THE SIGNALLING FUNCTION OF LONG-TERM INTEREST RATES AFTER QE

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Abstract

In this thesis I investigated the relation between the long-term interest rate, growth and inflation, i.e. the economic signalling function, before and after the implementation of QE programs by central banks. From my results can be concluded that this triangular relation has significantly changed after the financial crisis and there is a thorough reasoning this is caused by QE. Implications of this effect could be that a new anchor to price financial assets needs to be found in the future and another measure of investor expectations with respect to future trends on inflation and growth.

P.W. Duvekot
Student number: 362812

Supervisor:
M.A. Pieterse-Bloem

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Introduction

The sharp deterioration of the global financial crisis late 2008 led to the increased risk of a severe downturn on a scale not seen since the Great Depression of the 1930s (Kapetanios, Mumtaz, Stevens, & Theodoridis, 2012). Economic growth and inflation fell sharply at that time, causing central banks to undertake actions in reaction to this disturbing outlook.

One of the main tools of central banks in developed countries to control inflation is changing the level of short-term interest rates. However, after the financial crisis, central banks started using unconventional monetary policy tools, such as Quantitative Easing (QE). These new tools cause yields - even on longer maturities - to move closer to policy-determined prices as opposed to market-determined ones (Marcussen, 2016). This means that unconventional policy actions by central banks influences long-term interest rates.

Yields on sovereign bonds are used as proxy for the "risk-free" rate of return. However, this proxy is becoming an increasingly imperfect substitute with potentially dangerous consequences (Marcussen, 2016). Sovereign bonds are nowadays offering negative yields, meaning investors are guaranteed an expected loss instead of a return with no risk of financial loss. Although these yields can still be considered as risk-free - because the default risk and variance around the expected return are very low – they are becoming an unreliable measure of investor expectations with respect to future trends on inflation and growth. This is potentially a serious problem, as the risk-free rate is the price anchor of all risky assets.

There is a lot of speculation about the effects of QE programs in recent years. According to Bezemer (Dekker, 2016), the measures of QE mainly cause cheap money flowing to parties that do not need it. The money lingers as funds of commercial banks instead of flowing into the real economy. He claims there is no direct relation between the purchase of assets of commercial banks and an increase in lending.

Summers and Buiter (Boer, 2016) even proclaim deep negative rates are needed to encourage companies to invest in order to stimulate economic growth. Buiter says that only throwing money out of helicopters would work enough. Through long-term processes such as aging and growing income inequality and technological developments, the need of people to save has increasingly grown. These savings have exceeded investments and there is negligible or no economic growth now, also called secular stagnation. The world deals with a money demand that remains structurally lower than the supply. Summers believes the problem can only be fixed if the government enlarge their spending.

Rogoff and Borio (Boer, 2016) believe that not the demand is the problem, but the supply. Credit bubbles for the financial crisis provide low productive sectors with too much labour and capital. This problem continues to exist after the financial crisis through QE. Through the eased loan conditions, commercial banks can keep non-profitable companies alive, also called *evergreening*. This disturbs competition, the development of productivity and thus economic growth.

A considerable amount of research has been done on the effects of QE, amongst others on yields. Some of these studies will be discussed later. Unfortunately, there is relative little research on the relation between yields, growth and inflation, i.e. the economic signalling effect on yields, before and after QE. However, as mentioned this relation is really relevant, because yield curves of risk-free bonds are used to price other securities with risk and used as leading indicators for economic conditions. They are powerful predictors of future economic growth and inflation. With the central banks influencing the whole yield curves by QE, the triangular relation between the real growth rate, inflation rate and long-term interest rate can change.

I investigated whether there exists a triangular relation between the long-term interest rate, the real economic growth rate and the inflation rate. If this relation exists, the next step is to analyse whether this relation has changed after the start of unconventional policy actions by central banks, and then more in particular: QE. This brings me to the following research questions:

Q1: How do the real growth, inflation rate and the long-term interest rate relate to each other before the financial crisis?

Immediately followed by the question:

Q2: What is the effect of implementing QE programs by central banks on this relation?

To answer these research questions, I measure real growth by the change in the gross domestic product (GDP) and inflation rate by the change in the consumer price index (CPI). For the long-term interest rate I use the interest rates on government bonds with a maturity of ten years. For my second research question I focus on QE programs. I will therefore only examine the studied relation in countries where QE programs are executed for some time already. I focus on the effects of QE programs by the Federal bank in the United States, the Bank of England in the United Kingdom and the European Central Bank in Germany.

In the chapter “Theoretical Framework”, I will explain how central banks used to determine the level of the short-term interest rates by conventional policies. After this I will explain the unconventional QE policy, how it works and what the desired effect would be. As said, QE has effect on the whole yield curve. This effect and the exceptions will be explained in detail. After discussing some other studies on the effects of QE, I will specify my research and how it is different from other studies.

In the chapter “Methodology & Data”, I will explain the method I use to investigate my research questions and the data I use for it. The triangular relation between real growth, inflation and the long-term interest rate will be investigated by a simple regression model. This relation will be used to forecast the long-term interest rate after the financial crisis and especially after the implementation of QE programs. These forecasted values will be compared to the actual values. I will use a statistical test to prove if the value significantly differs and thus if the relation changes.

In the chapter “Results”, I describe the relation I find between the three investigated variables. This relation is investigated by two regression models. The results are shown in tables and graphs. The interpretation of the results will be discussed in de chapter “Conclusion & Discussion”. Here I will also make some suggestions for further research.

Theoretical Framework

The Taylor rule is used to determine how much the central bank should change the level of short-term interest rates in response to changes in inflation, output or other economic conditions. The rule was introduced by John Taylor (1993) to foster price stability and reduce unemployment. At that time this rule systematically reduced uncertainty and increased the credibility of future actions by the central bank. However, in the years after the financial crisis (2009) the growth of GDP has fallen sharply leading to some criticism about using the Taylor rule. Lowering the short-term interest rates by the Taylor rule is not the solution to increase growth (Gross, 2015). With interest rates reaching the zero lower bound (ZLB), the capacity of central banks reached a limit to stimulate economic growth by the conventional Taylor rule policy. To make financial conditions more favourable for growth when the short-term rates are constrained by the ZLB, some researchers (Bernanke & Reinhart, 2004; Bernanke, Reinhart, & Sack, 2004; McCallum, 2000; Svensson, 2001) argue that conventional policy actions must be complemented with unconventional policy actions: such as QE, steering market expectations through forward guidance, negative interest rates, overt money financing of fiscal deficits and monetising the debt (Bossone, 2016). By combining these policies, not only the toolkit of the central bank is expanded, but their objectives have expanded as well by targeting economic growth in order to prop up inflation.

In this thesis I will focus on unconventional QE policy. But what is QE exactly and what would the desired effect be on the real economy? This can be explained through Figure 1 below, and the following steps:

1. The central bank creates lots of money (with permission) by just crediting its own bank account.
2. This money is mainly used for buying government bonds from financial firms such as banks, insurance companies and pension funds.
3. By buying these bonds, they will get more expensive and thus less attractive to invest in (lower the interest rates).
4. This will cause companies that sold these bond to use the proceeds to invest in other companies or lend to individuals. It will also cause the term structure of interest rates to fall, giving an impulse to agents in the real economy to invest rather than save money.
5. The effect of both is that more money will be spent; creating jobs and stimulating the economy.

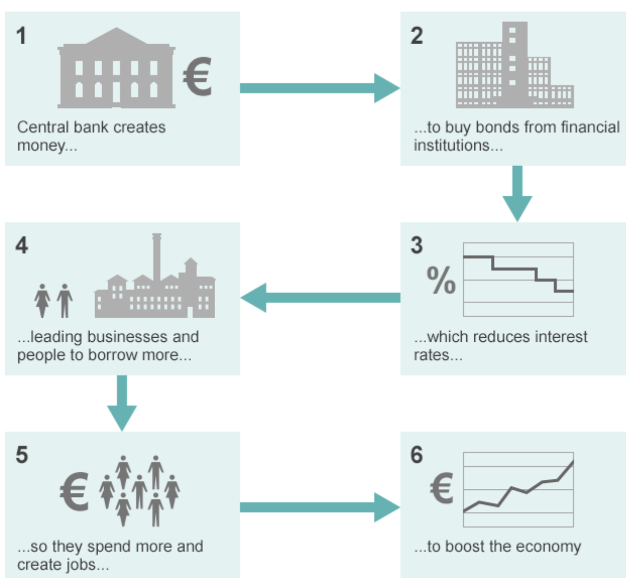


Figure 1, source: BBC news 13 July 2016

When there is enough economic growth and inflation, it can be considered that the economy is stimulated enough. The central bank will sell the bonds it has bought in the beginning and destroy the cash. This means in the long-term that no extra cash will be created. However, some risks emerge with QE, like no effect on the economic growth but just bolstered prices of some assets or too much inflation in the long run. The direct effect of the decreasing interest rates on bonds bought (step 3 in Figure 1) is observable and can be explained by the IS-LM model (Burda & Wyplosz, 2012).

The Investment Saving – Liquidity preference Money supply (IS-LM) model explains the relation between the interest rates and the total production (Figure 2). The IS-curve shows the combinations when the goods and services market is in equilibrium, meaning the savings equal the investments for a given interest rate determining the economy's total output (real GDP):

$$Y = C\big(Y - T(Y)\big) + I\ (r) + G + NX\ (Y), \qquad (1)$$

where the *Y* represents the real income or GDP, *C(Y-T(Y))* the consumer spending as a function of income minus taxes, *I(r)* the investments as a function of real interest rate, *G* the government spending and *NX(Y)* the net exports as function of Y.

Since the focus of this thesis is on QE, the LM-curve is more important. This curve shows the combinations when the money or asset market is in equilibrium, meaning the money demand equals the money supply:

$$\frac{M}{P} = L(i, Y), \qquad (2)$$

where *M/P* represents the real amount of money (M nominal amount, *P* the price level) and *L* the real demand for money as a function of interest rate (*i)* and real income (*Y)*. The demand for money depends on the transactions demand (willingness to hold cash and precautionary measure) and the speculative demand.

The money supply is determined by the central bank decisions and willingness of commercial banks to lend money. The function is represented as a vertical line (Figure 4 and 5) in the interest and real money space, because the money supply is in effect perfectly inelastic with respect to the interest rate. The money demand and supply curves are both plotted against the amount of money in Figure 2 and 3, but the LM-curve is plotted against the real GDP in Figure 4 and 5. There the LM-curve is positively sloped, because an increase in GDP causes an increase in demand for money. This causes the demand function *L* to shift to the right and thus a lower interest rate.

When the central bank decides to increase the money supply, which is the case with QE (see step 1), the supply function *M/P* will shift to the right (see Figure 5). This has also effects the LM-curve, because for each level of the demand curve *L* the interest rate will be lower. The LM-curve will therefore also shift to the right (see Figure 3), causing a lower interest rate and higher total production.

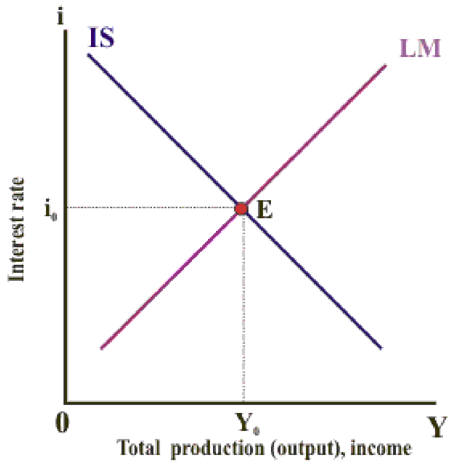


Figure 2, IS-LM model

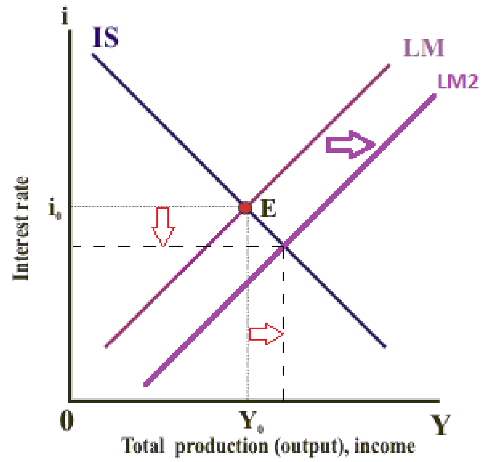


Figure 3, effect of QE on LM curve

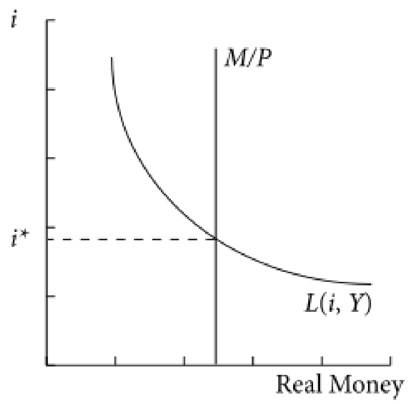


Figure 4, money supply and demand curve

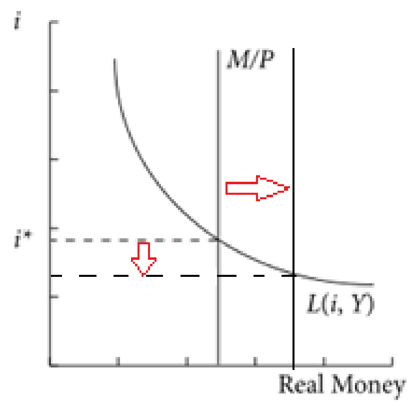


Figure 5, effect of QE on money supply curve

There are two exceptions a shift of the LM-curve will not cause this effect:

1) The IS-LM equilibrium coincides with an interest rate of zero or sinks even lower. At this point secular stagnation occurs. The neutral real interest rates cannot be achieved through conventional central-bank policies (Summers, 2016).
2) The LM-curve become flat. Private demand has fallen so far that the economy remains depressed even at a zero interest rate. Money is just being held as a store of value and changes in the money supply will have no effect. The economy is in a liquidity trap (Krugman, 2011).

The shift of the LM-curve is the theoretical effect of QE on interest rates, which is at one particular point of the yield curve, typically the short end because this is where the central bank sets its rates. But when interest rates approached zero or even go lower, central banks started to use QE which has an effect on the whole yield curve (Yu, 2016). The yield curve shows the interest rates (yields) for bonds of the same asset class and credit quality with different time-to-maturity. Because QE works on the entire term structure, i.e. puts downward pressure on interest rates at all maturities, the yield curve will also shift downwards. This curve usually has an upward slope to a horizontal asymptote (see Figure 6). This can be explained by investors being uncertain with respect to future inflation and other events, so they need to be compensated for this uncertainty when they invest long-term. The higher the expected volatility in the future the higher the premium for risk is.

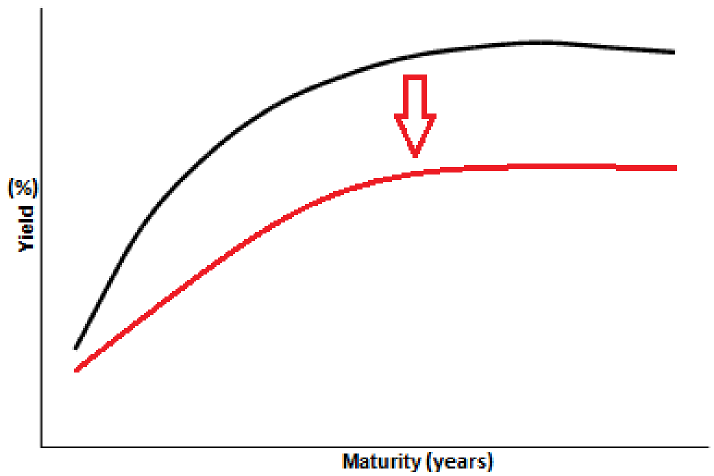


Figure 6, effect of QE on yield curve

A yield curve can be drawn for any type of security, but is often drawn for bonds with very little credit/default risk. Yield curves of these bonds are used to price other securities which do have risk (Pylypczak, 2014) and are historically also used as leading indicators for economic conditions. The slope is a very powerful predictor of future economic growth, inflation and recessions. This is the so called signalling function of the yield curve. Estrella and Mishkin (1998) conclude that the yield curve outperforms other indicators in one-on-one comparisons and the addition of other variables is generally more likely to hurt at longer horizons. Only at short horizons it is outperformed by other indicators, like stock price indexes.

While this effect is quite clear, it is more difficult to determine if QE eventually has the desired effect (step 4 and 5 in Figure 1). The monetarists argue for higher expected inflation increasing the velocity of money (Palley, 2011). Higher expected inflation gives households and firms an incentive to consume and invest now to avoid higher future prices which will cause more inflation and provoke an acceleration effect (Neary & Stiglitz, 1983).

New classical economist reject QE on the grounds that unemployment is a structural mismatch type and this problem cannot be easily fixed by a monetary policy (Palley, 2011). Keynesians reject the unemployment mismatch, but are concerned that the income distribution cannot be fixed.

Ugai (2006) empirically proves that the effect of the QE policy of the Bank of Japan (BoJ) on raising aggregate demand and prices was often limited. His research shows that commitment to maintain the QE program was more important than the expansion of the monetary base.

There are also various studies where evidence is given of QE programs having substantial effect on economic activity. Gagnon et al. (2011) present evidence that the programs lower long-term private borrowing rates, which should stimulate economic activity. QE led to economically meaningful and long-lasting reductions in long-term interest rates on a range of securities, including those who were not even in the purchase programs. This implies that this monetary policy remains potent even after the zero lower bound is reached. These reductions in interest rates primarily reflect lower risk premiums, rather than lower expectations of future short-term interest rates.

Joyce et al. (2011) investigate the impact of the QE policy of the Bank of England (BoE) on UK asset prices. They mention it is difficult to disentangle the specific impact of QE purchases from other factors, but it is likely that QE have had wider effects because most other asset prices showed a marked recovery through 2009. Their analysis suggests that the purchases have had a significant impact on financial markets and particularly on interest rates paid on British government bonds.

Neely (2010) also proves that the Federal Reserve's large scale asset purchase (LSAP) announcements had a substantially effect on the U.S. and foreign long-term bond yields. The asset price changes were much larger than they would be generated by chance. The research shows that a simple portfolio choice model explains the changes in foreign bond yields, but underestimates the U.S. yield changes. This could be explained by markets interpreting LSAP announcements as bad news for the world economy, which might have increased the demand for safe assets and caused a relatively small decline in the dollar exchange rate.

The studies of Neely (2010) and Joyce et al. (2011) show that asset prices are positively affected by QE. This increase is hoped to work on the real economy through the wealth effect. So people who own these assets feeling richer and starting to spend more, which has a positive effect on the rest of the real economy. There is however very little evidence that this wealth effect works. There is on the other hand a growing concern that all QE does is creating a boom – busts in financial markets.

Kozicki et al. (2010) examine the impact of QE on long-term interest rates taking into account the overall size of central bank's balance sheets. An increase in central bank claims on the central government or central bank assets is associated with a decline in long-term forward rates, controlling for expected inflation, projected deficits and other macro variables.

Kapetanios et al. (2012) have examined the macroeconomic impact of the first round of QE by the Bank of England (BoE) during March 2009 to January 2010. They suggest that without QE, real GDP would have fallen even more and annual CPI inflation would have reached low or even negative levels. The magnitude of its effects varies across the different models they use, but for all three models used QE had some effect and thus QE is an effective policy option during the financial crisis.

All of these studies indicate that QE programs have some effect on the long-term interest rates, but the evidence on the effect on growth and inflation is mixed. In this thesis, I am not so much concerned with whether QE works to raise growth and inflation. My departure point is that QE has an effect on long-term interest rates and I would like to research if those rates then still reflect the outlook for growth and inflation. I will do so by describing the triangular relation between the long-term interest rate, the real economic growth rate and the inflation rate before and after QE. As Estrella and Mishkin (1998) prove that the interest rate (yield) is a powerful predictor for these two variables, I will examine if this relation remains present after central banks resort to QE. This is an important matter because the ability of economic agents to predict the future state of the economy is important for determining their current actions. Vice versa, if economic agents' ability to predict the future state of the economy is severally impaired, then this is likely to lead to a misallocation of current resources.

Based on a literature survey and empirical findings, Ciocyte et al. (2016) conclude that there is a relation between the nominal long-term interest rate in high-income countries and the change in (expected) inflation (CPI) and potential growth (GDP) for the years 1990-2013. They find a low explanatory power in their regression analysis meaning the relation is relatively weak.

This relative weak relation could be the result of including data of the financial crisis years (2007-2008). Ciocyte et al. (2016) also do not make a distinction between the period before and after the financial crisis. In this thesis, I therefore take a different approach. I will rather examine if the explanatory power changes when only the years before the financial crisis are taken into account. These outcomes will be used to forecast the years after the financial crisis and to show if QE programs had an effect on this relation.

Methodology & Data

During periods of financial stress, sovereign bond yields can temporarily deviate from their long-run equilibrium level due to cyclical factors such as short-lived panics (Ciocyte, Muns, & Lever, 2016). In this thesis I will examine if this long-term equilibrium is dependent on differences in the real growth and inflation rates and if it changes after the introduction of QE programs.

The standard method in the literature to explain the long-term interest rate is to include the lagged interest rate from previous period (t-1). The reason for this is that the lagged interest rate contains a lot of information, including the current economic situation (growth and inflation level), and thus will have high influence on the current long-term interest rate. I will examine two models: one in which the lagged interest rate is included (Model I) and one in which this variable is excluded in order to force the explanatory power for the long-term interest rate on the growth and inflation rate (Model II). The main focus of this thesis will be on Model II, because I expect the effect of QE on the long-term interest rate to be less visible in model I. The effect of QE already had influence on the lagged interest rate and by using this variable, the total effect will flatten out.

Kapetanios et al. (2012) use three different models to investigate the effect of QE on different variables. In this thesis I only want to examine the effect of the difference in three (model I) and two (model II) variables on the long-term interest rate. Therefore, I will only need a simple regression model to find the relation between these variables. To estimate the corresponding coefficients for the betas, I use the following equations:

Model I: $$R_t = \beta_0 + \beta_1\, \Delta GDP_t + \beta_2\, \Delta CPI_t + \beta_3\, R_{t-1} + \varepsilon_t, \quad (3)$$

Model II: $$R_t = \beta_0 + \beta_1\, \Delta GDP_t + \beta_2\, \Delta CPI_t + \varepsilon_t, \quad (4)$$

where the dependent variable R_t is the interest rate on government bonds with a maturity of ten years at time t, β_0 is the constant term, β_1 is the sensitivity of the interest rates for a quarterly change in the real gross domestic product (ΔGDP_t), β_2 is the sensitivity of the interest rates for a quarterly change in the consumer price index (ΔCPI_t), β_3 is the sensitivity of the interest rates for the interest rate lagged by one (R_{t-1}) and ε_t is the error term.

The most commonly used method to estimate the coefficients for the betas is Ordinary Least Squares (OLS). This method takes the squared of the residuals ε_t, add them up and choose betas such that the sum of these squared residuals is as small as possible (Brooks, 2014). An often used criterion for the goodness-of-fit (quality) of the model is the R^2. Minimizing the sum of squared errors automatically maximizes the R^2. Regression-analysis makes it easy to overview relations, is expandable to a multivariate framework and is a sound framework to test hypothesis and judge the reliability of the results.

The interest rate on government bonds with a maturity of ten years is taken, because this maturity is used as benchmark for the long-term interest rate. The default risk of these bonds is very close to zero (capital repayment is guaranteed by governments). They are determinants of business investments and hence also influence economic growth. Maturities of bonds range from one to thirty years. In order to exclude as much as possible other influences and risks, a maturity of ten years is taken. Ten years is also long enough into the future to let the fundamental outlook, i.e. growth and inflation, be the main driver of interest rates at this maturity.

The changes in real GDP and CPI are taken as explanatory variables, because these measurements are good indicators for the outlook of the economy. Ex ante it is hard to say if the relation between a change in GDP or CPI and the interest rate on the bond yields will be positive or negative. On the one hand, higher growth and inflation rates can be expected to increase yields if the central bank is expected to raise short-term interest rates to cool the economy off. This prospect of higher short-term rates and higher inflation means that bond investors want to be compensated with higher yields. With the growth in GDP or CPI, alternative investment opportunities will also get more interesting. The expected returns on investment with more risks will be higher than the expected return on low risk government bonds. Both have the effect that relatively the demand for government bonds will thus decrease (Ciocyte, Muns, & Lever, 2016). On the other hand, when the GDP of a country increases, the inhabitants will relatively earn and spend more money and indirectly the government will also receive more grist to the mill through VAT and income taxes. This leads to lower default risk and makes it more interesting for bond investor to invest in these countries. This increases the demand for bonds, meaning the bond prices go up and thus the bond yields go down (Ciocyte, Muns, & Lever, 2016).

For the regression to estimate the coefficients of Equations 3 and 4, I will use the data from the first quarter of 1989 till the second quarter of 2007. The sample size consists of 74 observations. Considering the rule of thumb to have at least 60 observations, I include three more years entailing twelve more observations and the two extra quarters of 2007. These extra observations are taken to ensure sound outcomes and give some slack for potential outliers.

I will use data until the second quarter of 2007, because the start of the financial crisis on the ninth of August 2007 (third quarter). The start is characterized with the announcement of BNP Paribas that they had to suspend redemptions, because of the severe run on the assets of three structured investment vehicles (Acharya, Philippon, Richardson, & Roubini, 2009). This announcement caused the asset-back commercial paper market to freeze. By excluding the following period we will avoid a lot of noise which could have been the cause for the relatively weak relation found by Ciocyte et al. (2016).

The QE programs have been launched by central banks of different countries. The Bank of Japan (BoJ) was the first one executing QE in the early 2000s to keep the short-term interest rates close to zero. However, programs elsewhere have been undertaken after the financial crisis. The US Federal Reserves (Fed) started during the peak of the crisis in 2008 and already had three phases of QE. The Bank of England (BoE) started in March 2009 and the European Central Bank (ECB) began buying bonds in March 2015. Also the Swedish National Bank launched QE in February 2015.

In this thesis I will focus my empirical research on the QE programs launched by the Fed, the BoE and the ECB. I will thus use the data from the United States and the United Kingdom to examine the programs of the Fed and the BoE. For the QE program of the ECB I will use data of Germany. This country is taken as benchmark for Europe, because the ECB has been buying sovereign bonds proportionate to the size of its member countries (Randow, 2016). A significant part of the bonds bought by the ECB are thus from Germany.

The data of these countries is obtained from the database of the Organisation for Economic Cooperation and Development (OECD). In 1960 eighteen European countries plus the United States and Canada joined forces to create this organisation dedicated to economic development. The OECD collects and analyses data and has information on a broad range of topics.

The estimated coefficients for the betas ($\beta_0, \beta_1, \beta_2, \beta_3$) obtained from the regression model will be used to forecast the long-term interest rates for the fourth quarter of 2008 till the first quarter of 2016. This will be calculated by means of the following equations:

Model I: $$E(R_t) = \beta_0 + \beta_1 \Delta GDP_t + \beta_2 \Delta CPI_t + \beta_3 R_{t-1}, \quad (5)$$

Model II: $$E(R_t) = \beta_0 + \beta_1 \Delta GDP_t + \beta_2 \Delta CPI_t, \quad (6)$$

where $E(R_t)$ is the expected interest rate on government bonds with a maturity of ten years at time t and all other variables are the same as described above except I now use these variables to determine $E(R_t)$ instead of finding the best parameters (betas) based on the data.

This period is chosen because the actual data for this period is available. Starting the forecast in the fourth quarter of 2008 after the deepest stage of the financial crisis with the collapse of Lehman brothers in September (Acharya, Philippon, Richardson, & Roubini, 2009). This causes the sample size to consist of 30 observations. I take the period right after the financial crisis, because I want to examine if this event has effect on the studied relation.

When the expected interest rates are calculated for the described years, I will compare these with the actual values of this period. I will use a Pearson's chi-square test (1900) to examine if the values significantly follow a different path or in other words do not follow the relation found before. This is a statistical test to evaluate how likely it is that an observed difference between actual and expected value arose by chance. To calculate the value of the test-statistic (χ^2) I need to perform the following steps:

1) Calculate the differences between the actual (R_t) and the expected ($E(R_t)$) values
2) Square this difference and divide by the expected value ($E(R_t)$)
3) Compute the sum of the outcomes of all years

$$\chi^2 = \sum_{t=0}^{t=30} \frac{(\mathrm{E(Rt) - Rt})^2}{\mathrm{E(Rt)}} \quad (7)$$

After this value is calculated, the nearest critical value needs to be found in the chi-squared distribution table for the degrees of freedom of 29 (total observations minus one) to determine the probability. I can then determine on which confidence interval the expected values differ from the actual values.

Examining if the relation significantly changed after the QE programs means for the US that I can use the same period because the Fed started right after the peak of the financial crisis with their QE program. However, for the UK this means the second quarter of 2009. I will leave Germany out of this examination, because I will only have four values upward of the second quarter of 2015.

Results

As explained in the methodology and data chapter above, I will start my empirical research with two simple regression models. In Model I the coefficients for the relation between the lagged by one long-term interest rate (R_{t-1}), the economic growth rate (ΔGDP), the inflation rate (ΔCPI) and the long-term interest rate will be estimated. In Model II the coefficients for the previous mentioned relation without the lagged interest rate as explanatory variable. The coefficients for the betas ($\beta_0, \beta_1, \beta_2, \beta_3$) are estimated in EViews by the Ordinary Least Squares model.

Table 1: Estimated coefficients with probability and the R^2 for model I (Q1/1989-Q2/2007)

	United States	United Kingdom	Germany
β_0	0,024634	-0,363421	0,147805
p-value	(0,9106)	(0,1445)	(0,2868)
β_1	0,068116	0,162746	0,071526
p-value	(0,0394)	(0,0034)	(0,0008)
β_2	0,112034	0,150000	0,041890
p-value	(0,0442)	(0,0073)	(0,2966)
β_3	0,896644	0,926765	0,927894
p-value	(0,0000)	(0,0000)	(0,0000)
R^2	0,936870	0,973429	0,966295

Table 2: Estimated coefficients with probability and the R^2 for model II (Q1/1989-Q2/2007)

	United States	United Kingdom	Germany
β_0	2,698589	2,505195	3,295387
p-value	(0,0000)	(0,0009)	(0,0000)
β_1	0,92846	0,443478	0,31116
p-value	(0,0000)	(0,0118)	(0,0000)
β_2	0,161653	1,197034	0,817201
p-value	(0,0948)	(0,0000)	(0,0000)
R^2	0,437194	0,712989	0,601349

In Table 1 only the estimate for the constant term (β_0) for the UK is negative and all other coefficients are positive. The estimated coefficient β_0 is for all countries insignificant, on the other hand the estimates for GDP (β_1) and the lagged interest rate (β_3) are all significant. The estimated inflation coefficient (β_2) is only significant for the US and the UK. From Table 2 may be noted that all coefficients are positive and significant on a confidence interval of 99%, except for β_2 for the US which is significant on a confidence interval of 90%.

When a coefficient is significant, the null hypothesis can be rejected (the coefficient significant differs from zero). This means that the coefficient has effect on the dependent variable; the long-term interest rate. When a coefficient is not significant, it has no explanatory power to the dependent variable. This means that in Table 1 the constant term in all countries and the difference in CPI in Germany have no effect on the long-term interest rate, but in Table 2 all variables have explanatory power. However, the function of the constant term changes between both models. In model I the constant term represent the deviation of the long-term interest rate, whereas in model II it represent more or less the average rate.

Ignoring the negative β_0 for the UK, the positive nature of all other coefficients indicates that an increase in GDP or CPI will also cause an increase in the long-term interest rate. There is thus a positive relation between a change in GDP or CPI and the interest rate. All of the values are below 1, except for β_2 for the UK, meaning an increase of one unit in GDP or CPI causes a lower increase in the long-term interest rate than one unit. By contrast, an increase of CPI in the UK by one unit will cause an increase of 1,197 ($\beta_{2,US}$) in the long-term interest rate.

The R^2 indicates the goodness-of-fit of the model, how well do the independent variables define the dependent variable. For example, the R^2 of model II for Germany means that the independent variables GDP and CPI explain the long-term interest rate for 60,13%. The other part cannot be explained by this model. The R^2's of model I are for all countries above 90% and thus higher than the ones in model II. This means that there is a lot of information in the interest rate of the previous period. Because of the high explanation power of this variable (high significance), the explanation power of the other two variables decreases. This can increase again if the change of growth and inflation is taken instead of the absolute values as I did. The change represents the surprise which people include and base their interest rate level on. The R^2 of model II for the US is the smallest, meaning other variables (which are not included in my model) have more influence on the long-term interest rate in the US than in the UK or Germany.

I will forecast the long-term interest rate using these estimated coefficients for the betas in the following equations:

Model I:

$$E(R_{t,US}) = 0{,}02 + 0{,}07\ \Delta GDP_t + 0{,}11\ \Delta CPI_t + 0{,}90\ R_{t-1} \quad (8)$$

$$E(R_{t,UK}) = -0{,}36 + 0{,}16\ \Delta GDP_t + 0{,}15\ \Delta CPI_t + 0{,}93\ R_{t-1} \quad (9)$$

$$E(R_{t,GE}) = 0{,}15 + 0{,}07\ \Delta GDP_t + 0{,}04\ \Delta CPI_t + 0{,}93\ R_{t-1} \quad (10)$$

Model II:

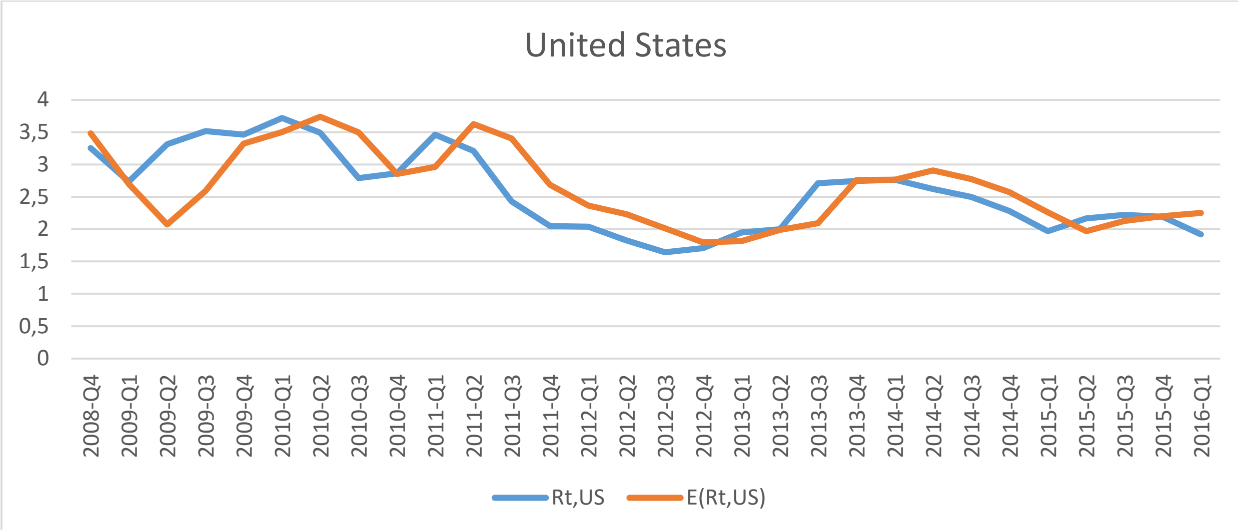
$$E(R_{t,US}) = 2{,}70 + 0{,}93\ \Delta GDP_{t,US} + 0{,}16\ \Delta CPI_{t,US} \quad (11)$$

$$E(R_{t,UK}) = 2{,}51 + 0{,}44\ \Delta GDP_{t,UK} + 1{,}20\ \Delta CPI_{t,UK} \quad (12)$$

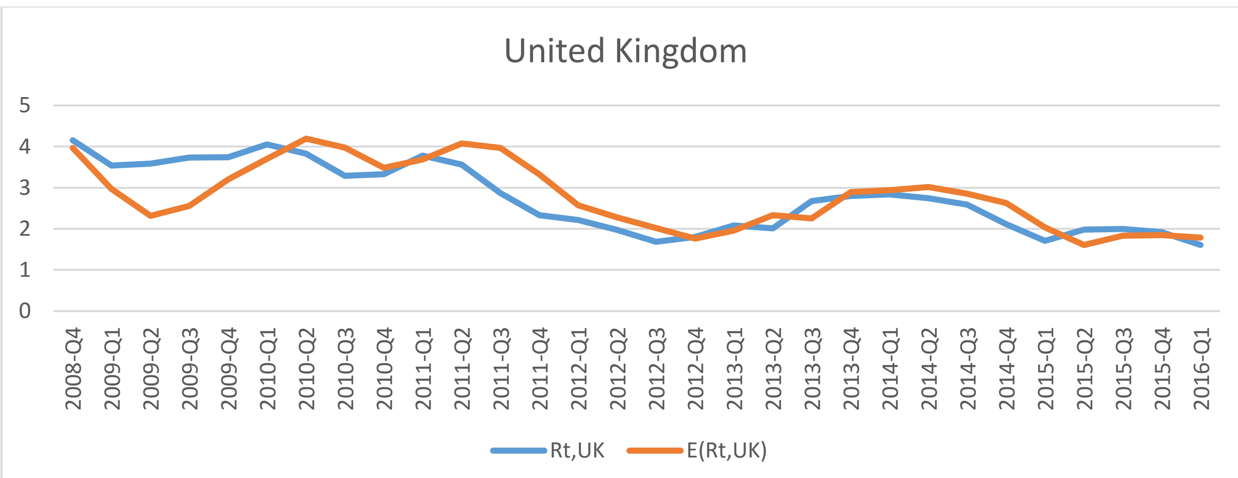
$$E(R_{t,GE}) = 3{,}30 + 0{,}31\ \Delta GDP_{t,GE} + 0{,}82\ \Delta CPI_{t,GE} \quad (13)$$

With these formulas, the expected long-term interest rates can be calculated for after the financial crisis (Q4-2008) till now (Appendix Table A). To clearly see the difference between the expected and the actual long-term interest rate, I have made line charts for both models and each country (Graph 1 to 6).

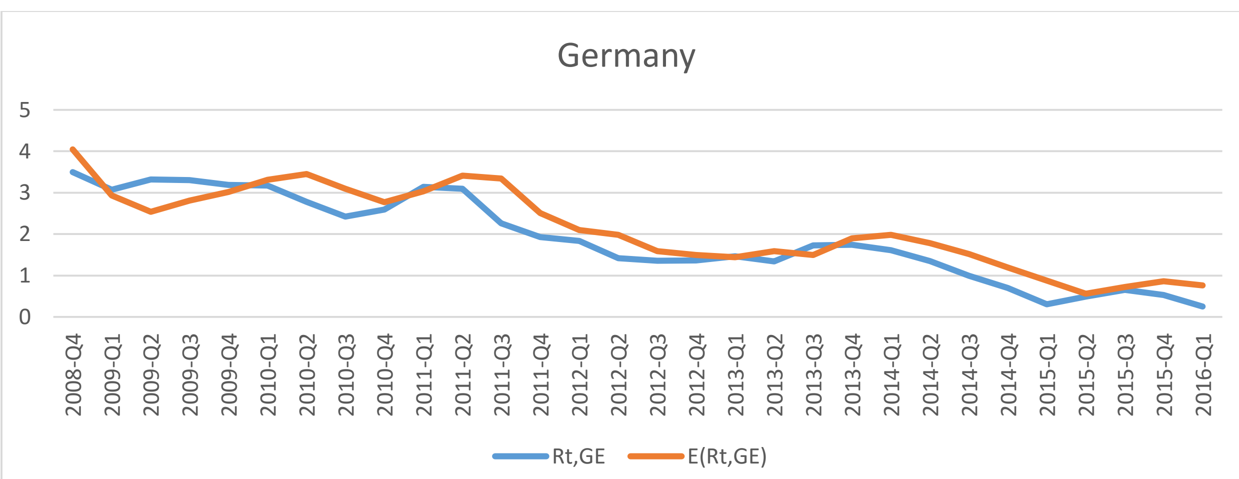
Graph 1 – 3: Difference expected and actual long-term interest rate for model I



Graph 1

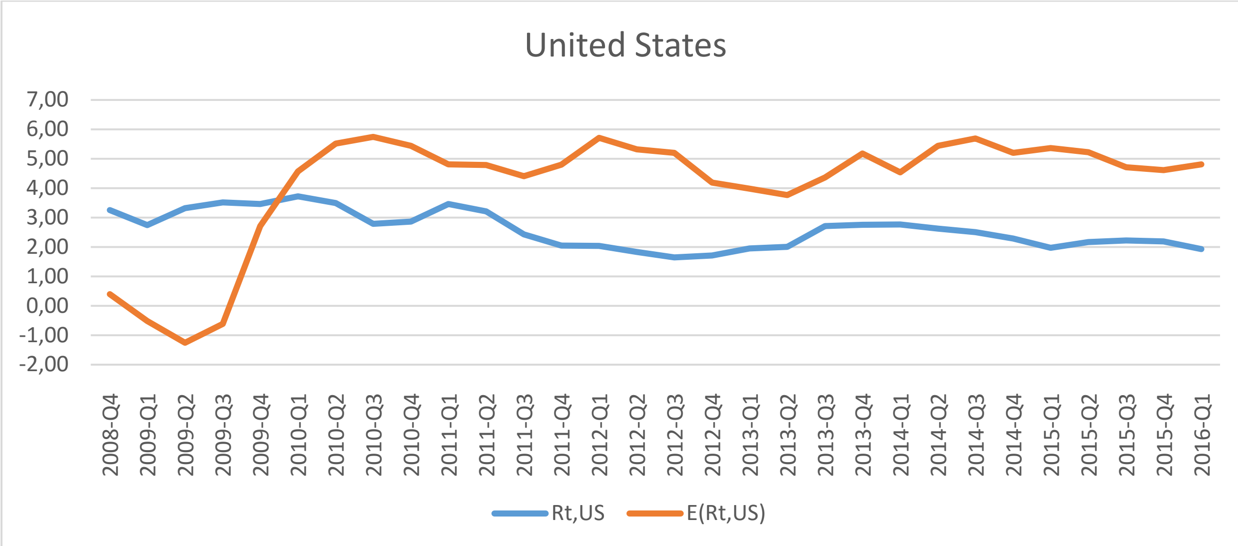


Graph 2

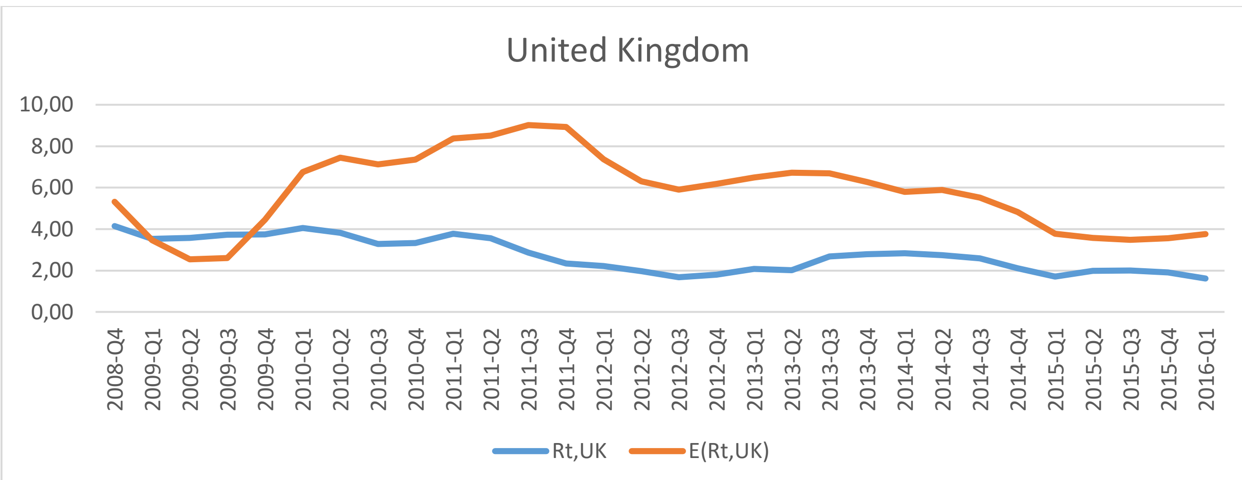


Graph 3

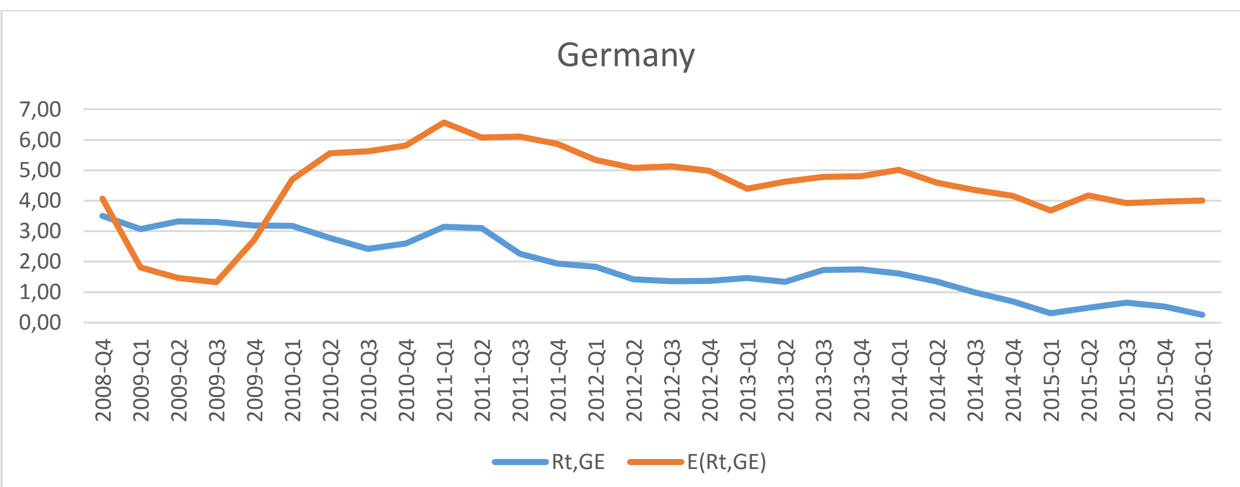
Graph 4 – 6: Difference expected and actual long-term interest rate for model II



Graph 4



Graph 5



Graph 6

From Graphs 1 to 3 for model I, it is clear that the expected long-term interest rate fluctuates around the actual long-term interest rate. This means that the model can predict the actual values quite well, which could be expected given the high R^2's. It also means however that there have not been a change in the relation of the dependent and independent variables. The values do not differ from each other and a Pearson's chi-square is therefore unnecessary.

From Graphs 4 to 6 for model II, we can see that in all three countries the expected long-term interest rate is higher than the actual rate after Q4-2009 till now. This effect remained hidden in model I. By placing the burden of explanation directly on real growth and inflation, it can be shown that the relation between interest rates – real growth – inflation has been broken after the crisis. We can also see a dip for all three countries between Q1-2009 till Q4-2009. For the UK, it looks like the expected and actual long-term interest rate are somewhat converging. For Germany, the distance between the two lines seems to stay the same as the lines are moving quite similar. For the UK, the distance between the two lines also keeps quite the same, but they are not moving as synchronously as the lines for Germany.

To examine if the expected long-term interest rate significantly follows a different path than the actual values, I conduct a Pearson's chi-squared test. Because we see a dip before Q4-2009 for all three countries, I will also calculate the chi-square after this period to see if this influences the outcomes.

Table 3: Chi-square value with probability

	United States	United Kingdom	Germany
χ^2 (Q4/2008-Q1/2016)	119,25	56,94	64,29
p-value	(0,0000)	(0,0025)	(0,0010)
χ^2 (Q4/2009-Q1/2016)	32,84	55,76	58,00
p-value	(0,2500)	(0,0025)	(0,0010)

As we can see from Table 3, for all three countries the expected long-term interest rates significantly differ from the actual values on a confidence interval of 99,75% after the financial crisis. In other words, the actual values follow a significant different path than would have been expected with the relation we found before the financial crisis.

If I take a look after the dip (Q4-2009) shown in the graphs, I see that the chi-square value for the UK and Germany not much has changed. From this information I can conclude that the chi-square value also must be significant after Q2-2009, when the BoE started with their QE program. For the US, the chi-square value has decreased substantially and is then only significant on a confidence interval of 75% which is very low. With this model we cannot say the expected values significantly differ from the actual ones after Q4-2009.

Conclusion & Discussion

I this thesis, I provide some new results and information about the triangular relation between the long-term interest rate, the real economic growth rate and the inflation rate before and after the financial crisis. The main focus was on the effects of QE on this triangular relation. The standard method in the literature to explain the long-term interest rate is to include the interest rate from previous period. My results show that, including this variable results in a very strong explanatory model for all investigated countries. But this model does not show a change in the examined triangular relation after the financial crisis. To get a better look I have excluded the lagged interest rate and placed the burden directly on real growth and inflation. Knowing this, I can give the following answers to my research questions.

Q1: How did the real growth, inflation rate and the long-term interest rate relate to each other before the financial crisis?

As we can see from the regression analysis I have performed, there is a positive relation between the real growth, inflation rate and the long-term interest rate before the crisis. An increase in GDP or CPI will also cause an increase in the long-term interest rate. The effect of lower demand for government bonds is thus stronger than a higher demand through inhabitants relatively earning and spending more as described in the chapter “Methodology & Data”. The real growth and inflation do not describe entirely the long-term interest rate, which can be seen at the relatively low R^2 of model II. To get a model with high explanatory power, you should include the lagged interest rate. Unfortunately by including this variable the effect of QE on this triangular relation is flatten out. That is why I focussed on the model without the lagged variable (II), to answer my second research question.

Q2: What is the effect of implementing QE programs by central banks on this relation?

As we can see from the graphs (4 to 6), where I have plotted the expected and actual long-term interest rate, the triangular relation has changed after the financial crisis. The values of the expected long-term interest rate are by definition higher than the actual values. Also when I conducted a Pearson’s chi-squared test, it follows that the expected and actual long-term interest rates differ significantly. Except for the values after Q4/2009 in the US which do not differ significantly, the expected values are all higher than the actual ones.

From this I can conclude that something caused the long-term interest rate to be lower than expected. As stated in the chapter “Theoretical Framework”, there is a thorough reasoning this lower long-term interest rate is caused by the QE programs. QE works on the entire yield curve and thus puts downward pressure on the interest rates at all maturities, so also on the bonds with a maturity of 10 years representing the long-term interest rate in my research.

Implications of this effect could be, as already mentioned, that the yield on long-term sovereign bonds can no longer be used as proxy for the “risk-free” rate of return. These yields are becoming an unreliable measure of investor expectations with respect to future trends on inflation and growth. The risk-free rate is also the anchor of all risky assets. If this is not reliable anymore, then another way to price these assets needs to be found.

Of course there are also a number of caveats to my research. I will summarise some of them and provide suggestions for further research. In my research I assume that QE has an effect on the long-term interest rate, but I am not explaining this relation in depth. It could be interesting to find out if there is a direct relation between QE and the long-term interest rate. In my thesis I am only interested if the long-term interest rates still reflect the outlook for growth and inflation after the QE programs.

I do not elaborate more on how QE is adopted into the economy either. QE works through several channels that affect particular assets differently (Krishnamurthy & Vissing-Jorgensen, 2011). However, I believe that this does not change my inference as I mainly focus on the reduced-form impact on the triangular relation between the real growth, inflation rate and the long-term interest rate. Still, it would be interesting to examine how QE works through to the economy. One channel worth investigating is the effect of yields of sovereign bonds in the pricing of other financial assets. With QE having an effect on the whole yield curve, it should also have indirect effect on other assets like equity prices. An interesting question in this case would be to what extend does QE have impact on the value of these assets.

While reading this thesis, one should also keep in mind the relative unique conditions QE took place in right after the financial crisis. This could for example explain the dip of the expected long-term interest rate for all three countries between Q1-2009 till Q4-2009. As said before the risk of a severe downturn have not been seen on such a scale since the Great Depression. This research would get even more support if it could be performed in another period than immediately after the financial crisis. However, central banks will only execute QE programs in situations where conventional policy do not work anymore and thus it would be hard to find such a situation.

Finally, in this thesis the usual caveats concerning specifications of variables, estimations of the betas and validations of the models I used must also be taken into account. However, I tried to be as specific as possible and hoped to minimise these deviations as much as possible.

Appendix

Table A: Expected values and the difference with actual values

	United States			United Kingdom			Germany		
TIME	$R_{t,US}$	$E(R_{t,US})$	$E(R_{t,US})-R_{t,GE}$	$R_{t,UK}$	$E(R_{t,UK})$	$E(R_{t,UK})-R_{t,UK}$	$R_{t,GE}$	$E(R_{t,GE})$	$E(R_{t,GE})-R_{t,GE}$
2008-Q4	3,25	0,39	-2,86	4,15	5,31	1,16	3,50	4,07	0,57
2009-Q1	2,74	-0,52	-3,25	3,54	3,47	-0,07	3,07	1,81	-1,26
2009-Q2	3,31	-1,26	-4,57	3,58	2,54	-1,05	3,32	1,46	-1,86
2009-Q3	3,52	-0,61	-4,13	3,73	2,60	-1,13	3,30	1,33	-1,98
2009-Q4	3,46	2,71	-0,75	3,74	4,46	0,72	3,19	2,71	-0,48
2010-Q1	3,72	4,56	0,85	4,05	6,75	2,70	3,18	4,69	1,52
2010-Q2	3,49	5,51	2,02	3,83	7,44	3,62	2,78	5,56	2,79
2010-Q3	2,79	5,74	2,96	3,29	7,12	3,83	2,42	5,63	3,20
2010-Q4	2,86	5,44	2,58	3,33	7,36	4,03	2,60	5,81	3,21
2011-Q1	3,46	4,80	1,34	3,78	8,37	4,58	3,14	6,56	3,42
2011-Q2	3,21	4,79	1,58	3,56	8,52	4,96	3,10	6,07	2,97
2011-Q3	2,43	4,40	1,98	2,87	9,02	6,15	2,26	6,11	3,85
2011-Q4	2,05	4,79	2,75	2,33	8,92	6,59	1,93	5,87	3,93
2012-Q1	2,04	5,71	3,67	2,22	7,37	5,15	1,83	5,34	3,50
2012-Q2	1,82	5,31	3,49	1,97	6,30	4,33	1,42	5,08	3,66
2012-Q3	1,64	5,20	3,55	1,68	5,91	4,23	1,36	5,13	3,77
2012-Q4	1,71	4,19	2,48	1,80	6,18	4,38	1,37	4,98	3,61
2013-Q1	1,95	3,98	2,03	2,08	6,49	4,41	1,47	4,39	2,93
2013-Q2	2,00	3,76	1,76	2,01	6,72	4,71	1,34	4,62	3,28
2013-Q3	2,71	4,36	1,65	2,67	6,69	4,01	1,73	4,79	3,06
2013-Q4	2,75	5,17	2,43	2,79	6,28	3,49	1,75	4,80	3,06
2014-Q1	2,76	4,53	1,77	2,84	5,79	2,96	1,61	5,01	3,40
2014-Q2	2,62	5,43	2,81	2,74	5,89	3,14	1,35	4,60	3,25
2014-Q3	2,50	5,69	3,19	2,59	5,52	2,94	0,99	4,35	3,36
2014-Q4	2,28	5,20	2,92	2,11	4,82	2,71	0,70	4,16	3,46
2015-Q1	1,97	5,36	3,39	1,71	3,78	2,08	0,31	3,68	3,37
2015-Q2	2,17	5,22	3,05	1,98	3,57	1,59	0,49	4,18	3,69
2015-Q3	2,22	4,71	2,49	2,00	3,48	1,48	0,66	3,92	3,27
2015-Q4	2,19	4,61	2,42	1,92	3,56	1,64	0,53	3,97	3,44
2016-Q1	1,92	4,81	2,89	1,61	3,76	2,15	0,26	4,00	3,75

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