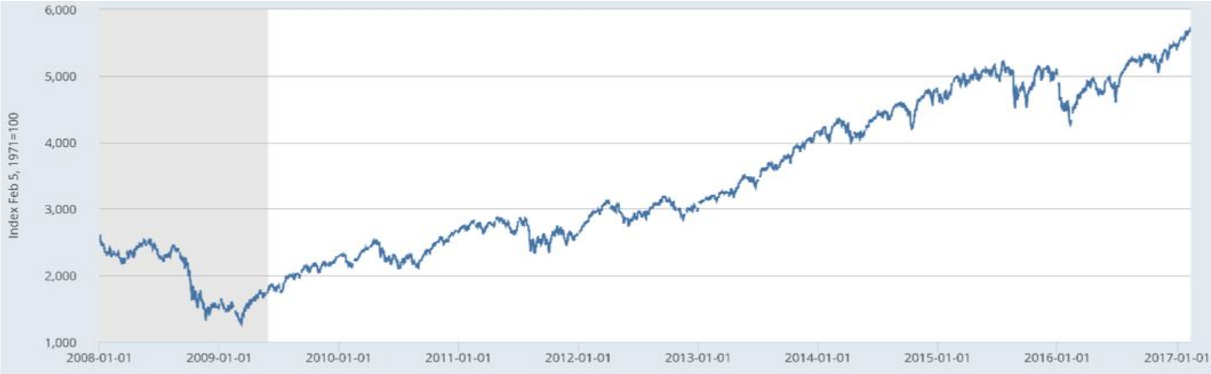
2.5 Financial effects

The main focus of the QE programs was to purchase mainly long term assets because different types of assets cannot be perfect substitutes in an investor's portfolio. The change in the supply of those assets held by private investors may change their yield and prices. The implementation of QE 1 by the Fed with the MBS purchases led investors to rebalance their portfolios by replacing MBS sold to Fed with central bank assets. As a result, the prices of the assets bought rise and yields declined. Direct consequence was to ease financial conditions and to stipulate the economy (Bernake, 2012).

The Fed's long term asset purchase program sent a strong signal to the economy that the bank planed to continue the expansionary policy with the goal of keeping long term real interest rates down with the ultimate goal of stimulating the economy and easing credit conditions. This was a signal that was also sent to the broader economy participants such as investors, businesses, households in order to increase confidence in these policy makers and relieve any worries regarding deflationary trends. Stock market was also boosted from the long term asset purchase program shortly after the implementation in March 2009. Furthermore, Cristensen and Gillan found that the LSAP increased market liquidity and decreased liquidity premiums and therefore improved market functioning. Monetary base was so expansive, as shown in the below figure that financial activity was greatly stimulated.

Figure 14,15

Fed's monetary base (source: FRED)



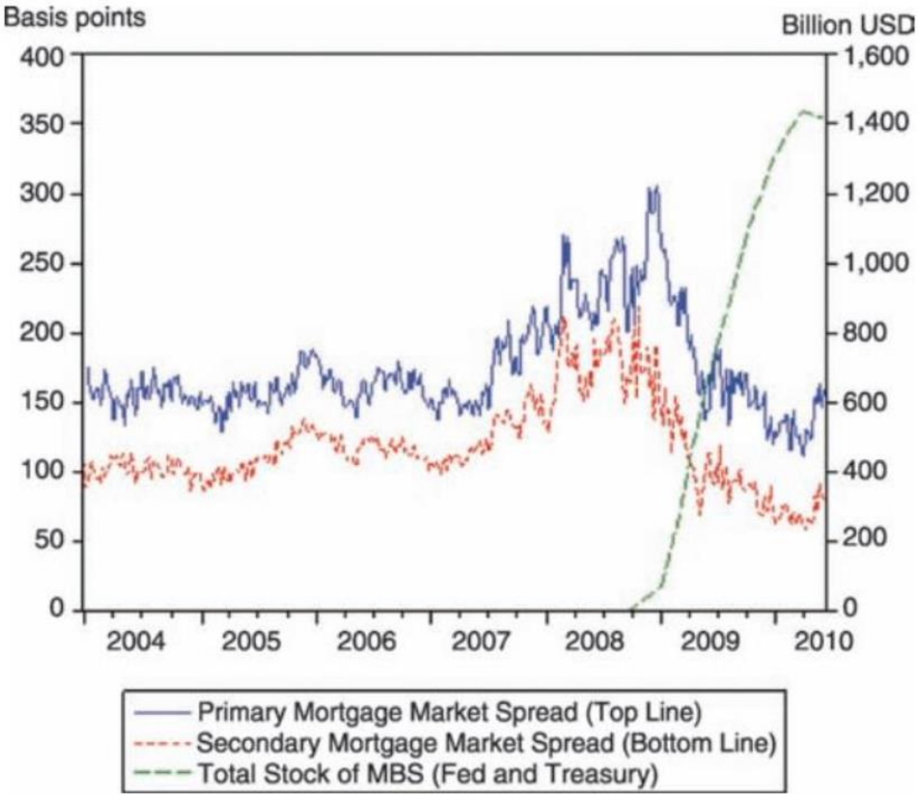
Nasdaq composite index (source: FRED)

2.5.1.Effects on interest rates

Interest rates were greatly impacted by the implementation of the quantitative easing. Empirical analysis also suggests that QE policies can have significant impact on interest rates. Gagnon, Raskin, Remache, and Sack (2010) concluded in their study that dates with positive QE announcements interest rates were decreased. Also Swason (2011) presented an event study regarding Operation Twist in 1961, a policy in which the Fed purchased long term Treasuries and concluded that interest rates were also affected.

More specifically, Arvind Krishnamurthy Annette Vissing-Jorgensen (2011) found the special effect that QE1 had in MBS interest rates due to the fact that QE1 was targeted in purchasing large amount of agency MBS securities. On the other hand QE2 which targeted only Treasury securities impacted Treasury and Agency bonds rates but impacted MBS rates on a smaller degree compared to QE1. The below figure from Stoebel and Taylor shows the difference between primary and secondary mortgage interest rate spreads. The primary market consists of lenders who make loans directly to consumers while the secondary market by institutions like Fannie Mae, Freddie Mac, and Ginnie Mae.

Figure 16



MBS spreads (source *source: Fawley and Neely, 2013)*

The below figure shows the level of interest rates over the past two decades and how the dramatically changed since the launch of the QE in 2008. The lower bound was reached at 2009 and the long term target remained between 0.25% and 0.5% over the following years

Figure 17

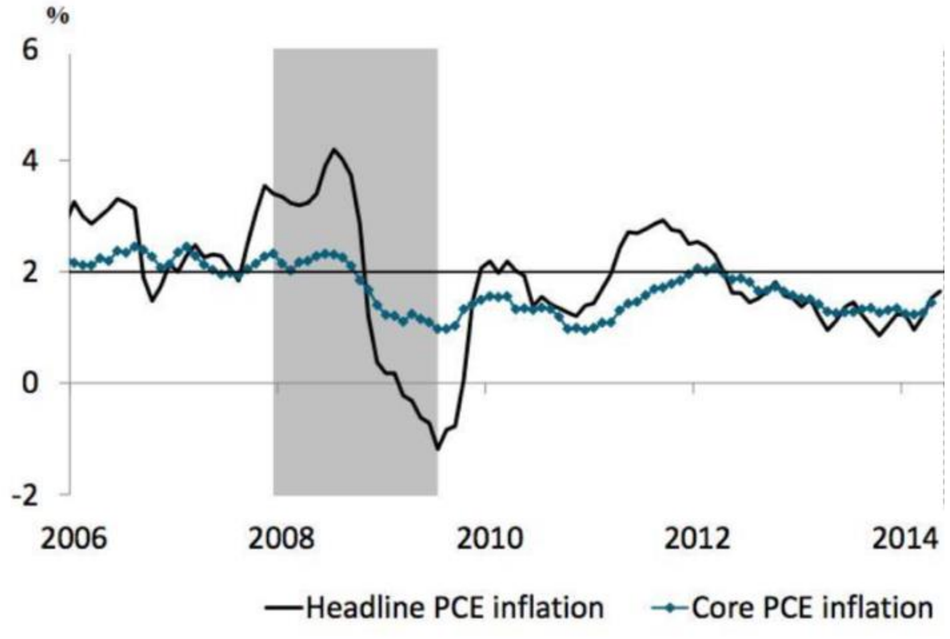
Effective Federal Funds Rate (source : FRED)

2.5.2 Effect of Quantitative easing on inflation and output.

Inflation

One of the macroeconomic factors that QE affected was inflation. The below figure from the Federal Reserve of Kansas City (Federal Reserve of Kansas City , 2014) shows clearly how the QE affected the inflation. The figure consists of three lines, the straight line represents the targeted inflation by the Fed which remained at 2% during pre-QE and post QE. The other two line represent the two different types of inflation; headline inflation and the most common core inflation. Headline inflation is more CPI based as it measures the difference in inflation by calculating in prices of a basket of goods. On the other hand, core inflation is a measure of inflation which does not include CPI components such as food, energy, fuel etc.

Figure 18



(*source: Fawley and Neely, 2013)*

Just before the housing crisis the headline inflation reached its peak at around 4%. The following years after the crisis, headline inflation declined sharply to negative territories even though the first phase of quantitative easing had already started. Stock and Watson (2010) state in their study that expectations regarding inflation were difficult to measure by inflation forecasts models because the economic shock was severe and it happened in a very short period of time. Furthermore, they advocate that the recession in the United states is associated with declining inflation rates, and that deviation from long-term core inflation can be predicted by the unemployment rate.

Real output

Many studies have analyzed whether the QE programs have significant effects in the real economy. This is a challenging task because the impact of money injections, especially to inflation and the real output, may take long time depending on how is transmitted though the various transmission mechanisms. Thus, it is difficult to measure the impact of QE given that there are several contributors over an extend period of time.

In the case of Japan several studies (Kimura, 2012), (Berkmen, 2012) found minor impacts of QE in both inflation and real outpout. The most common reason in all studies was that QE failed to improve banking lending a critical element of QE. Neither the expansion of Japan's the monetary base had great impact according to Ugai (2007) and Kimura (2003).

On the other hand, studies that analyze the effects of QE in US and UK are more positive and promising about the effects in inflation and real economy. In his study regarding the effects of QE 1 in the UK, Kapetanios (2012) suggests that the effects of QE in inflation and GDP became evident after approximately one year. In his study Chung (2012) found that the combination of QE1 and QE2 increased the GDP almost by 3% above the baseline the second half of 2012 and estimated that inflation was 1% higher than it would have been if the Fed had not implemented the two phases of QE. Consistent with these findings are also the studies of Putman (2013) and Milas (2012) which cocluded that despite the severe economic difficulties the initial QE programs had a positive impact in inflation and GDP.

2.5.3 Effects of quantitative easing on the exchange rate

Quantitative easing impacted the exchange rate of the USD compared to EUR especially at the beginning of its implementation. The exchange rate channel is important for open economies in which trade has a considerable share in the economic activity. If an asset purchase program causes the yields of assets denominated in domestic currency to fall in relation to those denominated in foreign currency, this will diminish the appeal of domestic bonds for foreign investors, and demand for domestic currency will decline. This causes downward pressure to the domestic currency.

As a result from this depreciation, exports of domestic products and services become cheaper to foreign countries, which increases their demand from abroad. Furthermore, foreign products and services become now more expensive for domestic consumers and consumers focus more on buying domestic products. Overall, this creates a positive effect in terms of domestic aggregate demand and spurs domestic inflation.

Empirical studies also point out that impact of QE in exchange rates. Neely (2014) that the US QE1 not only lowered the yields on governments like Germany, Canada and Australia but at the same time also depreciated the USD currency against the currencies of those countries.

When the Fed started the QE in 2008 we notice that the USD depreciated against EUR. The same happened when QE2 took place in November 2010.

Figure 19

Exchange rate USD/EUR (source: FRED)

2.5.4. Global effects and spillovers.

Quantitative easing is implemented by the central banks in order to confront domestic economic problems. However, because of global capital market linkages effects in foreigns countries are inevitable.
In his study 2014 Neely found that the US QE1 announcements had great impact to the foreign markets by reducing the international long term bond yields. More specifically, he found that while QE1 reduced domestic 10 year bills by 100 basis points at the same time foreign bond yields declined by 44 basis points. He also suggest that the impact on the foreign bond yields is greater in whenever announcements discussed short term or future purchases than when announcements suggested slowing or limiting purchases.

In accordance with Chen (2010) the impact of US QE was more dominant in emerging markets than in more advanced economies. QE impacted a wide range of emerging markets assets such as, raising equity prices and compressing CDS spreads.

More (2013) analyzed the link between the fist two phases of the US QE and the capital flows into the emerging market economies (EMEs). He found that the decreases in the 10 year US Treasury yields lead to increased share of foreign ownership in emerging market debt. He concluded that this situation contributed to capital inflows to EMEs resulting to lowered government bond yields in these EMEs.

Fratzscher et al. (2013) analyzed the effects of US QE1 and US QE2 and the findings showed different impact for every phase. While Q1 resulted in capital outflows for EMEs the QE2 triggered a portfolio rebalancing to the opposite direction pushing capital to the EMEs.

2.6 Summary of the monetary policy of central banks

After the financial crisis of 2008 all central banks responded with the conventional monetary policies; established liquidity programs and lowered the interest rates almost to zero percent. However, the economy and financial markets did not show any sign of improvement. It then became evident for central banks that more drastic measures should be taken to fight mainly the stagnant economy and inflation which was below the target that they had put. Immediately the central banks of Europe, the United States, the United Kingdom took action by expanding their balance sheets and therefore the monetary base by implementing the so called quantitative easing (QE). QE allowed central banks to provide liquidity to the market and to ease the credit conditions even when interest rates were to zero lower bound.

The various empirical studies suggest that quantitative easing in general had the desired results as far as concerned the assets prices. However, the impact that QE had in the economy is more difficult to be measured for various reasons. We are not in position to answer what it would have yielded if no quantitative easing had taken place.

At the beginning the main purpose of the QE was to relief the market from financial distress but subsequently it was used to serve a variety of purposes. It was used to help central bank to meet their targeted inflation, to stimulate the real economy and in the case of Europe to help restrain the debt crisis.
Even though all four central banks expanded the monetary base with the implementation of QE, none of them managed to increase significally the broader monetary aggregates. The most possible explanation to this, is that during times of financial distress and economic uncertainty the banks prefer to hold the expanded monetary base in form of bank reserves rather than lending to companies and individuals.

2.7 Timeline of Quantitative Easing from the four Central Banks

FED Quantitative Easing Timeline	
DATE	**ACTION TAKEN**
November 2008	Quantitative Easing (QE1) starts- First Long scale asset Purchases (LSAPs), 100$ billion GSE debt, 100$ billion in MBS
December 2008	FED changes the in interest rate from 1% to 0.25%
March 2009	Fed extends LSAP program, 300$ billion in Treasury bills, 100$billion in GSE, 750$ billion in MBS
April 2010	End of quantitative easing (QE) 1
November 2010	Fed starts new round of quantitative easing QE 2, purchases of 600$ billion begins
June 2011	Fed ends QE 2
September 2011	Fed implements Operation Twist, total amount of 400$ billion
June 2012	Fed announces that it will extended the operation twist program until the end of 2012
September 2012	Fed announces the third round of QE , purchases of 40$ billion in MBS
December 2012	Fed expands the QE 3, monthly purchases of 45$ billion in Treasuries
January 2013	Fed starts the last round of QE the QE4 with purchases of Treasury bills of 85$ billion each month

ECB Quantitative Easing Timeline	
DATE	**ACTION TAKEN**
September 2012	ECB introduces Outright monetary transactions
July 2013	ECB presents forward guidance on interest rates
June 2014	ECB cuts interest rates below zero
September 2014	ECB announces Asset Backed Securities (ABS) and covered bond program
September 2015	ECB announces it plan to purchase large scale government bonds
March 2015	ECB starts the QE
March 2016	ECB increases the monthly purchases of government bonds and starts the purchase of corporate bonds also
April 2017	ECB announces that it will reduce the monthly purchases of QE
October 2017	ECB decides to cut the monthly purchases to half amounted at 30 billion euros and continue the program until September 2018

Japan Quantitative Easing Timeline	
DATE	**ACTION TAKEN**
December 2008	BOJ starts QE with monthly asset purchases amounted 1.4¥ and at the same time lowers the interest rate from 0.3% to 0.1%
February 2009	BOJ extends the QE program, it will also purchase 1¥ trillion in corporate bonds
March 2009	BOJ increases the amount of monthly asset purchases to 1.8¥ trillion and decides to run the program until the end of 2009
December 2009	BOJ announces that it will offer 10¥ trillion in 3 months loans against collateral
March 2010	BOJ expands FROs to 20¥ trillion
August 2010	BOJ expands FROs by adding another 10¥ trillion in 6 months loans
October 2010	BOJ starts Asset Purchase Programm. Another 3.5¥ trillion is added to Japanese Government Bonds
August 2011	BOJ expands again the Asset Purchase Program and FROs by 5¥ trillion
October 11- February 2012	BOJ expands the Asset Purchase Program for another 15¥ trillion
July 2012	BOJ reduces the size of FROs by 5¥ trillion and increases the Asset Purchase Program by another 10¥ trillion

Bank of England Quantitative Easing Timeline	
DATE	**ACTION TAKEN**
January 2009	BOE creates the Asset Purchase Facility with the intention to buy up to 50£ billion assets from the private sector
March 2009	BOE starts the QE with the purchases of assets up to 75£ billion
July 2009	BOE expands the asset purchase program with another 125£ billion
August 2009	BOE expands again the asset purchase program with another 175£ billion in gilts with maturity of more than 3 years
October 2011	BOE expands the QE by purchasing another 275£ billion in assets
February 2012	BOE expands the QE by purchasing another 325£ billion in assets
July 2012	BOE expands the QE by purchasing another 375£ billion in assets

CHAPTER 3: THE EMPIRICAL STUDY

The analysis

In our analysis we would like to examine if the Federal Reserve's Bank Large Asset Purcase Program (QE) had notable impact in financial and macroeconomic variables. In order to do so, we examine how the net purchases of Treasury bills affected these variables. At the beginning we examine our model without the impact of the quantitative easing (QE). To do so, we examine our sample until 1/1/2009, a date which the QE program was initiated. This will allow us two things i) to have our predictions for the financial and macroeconomic variables without the impact of QE and ii) to make the comparison between the two periods pre-QE and post-QE. In the second step, we estimate the impact of QE in the variables for the period after 1/1/2009. The "break" and the comparison between the two periods will give us the answer in the question how quick and how efficient was the impact of QE. The estimation in the second step will show us how statistically significant was the QE.

Data

The frequency of all our data is on a monthly basis. As financial variables we use the term spread of Treasury bills with maturity 1 year, 2 year, 5 year, 10 year and the S&P500. The term spread is the difference between the fed funds rate – the rate with which the Fed implements monetary policy by increasing and decreasing – and the bond. The S&P 500 is an index which is based on the 500 large American companies. It is considered to be a leading indicator in the economic cycles and it is one of the famous equities indexes. As macroeconomic variables we use inflation expectations 1 year (university of Michigan), headline Consumer Price Index and the Fed funds rate. Headline inflation measures the inflation as a total and it takes into consideration food and energy prices. Fed funds rate, as mentioned above, is the rate at which banks lend money to other banks on overnight basis. It is a very crucial rate in the economy of the United States and affects the decisions of the economic participants.

Finance Variables	Macroeconomic Variables
Term spread (1y Treasury – Fed funds rate)	Inflation expectations 1 year michigan
Term spread (2y Treasury – Fed funds rate)	Headline CPI y-o-y
Term spread (5y Treasury – Fed funds rate)	Fed funds rate
Term spread (10y Treasury -Fed funds rate)	
S&P 500 absolute return	

The methodology

In order to examine the impact of QE in our variables before and after the implementation we run a simple regression analysis $yi = a + bxi + \varepsilon i$ where y is the dependent variable – the variable we want to see if it is impacted from the asset purchases and xi is the net Treasury purchases. So we have the following regressions for the finance variables

Term spread 1year = a + b*(net assets purchases) + εi

Term spread 2year= a + b*(net assets purchases) + εi

Term spread 5year = a + b*(net assets purchases) + εi

Term spread 10year = a + b*(net assets purchases) + εi

S&500absolutereturn =a +b*(net assets purchases) + εi

And for the macroeconomic variables

Inflation = a+b*(net assets purchases) + εi

Headline CPI =a +b*(net assets purchases) + εi

Fedfundsrate= a+b*(net assets purchases) + εi

We run these regressions for two periods one before the implementation of the QE and one after the implementation of the QE. For every regression that we run the following hypothesis test applies

Null hypothesis Ho : b=0 which means that our variable has no impact on y variable
Altr. Hypothesis Ha: b≠0 which means that our variable impacts y variable

Regarding the p-values the notations is as follows

P < 0.05 *
P < 0.01 **
P < 0.001***

A p-value of P < 0.001*** indicates that the relationship between y and x variable is statistically highly significant.

Results

Interpreting P-values for the financial and macroeconomic variables.
The P-values and the coefficients of our regressions analysis will show us which relationships in our model are statistically significant and what is the nature of these relationships. The p-values that we got for our coefficients will indicate if these relationships are statistically significant. Furthermore, the coefficients will describe the relationship between our independent and dependent variable. The p-value for the independent variable tests the null hypothesis which is that the variable has no correlation with the dependent variable. In case of no correlation there is no relationship between the changes in the independent variable and the shifts in the dependent. In other words there is no sufficient evidence to conclude that there is an effect between these two variables. If the p-value

The P-value.

If the p-value of our variable is less than the significance level (the probability of rejecting the null hypothesis when it is actually true), then we can conclude that our sample provides enough evidence to reject the null hypothesis and our data favor that hypothesis that there is non zero correlation. On the other hand , a p - value that is greater than the significance level indicates that there is no sufficient evidence in our sample to conclude that a non zero correlation exists.

Interpretation of regression coefficients for linear relationships

The sign of the regression coefficient will reveal if there is a positive or negative relationship between the independent variable and the dependent one. A positive sign in the coefficient reveals that as the value of the dependent of the independent variable increases the mean of the dependent variable also tends to increase. On the other hand, a negative coefficient suggests that as the independent variable increases, the dependent variable tends to decrease.

P-values in our model.

As previously described, in order to understand if there is any significant relationship between assets purchases and financial and macroeconomic variables we "run" a simple regression model for two periods one before the implementation of the QE and one after the implementation of the QE. This comparison will reveal if there is any significant relationship between asset purchases and our dependent variables.

Financial variables-Results of P-values for the Post QE and the Pre QE period.

Post QE

Regarding the financial variables for the post QE period it is clearly evident from the regression results that the asset purchases had a significant impact in those variables. The p-value in the regression results for all these variables was below <0.001 (***) which proves that the QE was extremely significant impact to these variables. More analytically, the p-value for the termspread1y, termspread2y, termspread5y, termspread10y was below 0.001 (***) and for the S&P500 was 0.0203 (**)

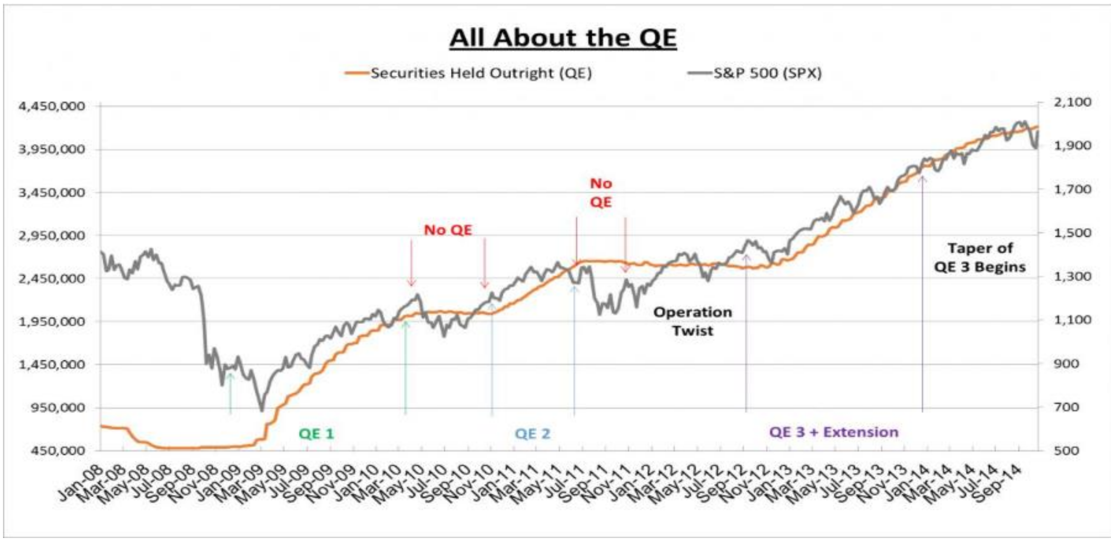
Pre QE

Regarding the financial variables for the pre QE period it seems that the asset purchases did not have significant impact to those variables. Out of five p-values only two were statistical significant with a p-value below <0.05. Termspread10y reveal a p-value of of <0.0896 (*) and S&P500 a p-value of <0.0178 (**).

Comparing the impact of the asset purchases in the financial variables between two periods we can safely conclude that the QE program clearly impacted the term spreads of 1year, 2year, 5 year, 10year and the S&P500.

Our findings regarding the impact of QE in the term spreads come in line with the findings of past literature on the effects of QE on asset prices and macroeconomic outcomes. Gagnon et al. (2011), D'Amico and King (2012) and Krishnamurthy and Vissing-Jorgensen (2011) showed that the first US large scale asset purchases program caused a statistically significant decline of about 30-90 basis point in Treasury yields. On the same page, Meier (2009) and Joyce et al. (2011) find a decline of UK gilt yields of about 40-100 basis points as result asset purchases by the Bank of England.

Regarding the S&P500 the results of our model reconfirm that indeed the implementation of the QE impacted the stock market. As shown from the below diagram, after the implementation of every phase of QE (QE1, QE2, QE3) the stock market showed an upward trend. When FED announced to purchase 600$ billion in Mortgage Backed Securities (MBS) the S&P 500 index rose approximately 70%. Again when at the end of 2010 the chairman of FED signaled to launch another round of QE markets rose approximately 18%. With the initiation of QE3, S&P 500 responded by following its upward trend like the previous two rounds of the QE.



S&P500 Index (source: Bloomberg)

When it comes to theory, low rates can boost equity prices in the long term. When using a lower discount rate, investors can anticipate an increase in the present value of the future cashflows which in turn boost the stock market. A dividend pricing model in its simplest form states that today's stock price should move in the opposite direction to the discount rate. As the yield on fixed income assets decline, investor may look into other assets classes in order to gain higher yields. This shift will increase the demand for these assets and therefore their price. Furthermore, as yields in fixed income securities decline corporate profits may increase through lower debt payments and stronger economic growth.

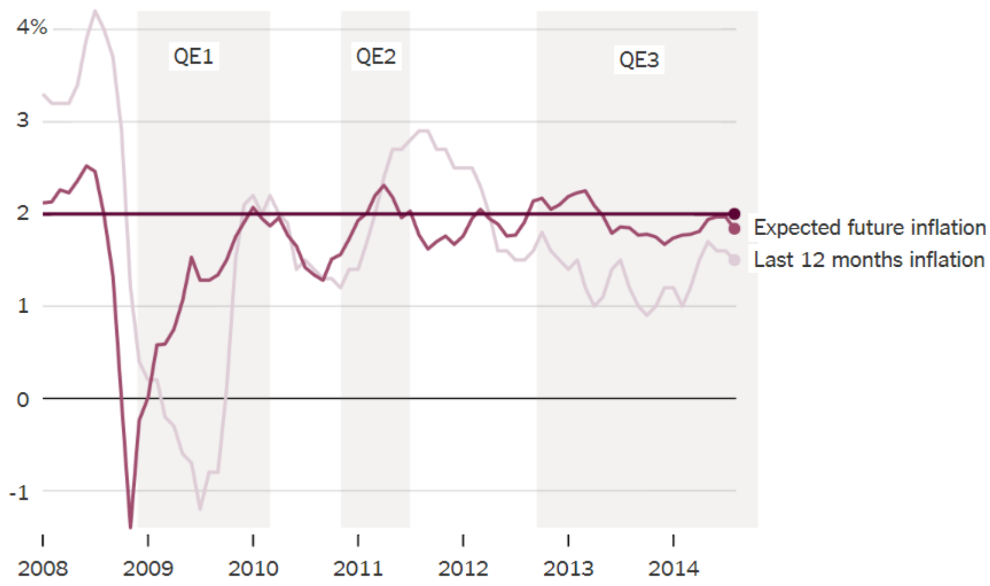
Macroeconomic variables – Results of P-values for the Post QE and Pre QE period.

Regarding our macroeconomic variables for the post QE period, two out three are extremely significant with a p value below <0.001 (***). One year inflation expectation from university of Michigan reveal a p-value of <0.001(***) and the headline CPI a p-value of 0.0022 (***) . Fed funds rate show no statistical significance as it reveals a p-value of 0.7278.

In the pre QE period, one year inflation expectations from university of Michigan shows no statistical significance like the Fed funds rate with p-values 0.1945 and

0.9884 respectively. On the other hand, Headline CPI is statistical significant with a p-value of 0.0025.

Even though the QE rounds affected the inflation expectations as it is depicted in the below diagram FED was unable to meet its target rate for inflation of 2% percent except for occasional periods. QE1 had the greatest impact in inflation expectations but overall the rounds of QE had not been powerful enough to generate as much inflation as the Fed mentioned that it wanted.



Expected future inflation and last 12 month inflation (source: Federal Reserve, Bureau of Economic Analysis)

The problem of autocorrelation.

One of the classical assumptions of the ordinary least squares process (OLS) is that the observations of the error term are independent of each other. Each error term observation must not be correlated with the error term observation that is next to it. If this assumption does not hold and the error term observations are correlated, autocorrelation is present.

The Durbin Watson Test

The Durbin-Watson statistic provides a test for first order autocorrelation only. It is computed by the following formula

$$\text{D.W.} = \frac{(\hat{e}_2 - \hat{e}_1)^2 + (\hat{e}_3 - \hat{e}_2)^2 + (\hat{e}_4 - \hat{e}_3)^2 + \cdots + (\hat{e}_n - \hat{e}_{n-1})^2}{\hat{e}_1^2 + \hat{e}_2^2 + \hat{e}_3^2 + \cdots + \hat{e}_n^2}$$

The numerator is computed by starting with the second error term observation, finding the difference between the current error term observation ê2 and the preceding time period's error term observation, ê1: (ê2-ê1) and squaring the difference. We repeat the procedure for all time periods and at the end we sum as the formula below shows

$$(\hat{e}_2 - \hat{e}_1)^2 + (\hat{e}_3 - \hat{e}_2)^2 + (\hat{e}_4 - \hat{e}_3)^2 + \cdots + (\hat{e}_n - \hat{e}_{n-1})^2$$

In order to compute the denominator we take each error term observation and square it ê1^ 2, ê2 ^2, ê3^ 2 and add it. One important note is that the Durbin Watson statistic is equal to 2-2p. From this relationship useful conclusions can be derived. If p equals zero then autocorrelation does not exist. As result, Durbin Watson statistic equals 2 when no autocorrelation exists. The worst case scenario happens when autocorrelation (p) is close to +1 . When p is close to +1 then the Durbin Watson statistic will be equal to 2-2*p = 2-(2)*1=0. From this relationship can be understood that the more closer to zero is the Durbin Watson statistic is the more likely is that positive autocorrelation exists. The second worst scenario negative autocorrelation. This scenario occurs when p is close to -1. When p equals to -1 then the Durbin Watson statistic will be 2-2*(-1)= 4. So, when Durbin Watson statistic is close to 4 the chance for negative autocorrelation increase. Summing up the Durbin Watson statistic value varies from 0 to 4 with values closer to 0 indicating positive autocorrelation and with values closer to 2 indicating no autocorrelation an lastly with values close to 4 indicating negative autocorrelation.

Hypothesis testing on Durbin Watson.

Unlike most hypothesis tests that use critical value to separate the regions when the null hypothesis test is accepted or rejected the Durbin Watson statistic has three regions i) reject the null hypothesis ii)do not reject the null hypothesis and iii) an inconclusive region.
When testing for positive autocorrelation we use the Durbin Watson statistic to test:

$$H_0: \rho \leq 0$$
$$H_A: \rho > 0$$

In that case this is a one side test in which the null hypothesis is the one of no autocorrelation versus the alternative hypothesis of positive autocorrelation.
When testing for negative autocorrelation the null and alternative hypothesis are the following:

$$H_0: \rho \geq 0$$
$$H_A: \rho < 0$$

Results of Durbin Watson in our model.

Financial variables

As it shown in the below table regarding the Durbin Watson statistic our models seems to show autocorrelation in the residuals in both periods, before the implementation of the QE and after the implementation of QE. The Durbin Watson statistic for the financial variables (spread1y, spread2y, spread5y, spread10y and S&P500) ranges from 0.0321 for spread1y to 0.3534 for the spread10y. As mentioned above, when the Durbin Watson statistic ranges between 0-2 is sign of positive autocorrelation, between 2-4 is sign of negative autocorrelation and values close to 2 is sign of no autocorrelation. As result, our model shows signs of positive autocorrelation. Furthermore, rho in all variables is pretty close to 1 (above 0.8 in all instances).

	spread1y		spread2y		spread5y		spread10y		S&P 500	
	DW	rho	DW	rho	DW	rho	DW	rho	DW	rho
pre QE	0.032136	0.996779	0.068231	0.97567	0.162364	0.94015	0.353412	0.854332	0.113924	0.937767
post QE	0.111588	0.872757	0.32937	0.80913	0.270309	0.858528	0.2475	0.870817	0.047689	0.961426

Macroeconomic Variables.

Also our macroeconomics variables show signs of autocorrelation. The Durbin Watson statistic ranges from 0.01688 for the fed funds rate variable to 0.564043 for the inflation_mich_1y. Furthermore, rho approaches 1 indication positive autocorrelation in all variables

	inflation_mich_1y		headline cpi		feds fund rate	
	DW	rho	DW	rho	DW	rho
pre QE	0.564043	0.696828	0.104936	0.965411	0.016877	0.99146
post QE	0.360727	0.817278	0.038103	0.972945	0.198131	0.866933

The solution to “fight” autocorrelation.

Lagged dependent variable

A lagged dependent variable in an ordinary least square model (OLS) is often used in order to overcome the problem of autocorrelation. In a multiple regression model with current and past values (lags) of X used as explanatory variables is shown by the equation:

$$Yt = \alpha + \beta_0 X_t + \beta_1 X_{t-1} + \ldots + \beta q Xt\text{-}q + e_t$$

Where q = lag length = lag order

and

Xt is the value of the variable in period t. X_{t-1} is the value of the variable in period t-1 or "lagged one period" or "lagged X".

Defining X and lagged X

X"	"lagged X"
X_2	X_1
X_3	X_2
.	
.	
.	
.	
X_T	X_{T-1}

Both columns will have T-1 and as a general rule when creating X lagged q periods, the observations will be T-q.

Lagged dependent variable in our model

Since in our model there seems to be significant autocorrelation in the residuals (high rho in the regressions), we will include the lagged dependent variable in the regressions. As lag period we use one month t-1. By doing so, it helped us to reduce the occurrence of autocorrelation from model specification. Thus the use of lagged dependent variables helped to defend the existence of autocorrelation on the model.

By using the lagged dependent variable in our model rho drops significant for both periods, pre QE and post QE compared to the initial model in which we do not include the dependent lagged variable. More specifically, the rho ranges from -0.237122 for the spread2y to 0.019554 for the spread10y.

	spread1y	spread2y	spread5y	spread10y	S&P 500
pre QE-rho	0.580002	0.256305	0.127279	0.116218	0.367787
post QE- rho	−0.011785	−0.237122	−0.067715	0.019554	−0.191343

Although lagged dependent variable is used as a method to overcome the model of autocorrelation, many studies contend that the lagged dependent variable is sometimes problematic in several situations. More characteristically ,when residual autocorrelation exists, the lagged dependent variable causes the coefficients for explanatory variables to be biased downward (Dynamic Models for Dynamic Theories: The Ins and Outs of Lagged Dependent Variables Luke Keely and Nathan J. Kelly ,2005)

Summary Table Pre QE and Post QE plus lagged dependent variable 1 year

	spread1y	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		3.01027	1.08E-05	-	0.000629	0.032136	0.996779		0.3103
post QE		0.175704	1.12E-06	-	0.168032	0.111588	0.872757		0.0001(***)
lag 1year	pre QE	−0.00527177	7.09E-07	0.998162	0.974733	-	0.580002	4.95354	
	post QE	0.0153705	−6.96692e-08	0.927213	0.945924	-	−0.011785	−0.105478	
	spread2y	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		3.17056	1.11E-05	-	0.006647	0.068231	0.97567		0.2286
post QE		0.393304	2.38E-06	-	0.196215	0.329365	0.809133		<0.0001
lag 1year	pre QE	0.0333979	−1.53131e-06	0.986153	0.946968	-	0.256305	2.223374	
	post QE	0.0585382	5.22E-07	0.824641	0.79007		−0.237122	−2.373425	
	spread5y	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		3.7099	9.09E-06	-	0.019557	0.162364	0.94015		0.1246
post QE		1.2196	5.90E-06	-	0.256747	0.270309	0.858528		<0.0001
lag 1year	pre QE	0.141347	−1.40076e-06	0.95836	0.861966	-	0.127279	1.166618	
	post QE	0.133518	1.77E-06	0.849397	0.862939	-	−0.067715	−0.643036	

	spread10y	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		4.25094	6.21E-06	-	0.026906	0.353412	0.854332		0.0896
post QE		2.22054	7.50E-06	-	0.320625	0.2475	0.870817		<0.0001
lag 1year	pre QE	0.550508	1.00E-07	0.86802	0.683163	-	0.116218	1.236507	
	post QE	0.266738	2.26E-06	0.849735	0.888726	-	0.019554	0.183228	

	S&P 500	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		1214.67	−0.00295054	-	0.06441	0.113924	0.937767		0.0178
post QE		1554.44	−0.0019861	-	0.05659	0.047689	0.961426		0.0203
lag 1year	pre QE	41.6339	−0.000104284	0.965694	0.931095	-	0.367787	3.22442	
	post QE	14.6466	0.000201307	0.995656	0.982585	-	−0.191343	−1.673013	

	inflation_mich_1y	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		2.96626	−4.22509e-06		0.009979	0.564043	0.696828		0.1945
post QE		2.94765	5.66E-06		0.162739	0.360727	0.817278		<0.0001
lag 1year	pre QE	0.745798	−8.87362e-06	0.761844	0.72228		0.080929	0.834435	
	post QE	0.824028	4.83E-07	0.726922	0.555474		−0.068445	−0.779180	

	headline cpi	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		192.948	−0.000204108		0.111129	0.104936	0.965411		0.0025
post QE		227.726	−5.58332e-05		0.093837	0.038103	0.972945		0.0022
lag 1year	pre QE	−0.578485	5.15E-07	1.00456	0.999506		0.211103	1.779303	
	post QE	−1.09864	1.47E-07	1.00617	0.999549		0.382582	3.314093	

	feds fund rate	a	b	c (t-1)	adj R-Squared	DW	rho	Durbin's h	p-value
pre QE		2.91803	−1.75028e-07		-0.014283	0.016877	0.99146		0.9884
post QE		0.125999	3.33E-08		-0.011844	0.198131	0.866933		0.7278
lag 1year	pre QE	−0.0243445	4.77E-06	1.00585	0.984836		0.544442	4.624209	
	post QE	0.017126	−9.50465e-08	0.892011	0.823536		0.094612	0.900596	

Conclusion

After the financial crisis of 2008 central banks responded with the conventional monetary tools in order to cure the financial markets and avoid financial distress. Despite the conventional monetary tools that were implemented the markets did not respond appropriately. It became evident for the central banks that unconventional measures like the quantitative easing should be implemented. When a central bank purchases predetermined amount assets from other institutions and commercial banks the price of those assets rises and their yield falls and at the same time the monetary base is increased.

Overall the implementation of the QE by the four central banks had positive affects not only in the financial assets but also at the domestic economies. The topic of unconventional monetary policy was, is and will be colossal topic in the economic theory as it involves the biggest interventions of the central's banks in the economy.

Appendix 1

Regression results

Summary table Breusch Godfrey test

spread1y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.0154702	0.00938911	1.648	0.1037	0.771657
assetpurchasesnet	−2.95672e-07	1.35E-07	−2.185	0.0321**	
uhat_1	0.89006	0.0566682	15.71	4.09E-25***	

spread2y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.0109692	0.0225075	0.4874	0.6275	0.648629
assetpurchasesnet	−1.76732e-07	3.23E-07	−0.5470	0.586	
uhat_1	0.81106	0.0698677	11.61	3.02E-18***	

spread5y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	−0.00609827	0.0410985	−0.1484	0.8825	0.734458
assetpurchasesnet	1.87E-07	5.90E-07	0.3168	0.7523	
uhat_1	0.859001	0.0604527	14.21	1.03E-22***	

spread10y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	−0.0138391	0.0428646	−0.3229	0.7477	0.758552
assetpurchasesnet	2.59E-07	6.15E-07	0.4209	0.6751	
uhat_1	0.871495	0.057547	15.14	3.16E-24***	

S&P 500	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	−17.2523	17.8779	−0.9650	3.38E-01	0.905171
assetpurchasesnet	0.000493858	0.000260387	1.897	0.0617*	
uhat_1	0.966612	0.0361267	26.76	4.16E-40***	

headline cpi	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	−0.122914	0.292963	−0.4196	0.6759	0.935103
assetpurchasesnet	5.17E-06	4.52E-06	1.143	0.2564	
uhat_1	0.974133	0.0278351	35	2.95E-52***	

inflation_mich_1y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.0175308	0.0501692	0.3494	0.7276	0.66858
assetpurchasesnet	−4.54382e-07	7.75E-07	−0.5863	0.5592	
uhat_1	0.81893	0.0625389	13.09	4.34E-22***	

fedfundsrate	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.005109	0.00324389	1.575	0.1196	0.767601
assetpurchasesnet	−1.05726e-07	4.68E-08	−2.259	0.0269**	
uhat_1	0.885675	0.0570378	15.53	7.8E-25***	

Summary table White test

spread1y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.00621019	0.00373337	1.663	0.1005	0.10054
assetpurchasesnet	2.47E-07	1.08E-07	2.28	0.0255**	
sq_assetspurchas~	−8.67656e-013	7.17E-13	−1.211	0.2299	

spread2y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.0258363	0.0106828	2.418	0.0181**	0.15792
assetpurchasesnet	1.11E-06	3.10E-07	3.571	0.0266**	
sq_assetspurchas~	−5.54557e-012	2.05E-12	−2.705	0.0085***	

spread5y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.149012	0.0472156	3.156	0.0023***	0.086945
assetpurchasesnet	3.49E-06	1.37E-06	2.548	0.0129**	
sq_assetpurchase~	−1.75424e-11	9.06E-12	−1.936	0.0568*	

spread10y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.205654	0.0620339	3.315	0.0014***	0.040093
assetpurchasesnet	1.11E-06	3.10E-07	3.571	0.0006***	
sq_assetspurchas~	−5.54557e-012	2.05E-12	−2.705	0.0085***	

S&P 500	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	155944	17472.6	8.925	2.07E-13	0.058945
assetpurchasesnet	−0.574962	0.516286	−1.114	2.69E-01	
sq_assetpurchase~	4.09E-07	3.43E-06	0.119	9.06E-01	

headline cpi	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	73.6509	6.53458	11.27	1.49E-18**	0.058945
assetpurchasesnet	−3.32459e-05	2.09E-04	−0.1588	0.8742	
sq_assetpurchase~	−1.90087e-09	1.43E-09	−1.327	1.88E-01	

inflation_mich_1y	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.245328	0.0968633	2.533	0.0132**	0.050915
assetpurchasesnet	2.48E-06	3.10E-06	0.7998	0.426	
sq_assetpurchase~	4.36E-12	2.12E-11	0.2051	8.38E-01	

fedfundsrate	coefficient	std.error	t-ratio	p-value	unadjusted R squared
const	0.00172126	0.000281552	6.113	0.0000000436***	0.014729
assetpurchasesnet	2.68E-09	8.17E-09	0.3284	0.7435	
sq_assetpurchase~	0	0	−0.7541	4.53E-01	

Summary table Unit ADF test

	(a - 1)	tau_nc(1)	asymptotic p-value	1st-order autocorrelation coeff. for e
assetpurchasesnet	-0.09716	-2.67297	0.007294	-0.054
spread1y	-0.0369	-2.85078	0.004903	0.037
spread2y	-0.04273	-1.68662	0.08684	0.021
spread5y	-0.01439	-0.88325	0.3302	-0.055
spread10y	-0.00834	-0.80285	0.365	0.03
S&P500	-0.16472	-2.60062	0.2814	-0.067
inflation_mich_1y	-0.00103	-0.09835	0.6499	-0.003
headlinecpi	-0.04731	-2.10641	0.5417	-0.062
fedsfundrate	-0.02149	-1.40449	0.1479	0.103

FINANCIAL VARIABLES

Term spread 1y -→ 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: termspread1y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	3.01027	0.180155	16.7093	<0.0001	***
assetpurchasesnet	1.07708e-05	1.0538e-05	1.0221	0.3103	

Mean dependent var	2.991528	S.D. dependent var	1.521208
Sum squared resid	161.8834	S.E. of regression	1.520730
R-squared	0.014704	Adjusted R-squared	0.000629
F(1, 70)	1.044668	P-value(F)	0.310258
Log-likelihood	−131.3311	Akaike criterion	266.6623
Schwarz criterion	271.2156	Hannan-Quinn	268.4750
rho	0.996779	Durbin-Watson	0.032136

Term spread 1y -→ 2nd period

Model 1: OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: termspread1y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.175704	0.0194077	9.0533	<0.0001	***
assetpurchasesnet	1.11918e-06	2.78514e-07	4.0184	0.0001	***

Mean dependent var	0.230526	S.D. dependent var	0.131928
Sum squared resid	1.071553	S.E. of regression	0.120335
R-squared	0.179125	Adjusted R-squared	0.168032
F(1, 74)	16.14770	P-value(F)	0.000139
Log-likelihood	54.10240	Akaike criterion	−104.2048
Schwarz criterion	−99.54333	Hannan-Quinn	−102.3418
rho	0.872757	Durbin-Watson	0.111588

Term spread 2y → 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: termspread2y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	3.17056	0.155665	20.3679	<0.0001	***
assetpurchasesnet	1.10589e-05	9.10546e-06	1.2145	0.2286	

Mean dependent var	3.151321	S.D. dependent var	1.318389
Sum squared resid	120.8617	S.E. of regression	1.314000
R-squared	0.020638	Adjusted R-squared	0.006647
F(1, 70)	1.475098	P-value(F)	0.228624
Log-likelihood	−120.8109	Akaike criterion	245.6218
Schwarz criterion	250.1751	Hannan-Quinn	247.4345
rho	0.975670	Durbin-Watson	0.068231

Term spread 2y → 2nd period

Model 1: OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: termspread2y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.393304	0.0376797	10.4381	<0.0001	***
assetpurchasesnet	2.37604e-06	5.4073e-07	4.3941	<0.0001	***

Mean dependent var	0.509692	S.D. dependent var	0.260588
Sum squared resid	4.039069	S.E. of regression	0.233628
R-squared	0.206932	Adjusted R-squared	0.196215
F(1, 74)	19.30850	P-value(F)	0.000037
Log-likelihood	3.679998	Akaike criterion	−3.359996
Schwarz criterion	1.301470	Hannan-Quinn	−1.497049

rho	0.809133	Durbin-Watson	0.329365

Term spread 5y → 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: termspread5y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	3.7099	0.0999416	37.1207	<0.0001	***
assetpurchasesnet	9.08713e-06	5.846e-06	1.5544	0.1246	

Mean dependent var	3.694092	S.D. dependent var	0.852002
Sum squared resid	49.81982	S.E. of regression	0.843630
R-squared	0.033366	Adjusted R-squared	0.019557
F(1, 70)	2.416219	P-value(F)	0.124594
Log-likelihood	−88.90646	Akaike criterion	181.8129
Schwarz criterion	186.3663	Hannan-Quinn	183.6256
rho	0.940150	Durbin-Watson	0.162364

Term spread 5y → 2nd period

Model 1: OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: termspread5y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1.2196	0.0792102	15.3970	<0.0001	***
assetpurchasesnet	5.89648e-06	1.13672e-06	5.1873	<0.0001	***

Mean dependent var	1.508434	S.D. dependent var	0.569679
Sum squared resid	17.84965	S.E. of regression	0.491133
R-squared	0.266657	Adjusted R-squared	0.256747
F(1, 74)	26.90775	P-value(F)	1.80e-06
Log-likelihood	−52.78684	Akaike criterion	109.5737
Schwarz criterion	114.2352	Hannan-Quinn	111.4366
rho	0.858528	Durbin-Watson	0.270309

Term spread 10y -→ 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: termspread10y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	4.25094	0.0616699	68.9306	<0.0001	***
assetpurchasesnet	6.20957e-06	3.60733e-06	1.7214	0.0896	*

Mean dependent var	4.240139	S.D. dependent var	0.527718
Sum squared resid	18.96951	S.E. of regression	0.520570
R-squared	0.040611	Adjusted R-squared	0.026906
F(1, 70)	2.963131	P-value(F)	0.089600
Log-likelihood	−54.14558	Akaike criterion	112.2912
Schwarz criterion	116.8445	Hannan-Quinn	114.1039
rho	0.854332	Durbin-Watson	0.353412

Term spread 10y -→ 2nd period

Model 1: OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: termspread10y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	2.22054	0.0866232	25.6345	<0.0001	***
assetpurchasesnet	7.49949e-06	1.2431e-06	6.0329	<0.0001	***

Mean dependent var	2.587895	S.D. dependent var	0.651624
Sum squared resid	21.34693	S.E. of regression	0.537096
R-squared	0.329684	Adjusted R-squared	0.320625
F(1, 74)	36.39565	P-value(F)	5.86e-08
Log-likelihood	−59.58597	Akaike criterion	123.1719
Schwarz criterion	127.8334	Hannan-Quinn	125.0349
rho	0.870817	Durbin-Watson	0.247500

S&P 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: SP

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1214.67	20.7878	58.4317	<0.0001	***
assetpurchasesnet	−0.00295054	0.00121597	−2.4265	0.0178	**

Mean dependent var	1219.801	S.D. dependent var	181.4144
Sum squared resid	2155397	S.E. of regression	175.4747
R-squared	0.077587	Adjusted R-squared	0.064410
F(1, 70)	5.887909	P-value(F)	0.017824
Log-likelihood	−473.2091	Akaike criterion	950.4181
Schwarz criterion	954.9715	Hannan-Quinn	952.2308
rho	0.937767	Durbin-Watson	0.113924

S&P 2st period

Model 1: OLS, using observations 2009:02-2015:07 (T = 78)
Dependent variable: SP

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	1554.44	57.6351	26.9703	<0.0001	***
assetpurchasesnet	−0.0019861	0.000837873	−2.3704	0.0203	**

Mean dependent var	1459.433	S.D. dependent var	376.6049
Sum squared resid	10169180	S.E. of regression	365.7937
R-squared	0.068842	Adjusted R-squared	0.056590
F(1, 76)	5.618827	P-value(F)	0.020305
Log-likelihood	−570.0256	Akaike criterion	1144.051

Schwarz criterion	1148.765	Hannan-Quinn	1145.938
rho	0.961426	Durbin-Watson	0.047689

MACRO VARIABLES

inflation

inflation 1st period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: infl_1y_mich

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	2.96626	0.0551456	53.7896	<0.0001	***
assetpurchasesnet	−4.22509e-06	3.2257e-06	−1.3098	0.1945	

Mean dependent var	2.973611	S.D. dependent var	0.467837
Sum squared resid	15.16811	S.E. of regression	0.465497
R-squared	0.023923	Adjusted R-squared	0.009979
F(1, 70)	1.715635	P-value(F)	0.194538
Log-likelihood	−46.09461	Akaike criterion	96.18922
Schwarz criterion	100.7426	Hannan-Quinn	98.00191
rho	0.696828	Durbin-Watson	0.564043

inflation 2nd period

Model 1: OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: infl_1y_mich

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	2.94765	0.086607	34.0347	<0.0001	***
assetpurchasesnet	5.65808e-06	1.33696e-06	4.2320	<0.0001	***

Mean dependent var	3.187500	S.D. dependent var	0.671388

Sum squared resid	32.45684	S.E. of regression	0.614333
R-squared	0.172362	Adjusted R-squared	0.162739
F(1, 86)	17.91022	P-value(F)	0.000058
Log-likelihood	−80.97987	Akaike criterion	165.9597
Schwarz criterion	170.9144	Hannan-Quinn	167.9558
rho	0.817278	Durbin-Watson	0.360727

Headline CPI period 1

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: headlineCPI

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	192.948	1.11031	173.7783	<0.0001	***
assetpurchasesnet	−0.000204108	6.49466e-05	−3.1427	0.0025	***

Mean dependent var	193.3028	S.D. dependent var	9.941010
Sum squared resid	6148.904	S.E. of regression	9.372379
R-squared	0.123648	Adjusted R-squared	0.111129
F(1, 70)	9.876622	P-value(F)	0.002455
Log-likelihood	−262.2686	Akaike criterion	528.5373
Schwarz criterion	533.0906	Hannan-Quinn	530.3500
rho	0.965411	Durbin-Watson	0.104936

Headline CPI period 2

Model 1: OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: headlineCPI

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	227.726	1.14322	199.1980	<0.0001	***
assetpurchasesnet	−5.58332e-05	1.76479e-05	−3.1637	0.0022	***

Mean dependent var	225.3594	S.D. dependent var	8.518746
Sum squared resid	5655.308	S.E. of regression	8.109217
R-squared	0.104252	Adjusted R-squared	0.093837
F(1, 86)	10.00917	P-value(F)	0.002153
Log-likelihood	−308.0392	Akaike criterion	620.0783
Schwarz criterion	625.0330	Hannan-Quinn	622.0744
rho	0.972945	Durbin-Watson	0.038103

Fed funds rate 1 period

Model 1: OLS, using observations 2003:02-2009:01 (T = 72)
Dependent variable: fedfundsrate

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	2.91803	0.205162	14.2230	<0.0001	***
assetpurchasesnet	−1.75028e-07	1.20008e-05	−0.0146	0.9884	

Mean dependent var	2.918333	S.D. dependent var	1.719586
Sum squared resid	209.9448	S.E. of regression	1.731823
R-squared	0.000003	Adjusted R-squared	-0.014283
F(1, 70)	0.000213	P-value(F)	0.988405
Log-likelihood	−140.6900	Akaike criterion	285.3800
Schwarz criterion	289.9333	Hannan-Quinn	287.1927
rho	0.991460	Durbin-Watson	0.016877

Feds funds rate 2nd period

Model 1: OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: fedfundsrate

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.125999	0.00664888	18.9504	<0.0001	***
assetpurchasesnet	3.33365e-08	9.54161e-08	0.3494	0.7278	

Mean dependent var	0.127632	S.D. dependent var	0.040984
Sum squared resid	0.125766	S.E. of regression	0.041226
R-squared	0.001647	Adjusted R-squared	-0.011844

F(1, 74)	0.122067	P-value(F)	0.727796
Log-likelihood	135.5151	Akaike criterion	−267.0302
Schwarz criterion	−262.3687	Hannan-Quinn	−265.1672
rho	0.866933	Durbin-Watson	0.198131

Appendix 2

Regressions with lagged dependent variables

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: termspread1y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.00527177	0.0656337	−0.08032	0.9362	
assetspurchasesnet	7.09324e-07	1.68546e-06	0.4208	0.6752	
termspread1y_1	0.998162	0.0193602	51.56	<0.0001	***

Mean dependent var	3.015352	S.D. dependent var	1.518447
Sum squared resid	3.961548	S.E. of regression	0.241367
R-squared	0.975455	Adjusted R-squared	0.974733
F(2, 68)	1351.197	P-value(F)	1.82e-55
Log-likelihood	1.709963	Akaike criterion	2.580074
Schwarz criterion	9.368114	Hannan-Quinn	5.279462
rho	0.580002	Durbin's h	4.953540

Model 2: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: termspread1y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0153705	0.00675457	2.276	0.0258	**
assetspurchasesnet	−6.96692e-08	7.71207e-08	−0.9034	0.3693	
termspread1y_1	0.927213	0.0291692	31.79	<0.0001	***

Mean dependent var	0.225333	S.D. dependent var	0.124752
Sum squared resid	0.060595	S.E. of regression	0.029010
R-squared	0.947385	Adjusted R-squared	0.945924
F(2, 72)	648.2191	P-value(F)	9.12e-47
Log-likelihood	160.6185	Akaike criterion	−315.2370
Schwarz criterion	−308.2845	Hannan-Quinn	−312.4610
rho	−0.011785	Durbin's h	−0.105478

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: termspead2y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0333979	0.0973601	0.3430	0.7326	
assetspurchasesnet	−1.53131e-06	2.12877e-06	−0.7193	0.4744	
termspead2y_1	0.986153	0.0282064	34.96	<0.0001	***

Mean dependent var	3.174354	S.D. dependent var	1.313103
Sum squared resid	6.217953	S.E. of regression	0.302391
R-squared	0.948483	Adjusted R-squared	0.946968
F(2, 68)	625.9740	P-value(F)	1.61e-44
Log-likelihood	−14.29365	Akaike criterion	34.58730
Schwarz criterion	41.37534	Hannan-Quinn	37.28668
rho	0.256305	Durbin's h	2.223374

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: termspread2y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0585382	0.0298353	1.962	0.0536	*
assetspurchasesnet	5.22474e-07	3.02148e-07	1.729	0.0881	*
termspread2y_1	0.824641	0.0578957	14.24	<0.0001	***

Mean dependent var	0.503395	S.D. dependent var	0.256455
Sum squared resid	0.994099	S.E. of regression	0.117503
R-squared	0.795743	Adjusted R-squared	0.790070
F(2, 72)	140.2490	P-value(F)	1.47e-25
Log-likelihood	55.70734	Akaike criterion	−105.4147
Schwarz criterion	−98.46222	Hannan-Quinn	−102.6386
rho	−0.237122	Durbin's h	−2.373425

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: termspread5y

	Coefficient	Std. Error	t-ratio	p-value	
const	0.141347	0.178681	0.7911	0.4317	
assetspurchasesnet	−1.40076e-06	2.24837e-06	−0.6230	0.5354	
termspread5y_1	0.958360	0.0467072	20.52	<0.0001	***

Mean dependent var	3.708580	S.D. dependent var	0.849087
Sum squared resid	6.767065	S.E. of regression	0.315461
R-squared	0.865909	Adjusted R-squared	0.861966
F(2, 68)	219.5599	P-value(F)	2.15e-30
Log-likelihood	−17.29789	Akaike criterion	40.59579
Schwarz criterion	47.38383	Hannan-Quinn	43.29517
rho	0.127279	Durbin's h	1.166618

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: termspead5y

	Coefficient	Std. Error	t-ratio	p-value	
const	0.133518	0.0691824	1.930	0.0576	*
assetspurchasesnet	1.77280e-06	5.41011e-07	3.277	0.0016	***
termspread5y_1	0.849397	0.0473722	17.93	<0.0001	***

Mean dependent var	1.502005	S.D. dependent var	0.570734
Sum squared resid	3.214507	S.E. of regression	0.211296
R-squared	0.866643	Adjusted R-squared	0.862939
F(2, 72)	233.9521	P-value(F)	3.17e-32
Log-likelihood	11.69764	Akaike criterion	−17.39528
Schwarz criterion	−10.44282	Hannan-Quinn	−14.61924
rho	−0.067715	Durbin's h	−0.643036

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: termspead10y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.550508	0.311601	1.767	0.0818	*
assetspurchasesnet	1.00150e-07	2.12349e-06	0.04716	0.9625	
termspead10y_1	0.868020	0.0724613	11.98	<0.0001	***

Mean dependent var	4.247606	S.D. dependent var	0.527629
Sum squared resid	5.997948	S.E. of regression	0.296993
R-squared	0.692216	Adjusted R-squared	0.683163
F(2, 68)	76.46691	P-value(F)	3.98e-18
Log-likelihood	−13.01482	Akaike criterion	32.02963
Schwarz criterion	38.81767	Hannan-Quinn	34.72902
rho	0.116218	Durbin's h	1.236507

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: termspread10y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.266738	0.107005	2.493	0.0150	**
assetspurchasesnet	2.26275e-06	5.74023e-07	3.942	0.0002	***
termspread10y_1	0.849735	0.0440956	19.27	<0.0001	***

Mean dependent var	2.582133	S.D. dependent var	0.654061
Sum squared resid	3.427367	S.E. of regression	0.218180
R-squared	0.891734	Adjusted R-squared	0.888726
F(2, 72)	296.5139	P-value(F)	1.74e-35
Log-likelihood	9.293206	Akaike criterion	−12.58641
Schwarz criterion	−5.633948	Hannan-Quinn	−9.810370
rho	0.019554	Durbin's h	0.183228

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: fedfundsrate

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	−0.0243445	0.0507313	−0.4799	0.6329	
assetspurchasesnet	4.77098e-06	1.47018e-06	3.245	0.0018	***
fedfundsrate_1	1.00585	0.0149146	67.44	<0.0001	***

Mean dependent var	2.941690	S.D. dependent var	1.720285
Sum squared resid	3.051535	S.E. of regression	0.211838
R-squared	0.985269	Adjusted R-squared	0.984836
F(2, 68)	2274.125	P-value(F)	5.24e-63
Log-likelihood	10.97511	Akaike criterion	−15.95022
Schwarz criterion	−9.162177	Hannan-Quinn	−13.25083
rho	0.544442	Durbin's h	4.624209

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: fedfundsrate

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.0171260	0.00637727	2.685	0.0090	***
assetspurchasesnet	−9.50465e-08	3.93664e-08	−2.414	0.0183	**
fedfundsrate_1	0.892011	0.0479252	18.61	<0.0001	***

Mean dependent var	0.126400	S.D. dependent var	0.039819
Sum squared resid	0.020145	S.E. of regression	0.016727
R-squared	0.828306	Adjusted R-squared	0.823536
F(2, 72)	173.6748	P-value(F)	2.83e-28
Log-likelihood	201.9162	Akaike criterion	−397.8324
Schwarz criterion	−390.8799	Hannan-Quinn	−395.0564
rho	0.094612	Durbin's h	0.900596

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: SP500

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	41.6339	40.3733	1.031	0.3061	
assetspurchasesnet	−0.000104284	0.000335425	−0.3109	0.7568	
SP500_1	0.965694	0.0327746	29.46	<0.0001	***

Mean dependent var	1225.134	S.D. dependent var	176.9301
Sum squared resid	146676.3	S.E. of regression	46.44357
R-squared	0.933064	Adjusted R-squared	0.931095
F(2, 68)	473.9492	P-value(F)	1.18e-40
Log-likelihood	−371.7269	Akaike criterion	749.4538
Schwarz criterion	756.2419	Hannan-Quinn	752.1532
rho	0.367787	Durbin's h	3.224420

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: SP500

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	14.6466	25.5271	0.5738	0.5679	
assetspurchasesnet	0.000201307	0.000114473	1.759	0.0829	*
SP500_1	0.995656	0.0158979	62.63	<0.0001	***

Mean dependent var	1452.476	S.D. dependent var	360.4615
Sum squared resid	162921.0	S.E. of regression	47.56880
R-squared	0.983056	Adjusted R-squared	0.982585
F(2, 72)	2088.589	P-value(F)	1.76e-64
Log-likelihood	−394.5529	Akaike criterion	795.1057
Schwarz criterion	802.0582	Hannan-Quinn	797.8817
rho	−0.191343	Durbin's h	−1.673013

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: inflation_mich_1y

	Coefficient	*Std. Error*	*t-ratio*	*p-value*	
const	0.745798	0.223568	3.336	0.0014	***
assetspurchasesnet	−8.87362e-06	2.82451e-06	−3.142	0.0025	***
inflation_mich_1	0.761844	0.0683963	11.14	<0.0001	***

Mean dependent var	3.221127	S.D. dependent var	0.719705
Sum squared resid	9.781950	S.E. of regression	0.379279
R-squared	0.730215	Adjusted R-squared	0.722280
F(2, 68)	92.02626	P-value(F)	4.51e-20
Log-likelihood	−30.37863	Akaike criterion	66.75726
Schwarz criterion	73.54530	Hannan-Quinn	69.45664
rho	0.080929	Durbin's h	0.834435

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: inflation_mich_1y

	Coefficient	Std. Error	t-ratio	p-value	
const	0.824028	0.238837	3.450	0.0009	***
assetspurchasesnet	4.83106e-07	6.69009e-07	0.7221	0.4726	
inflation_mich_1	0.726922	0.0749470	9.699	<0.0001	***

Mean dependent var	3.076000	S.D. dependent var	0.429280
Sum squared resid	5.898073	S.E. of regression	0.286213
R-squared	0.567488	Adjusted R-squared	0.555474
F(2, 72)	47.23478	P-value(F)	7.87e-14
Log-likelihood	−11.06305	Akaike criterion	28.12610
Schwarz criterion	35.07856	Hannan-Quinn	30.90214
rho	−0.068445	Durbin's h	−0.779180

Model 1: OLS, using observations 2003:03-2009:01 (T = 71)
Dependent variable: headlinecpi

	Coefficient	Std. Error	t-ratio	p-value	
const	−0.578485	0.585713	−0.9877	0.3268	
assetspurchasesnet	5.15472e-07	1.31028e-06	0.3934	0.6953	
headlinecpi_1	1.00456	0.00287382	349.6	<0.0001	***

Mean dependent var	204.3342	S.D. dependent var	7.895060
Sum squared resid	2.094161	S.E. of regression	0.175489
R-squared	0.999520	Adjusted R-squared	0.999506
F(2, 68)	70805.85	P-value(F)	1.4e-113
Log-likelihood	24.34056	Akaike criterion	−42.68112
Schwarz criterion	−35.89308	Hannan-Quinn	−39.98173
rho	0.211103	Durbin's h	1.779303

Model 1: OLS, using observations 2009:03-2015:05 (T = 75)
Dependent variable: headlinecpi

	Coefficient	Std. Error	t-ratio	p-value	
const	−1.09864	0.599377	−1.833	0.0709	*
assetspurchasesnet	1.47418e-07	3.68394e-07	0.4002	0.6902	
headlinecpi_1	1.00617	0.00259610	387.6	<0.0001	***

Mean dependent var	228.9780	S.D. dependent var	7.169494
Sum squared resid	1.669847	S.E. of regression	0.152290
R-squared	0.999561	Adjusted R-squared	0.999549
F(2, 72)	81967.91	P-value(F)	1.3e-121
Log-likelihood	36.25797	Akaike criterion	−66.51594

Schwarz criterion	−59.56348	Hannan-Quinn	−63.73990
rho	0.382582	Durbin's h	3.314093

Appendix 3

Hypothesis Tests – Unit Roots (2nd period)

```
Augmented Dickey-Fuller test for assetspurchasesnet
testing down from 11 lags, criterion AIC
sample size 72
unit-root null hypothesis: a = 1

  test without constant
  including 3 lags of (1-L)assetspurchasesnet
  model: (1-L)y = (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.0971556
  test statistic: tau_nc(1) = -2.67297
  asymptotic p-value 0.007294
  1st-order autocorrelation coeff. for e: -0.054
  lagged differences: F(3, 68) = 0.211 [0.8886]
```

```
Augmented Dickey-Fuller test for termspread1y
testing down from 11 lags, criterion AIC
sample size 75
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)termspread1y
  model: (1-L)y = (a-1)*y(-1) + e
  estimated value of (a - 1): -0.0368988
  test statistic: tau_nc(1) = -2.85078
  p-value 0.004903
  1st-order autocorrelation coeff. for e: 0.037
```

```
Augmented Dickey-Fuller test for termspread2y
testing down from 11 lags, criterion AIC
sample size 68
unit-root null hypothesis: a = 1
```

```
  test without constant
  including 7 lags of (1-L)termspread2y
  model: (1-L)y = (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.0427263
  test statistic: tau_nc(1) = -1.68662
  asymptotic p-value 0.08684
  1st-order autocorrelation coeff. for e: 0.021
  lagged differences: F(7, 60) = 4.156 [0.0009]


Augmented Dickey-Fuller test for termspead5y
testing down from 11 lags, criterion AIC
sample size 75
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)termspead5y
  model: (1-L)y = (a-1)*y(-1) + e
  estimated value of (a - 1): -0.0143873
  test statistic: tau_nc(1) = -0.883254
  p-value 0.3302
  1st-order autocorrelation coeff. for e: -0.055


Augmented Dickey-Fuller test for termspread10y
testing down from 11 lags, criterion AIC
sample size 75
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)termspread10y
  model: (1-L)y = (a-1)*y(-1) + e
  estimated value of (a - 1): -0.0083423
  test statistic: tau_nc(1) = -0.802846
  p-value 0.365
  1st-order autocorrelation coeff. for e: 0.030


Augmented Dickey-Fuller test for SP500
testing down from 11 lags, criterion AIC
sample size 75
unit-root null hypothesis: a = 1

  with constant and trend
  including 0 lags of (1-L)SP500
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
  estimated value of (a - 1): -0.164721
  test statistic: tau_ct(1) = -2.60062
  p-value 0.2814
  1st-order autocorrelation coeff. for e: -0.067

Augmented Dickey-Fuller test for inflation_mich
testing down from 11 lags, criterion AIC
sample size 67
unit-root null hypothesis: a = 1

  test without constant
  including 8 lags of (1-L)inflation_mich
  model: (1-L)y = (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.00103492
```

```
  test statistic: tau_nc(1) = -0.0983512
  asymptotic p-value 0.6499
  1st-order autocorrelation coeff. for e: -0.003
  lagged differences: F(8, 58) = 2.199 [0.0405]


Augmented Dickey-Fuller test for headlinecpi
testing down from 11 lags, criterion AIC
sample size 74
unit-root null hypothesis: a = 1

  with constant and trend
  including one lag of (1-L)headlinecpi
  model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + ... + e
  estimated value of (a - 1): -0.0473061
  test statistic: tau_ct(1) = -2.10641
  asymptotic p-value 0.5417
  1st-order autocorrelation coeff. for e: -0.062


Augmented Dickey-Fuller test for fedfundsrate
testing down from 11 lags, criterion AIC
sample size 75
unit-root null hypothesis: a = 1

  test without constant
  including 0 lags of (1-L)fedfundsrate
  model: (1-L)y = (a-1)*y(-1) + e
  estimated value of (a - 1): -0.0214878
  test statistic: tau_nc(1) = -1.40449
  p-value 0.1479
  1st-order autocorrelation coeff. for e: 0.103
```

Hypothesis Tests

1 year term spread post QE

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat^2

                       coefficient    std. error   t-ratio  p-value
  -----------------------------------------------------------------
  const                0.00621019    0.00373337     1.663   0.1005
  assetspurchasesn~    2.47065e-07   1.08344e-07    2.280   0.0255  **
  sq_assetspurchas~   −8.67656e-013  7.16591e-013  −1.211   0.2299

  Unadjusted R-squared = 0.100540

Test statistic: TR^2 = 7.641042,
with p-value = P(Chi-square(2) > 7.641042) = 0.021916
```

```
Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat

                      coefficient   std. error   t-ratio  p-value
  ---------------------------------------------------------------
  const                0.0154702    0.00938911    1.648   0.1037
  assetpurchasesnet   -2.95672e-07  1.35313e-07  -2.185   0.0321   **
  uhat_1               0.890060     0.0566682    15.71    4.09e-25 ***

  Unadjusted R-squared = 0.771657

Test statistic: LMF = 246.694371,
with p-value = P(F(1,73) > 246.694) = 4.09e-25

Alternative statistic: TR^2 = 58.645925,
with p-value = P(Chi-square(1) > 58.6459) = 1.89e-14

Ljung-Box Q' = 59.4096,
with p-value = P(Chi-square(1) > 59.4096) = 1.28e-14
```

2year term spread post QE

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat^2

                      coefficient    std. error   t-ratio  p-value
  ----------------------------------------------------------------
  const               0.0258363     0.0106828      2.418   0.0181  **
  assetspurchasesn~   1.10724e-06   3.10021e-07    3.571   0.0006  ***
  sq_assetspurchas~  -5.54557e-012  2.05048e-012  -2.705   0.0085  ***

  Unadjusted R-squared = 0.157920

Test statistic: TR^2 = 12.001906,
with p-value = P(Chi-square(2) > 12.001906) = 0.002476
```

```
Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat

                      coefficient   std. error   t-ratio  p-value
  ---------------------------------------------------------------
  const                0.0109692    0.0225075     0.4874  0.6275
  assetpurchasesnet   -1.76732e-07  3.23073e-07  -0.5470  0.5860
  uhat_1               0.811060     0.0698677    11.61    3.02e-18 ***

  Unadjusted R-squared = 0.648629

Test statistic: LMF = 134.757502,
with p-value = P(F(1,73) > 134.758) = 3.02e-18

Alternative statistic: TR^2 = 49.295790,
```

```
with p-value = P(Chi-square(1) > 49.2958) = 2.2e-12

Ljung-Box Q' = 50.5515,
with p-value = P(Chi-square(1) > 50.5515) = 1.16e-12
```

---

5 year term spread post QE

```
Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat

                     coefficient   std. error   t-ratio  p-value
  --------------------------------------------------------------
  const              -0.00609827   0.0410985    -0.1484  0.8825
  assetpurchasesnet   1.86864e-07  5.89907e-07   0.3168  0.7523
  uhat_1              0.859001     0.0604527    14.21    1.03e-22 ***

  Unadjusted R-squared = 0.734458

Test statistic: LMF = 201.909139,
with p-value = P(F(1,73) > 201.909) = 1.03e-22

Alternative statistic: TR^2 = 55.818787,
with p-value = P(Chi-square(1) > 55.8188) = 7.95e-14

Ljung-Box Q' = 57.7821,
with p-value = P(Chi-square(1) > 57.7821) = 2.93e-14
```

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat^2

                      coefficient   std. error   t-ratio  p-value
  --------------------------------------------------------------
  const                0.149012     0.0472156     3.156   0.0023  ***
  assetpurchasesnet    3.49159e-06  1.37022e-06   2.548   0.0129  **
  sq_assetpurchase~   -1.75424e-11  9.06266e-12  -1.936   0.0568  *

  Unadjusted R-squared = 0.086945

Test statistic: TR^2 = 6.607795,
with p-value = P(Chi-square(2) > 6.607795) = 0.036740
```

---

10 year term spread post QE

```
Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat

                     coefficient   std. error   t-ratio  p-value
  ---------------------------------------------------------------
  const              −0.0138391    0.0428646    −0.3229  0.7477
  assetpurchasesnet   2.58956e-07  6.15235e-07   0.4209  0.6751
  uhat_1              0.871495     0.0575470    15.14    3.16e-24 ***

  Unadjusted R-squared = 0.758552

Test statistic: LMF = 229.342862,
with p-value = P(F(1,73) > 229.343) = 3.16e-24

Alternative statistic: TR^2 = 57.649972,
with p-value = P(Chi-square(1) > 57.65) = 3.13e-14

Ljung-Box Q' = 59.8808,
with p-value = P(Chi-square(1) > 59.8808) = 1.01e-14


White's test for heteroskedasticity
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat^2

                      coefficient   std. error   t-ratio  p-value
  ---------------------------------------------------------------
  const                0.205654     0.0620339     3.315   0.0014  ***
  assetpurchasesnet    3.02278e-06  1.80026e-06   1.679   0.0974  *
  sq_assetpurchase~   −1.50012e-11  1.19069e-11  −1.260   0.2117

  Unadjusted R-squared = 0.040093

Test statistic: TR^2 = 3.047095,
with p-value = P(Chi-square(2) > 3.047095) = 0.217937
```

inflation post QE

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: uhat^2

                      coefficient  std. error   t-ratio  p-value
  --------------------------------------------------------------
  const               0.245328     0.0968633    2.533    0.0132  **
  assetpurchasesnet   2.48213e-06  3.10330e-06  0.7998   0.4260
  sq_assetpurchase~   4.35616e-12  2.12342e-11  0.2051   0.8379

  Unadjusted R-squared = 0.050915

Test statistic: TR^2 = 4.480484,
with p-value = P(Chi-square(2) > 4.480484) = 0.106433


Breusch-Godfrey test for first-order autocorrelation
```

```
OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: uhat

                    coefficient   std. error   t-ratio  p-value
  --------------------------------------------------------------
  const               0.0175308    0.0501692     0.3494  0.7276
  assetpurchasesnet  -4.54382e-07  7.74967e-07  -0.5863  0.5592
  uhat_1              0.818930     0.0625389    13.09    4.34e-22 ***

  Unadjusted R-squared = 0.668580

Test statistic: LMF = 171.472057,
with p-value = P(F(1,85) > 171.472) = 4.34e-22

Alternative statistic: TR^2 = 58.835029,
with p-value = P(Chi-square(1) > 58.835) = 1.71e-14

Ljung-Box Q' = 60.6763,
with p-value = P(Chi-square(1) > 60.6763) = 6.73e-15
```

---

headline cpi post QE

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: uhat^2

                     coefficient   std. error   t-ratio  p-value
  --------------------------------------------------------------
  const              73.6509       6.53458      11.27    1.49e-18 ***
  assetpurchasesnet  -3.32459e-05  0.000209354  -0.1588  0.8742
  sq_assetpurchase~  -1.90087e-09  1.43250e-09  -1.327   0.1881

  Unadjusted R-squared = 0.106421

Test statistic: TR^2 = 9.365024,
with p-value = P(Chi-square(2) > 9.365024) = 0.009256


Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2016:05 (T = 88)
Dependent variable: uhat

                    coefficient   std. error   t-ratio  p-value
  --------------------------------------------------------------
  const             -0.122914     0.292963     -0.4196  0.6759
  assetpurchasesnet  5.17046e-06  4.52458e-06   1.143   0.2564
  uhat_1             0.974133     0.0278351    35.00    2.95e-52 ***

  Unadjusted R-squared = 0.935103

Test statistic: LMF = 1224.763648,
with p-value = P(F(1,85) > 1224.76) = 2.95e-52

Alternative statistic: TR^2 = 82.289046,
with p-value = P(Chi-square(1) > 82.289) = 1.18e-19

Ljung-Box Q' = 83.8857,
with p-value = P(Chi-square(1) > 83.8857) = 5.24e-20
```

S&P500 post QE

```
White's test for heteroskedasticity
OLS, using observations 2009:02-2015:07 (T = 78)
Dependent variable: uhat^2

                        coefficient       std. error     t-ratio  p-value
  ---------------------------------------------------------------------
-
  const               155944           17472.6          8.925   2.07e-
13 ***
  assetpurchasesnet       -0.574962         0.516286     -1.114   0.2690
  sq_assetpurchase~        4.08503e-07      3.43211e-06   0.1190  0.9056

  Unadjusted R-squared = 0.058945

Test statistic: TR^2 = 4.597701,
with p-value = P(Chi-square(2) > 4.597701) = 0.100374


Breusch-Godfrey test for first-order autocorrelation
OLS, using observations 2009:02-2015:07 (T = 78)
Dependent variable: uhat

                      coefficient    std. error   t-ratio  p-value
  -----------------------------------------------------------------
  const              -17.2523       17.8779       -0.9650  0.3376
  assetpurchasesnet    0.000493858   0.000260387   1.897   0.0617   *
  uhat_1               0.966612      0.0361267    26.76    4.16e-40 ***

  Unadjusted R-squared = 0.905171

Test statistic: LMF = 715.893420,
with p-value = P(F(1,75) > 715.893) = 4.16e-40

Alternative statistic: TR^2 = 70.603302,
with p-value = P(Chi-square(1) > 70.6033) = 4.37e-17

Ljung-Box Q' = 71.0641,
with p-value = P(Chi-square(1) > 71.0641) = 3.46e-17


FEDfundsrate

White's test for heteroskedasticity
OLS, using observations 2009:02-2015:05 (T = 76)
Dependent variable: uhat^2

                     coefficient  std. error   t-ratio  p-value
  -------------------------------------------------------------
  const              0.00172126   0.000281552   6.113   4.36e-08 ***
  assetspurchasesn~  2.68353e-09  8.17078e-09   0.3284  0.7435
  sq_assetspurchas~  0.000000     0.000000     -0.7541  0.4532

  Unadjusted R-squared = 0.014729

Test statistic: TR^2 = 1.119394,
with p-value = P(Chi-square(2) > 1.119394) = 0.571382
```

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