Spring 2017

Impact of Quantitative Easing on the Term Structure of Interest Rates

David Angelo
Merrimack College, angelod@merrimack.edu

IMPACT OF QUANTITATIVE EASING ON THE TERM STRUCTURE OF INTEREST RATES

Senior Honors Capstone Project

David Angelo

Merrimack College

Abstract:

The goal of this paper is to understand the term structure of interest rates. The term structure of interest rates shows how interest rates on the same assets with different maturities change. The term structure is displayed in what is known as a yield curve. While it is typically upward sloping, the yield curve shifts and changes slope as the economy changes. Looking at the history of yield curve can help predict different phases of the economy over time. During the recent financial crisis, a form of monetary policy, known as quantitative easing (QE), was used to lower long term interest rates. This paper will explore the history, rationale, and opinions on quantitative easing. In addition, for illustrative purposes, data were collected in an attempt to discover a relationship between the yields on one and ten-year treasury bonds.

I. Introduction

According to Frederick Mishkin (2015), the term structure of interest rates shows how interest varies with different maturities while holding risk, liquidity and tax treatment equal. A graph of the term structure of interest rates is called the yield curve. The yield curve can take on a variety of shapes: flat, upward sloping, and downward sloping. The downward sloping yield curve is called the inverted yield curve and it has been an indicator of recession (Mishkin, 2015).

Quantitative easing, an unconventional monetary policy, has been used in recent times to lower longer term interest rates because the Federal Reserve already controls short-term interest rates. So, the central bank purchases government securities from the market in order to lower long-term rates and increase the money supply (The Economist, 2015). This approach increases the money supply by providing financial institutions with capital in order to promote increased lending and liquidity. Liquidity is essentially how quickly an asset can be turned into cash. Quantitative easing is considered when short-term interest rates are at or approaching zero and when the spreads between long term yields and short term yields are high (Yu, 2016).

This is a policy used to kick start economic growth, and typically works by bringing liquidity to the market while decreasing interest rates. The Federal Reserve used multiple rounds of quantitative easing to get the economy back on track in the wake of the global financial crisis (Forbes, 2015). The various rounds of QE caused the Fed to buy various financial instruments in order to increase prices and lower yields. This will reduce the spread between short and long term interest rates. With this logic, quantitative easing should have been successful during the Great Recession.

To develop a theory of the yield curve, Mishkin (2015) believes we need to explain three empirical facts:

1. Interest rates on bonds of different maturities tend to move together.
2. When short-term interest rates are low, the yield curve tends to be upward sloping. When the short-term rates are high, the yield curve tends to be downward sloping.
3. Yield curves usually slope upward.

II. Theories of the Yield Curve

These facts can be explained with three theories: *Expectations Theory*, *Segmented Market Theory*, *Liquidity Premium Theory* (Mishkin, 2015). The Expectations Theory explains the first two empirical facts, but not the third. The Segmented Market Theory explains the third fact, but not the first two. The Liquidity Premium Theory explains all three facts, but we do not ignore the other theories because they provided the foundations for this theory.

Expectations Theory

With this theory, any given rate of interest on a bond that matures in n years is equal to the average expected short-term rates over n years. It suggests that bonds of different maturities are perfect substitutes, holding risk, liquidity and tax treatment constant. An investor is indifferent between holding short-term bonds whose average yield is equal to that of a long-term bond. If the average expected yield on short-term bonds is greater than the expected yield on a long-term bond, then investors will sell the long-term bond and buy the short-term bonds. Therefore, an increase in the long-term bond yield results in a decrease in the short-term bond yield until the average expected yields of the two are equal.

On the other hand, if the average expected yield on short-term bonds is less than the average expected yield on a long-term bond, investors will buy the long-term bonds and sell the short-term bonds. Thus, as the long-term bond yield decreases, the short-term yield increases until the average expected yield of the two are equal.

This theory explains the first two empirical facts:

1. Short-term and long-term interest rates move together. An increase in short-term interest rates causes an increase in the expected short-term interest rate and increases the long-term rates on interest.
2. When short-term interest rates are low, interest rates are expected to be higher in the future, causing the long-term rate to be higher, and vice-versa.

The problem with the expectations theory is that it does not explain why the yield curve is usually upward sloping. If the short-term interest rates are just as likely to fall as they are to rise, the yield curve should be flat. This difficulty led to the development of the Segmented Market Theory of the term structure (Mishkin, 2015).

Segmented Market Theory

With this theory, each maturity is traded in a market that is unrelated to the market that another maturity is traded in. In this case, the bonds of different maturities are completely unrelated, instead of being perfect substitutes. Investors must have strong preferences for maturities for this to happen.

This theory explains the third empirical fact:

3. Yield curves almost always slope upward. Investors have strong preferences for short-term bonds because they are risk-averse and want to avoid interest rate risk. They are hesitant to take risks on long-term bonds because short-term bonds will have higher prices and lower yields. If short-term yields are high, the yield curve will be inverted.

If markets are unrelated, why do interest rates move together? Why are high short-term interest rates and low long-term interest rates correlated, and vice-versa? The Liquidity Premium Theory explains the answers to these questions.

Liquidity Premium Theory

In this theory, the expected short-term interest rates determine the yield on long term bonds, just like the Expectations Theory. Short-term interest rates are more desirable than long- term interest rates for risk-averse investors, just like the Segmented Market Theory. For investors to be enticed to hold long-term, they must receive a liquidity premium to compensate them for interest rate risk. The liquidity function is an increasing function of the years to maturity because the interest rate risk increases with the maturity of the bond. So how do we now explain the inverted yield curve? The expectation of falling short-term interest rates effect on the long-term interest rates is greater than the liquidity premium effect on the yield curve (Mishkin, 2015).

III. Why Quantitative Easing?

Quantitative easing stimulates borrowing and spending activity, thus promoting economic growth. Its effect on the economy is through changes in interest rates on long-term securities. It is not a new approach, as it was used by the Federal Reserve in the 1930s, the Bank of Japan in 2001, and the Bank of England in 2009. The world faced the worst economic crisis in 2008 since the Great Depression. It began in the U.S. housing market, quickly spread to the U.S. financial sector, and finally the global financial sector. Bringing down investment banks, commercial banks, insurance companies, and mortgage lenders, this crisis caused a steepening of the yield curve and led to a slowdown in U.S. and global growth.

In response to a deteriorating economy, the Federal Reserve purchased hundreds of billions of dollars' worth of assets such as government bonds and mortgage-backed securities. The idea behind these purchases was to increase demand for those securities and raise their prices. Because prices and yields are inversely related, interest rates fall as prices increase. This causes a decrease in the cost to businesses for financing capital investments. An increase in investment should boost economic activity, create new jobs, and thus reduce the unemployment rate. Three rounds of quantitative easing were used since 2009, all with different goals (FRED, 2016).

During the first round of quantitative easing, known as QE1, which ran from March 2009 through March 2010, the treasury yield curve was very steep. The primary goal was to increase the availability of credit in private markets in order to restart mortgage lending in the housing market. The Fed purchased $1.25 trillion in mortgage-backed securities and $200 billion in federal agency debt. Federal agency debt is issued by agencies, such as Fannie Mae and Freddie Mac, to fund mortgages. The Fed also purchased $300 billion in long-term Treasury securities in order to help lower interest rates in general (Forbes, 2015).

The second round of quantitative easing, QE2, began in November 2010 and ended in June 2011. This was used to strengthen the economic recovery and combat possible deflation. The Federal Reserve purchased $600 billion of long-term treasury bonds. The hope was to encourage economic growth through lower interest rates because of increased consumer spending and business investment. At this point, the yield curve started to become less steep (Forbes, 2015).

There was also a third round of quantitative easing, known as QE3, which lasted from September 2012 through October 2014. The U.S. economy needed QE3 because it was suffering from a deficiency of demand. So, the Federal Reserve purchased $40 billion per month worth of mortgage-backed securities. With this round, the yield curve transformed back to the state it was before the recession in 2007 (Forbes, 2015).

In between QE2 and QE3, the Federal Reserve launched a program called Operation Twist. During this time between September 2011 and June 2012, the Fed sold short-term Treasury securities and used the proceeds to purchase long-term Treasuries. This program was meant to put downward pressure on longer-term interest rates. The twist shifted the central bank's focus from repairing the damage from the mortgage crisis to supporting general lending. The Fed was moving investors away from safe Treasuries into riskier loans with higher returns. Intentionally lowering yields forced investors to help the economy by considering different investments (Forbes, 2015).

IV. Literature Review: An Assessment of Quantitative Easing

This section aims to sample other opinions on the effectiveness of quantitative easing. As a controversial policy decision, it is important to see what other people thought of the Federal Reserve in action. Researchers need to examine the views of the Federal Reserve in action in order to develop their own argument to explain the impact of quantitative easing on the term structure of interest rates. The literature has been separated into three main parts, exploring how others define quantitative easing and whether they believe it should/did work.

What QE is?

Tropeano (2012) offers varying interpretations of quantitative easing in her article, "*Quantitative easing in the United States after the crisis: conflicting views.*" The first interpretation was the central bank will continue to flood the market with money to cause inflation. Her second claims the goal of monetary policy is to recover financial asset prices to sustain banks' profits and to restore the value of household wealth. She aims to explain the first interpretation with those of other economists, beginning with quantitative easing and the liquidity trap. This is a situation in which more cash introduced to the private banking system by a central bank fails to decrease interest rates, making monetary policy ineffective.

Krugman (2012) believes monetary policy is not ineffective during a liquidity trap situation. Rather, it may be effective if people believe that the increase in money supply will continue in the future and price levels will increase in the long run. It will be ineffective if the interest rate is zero and negative interest is not possible. If prices are flexible, monetary policy may affect consumption because people will prefer to consume more in the present if inflation is expected to rise in the future. Krugman argues that a liquidity trap can occur even in a flexible prices economy and that monetary policy will not cause unemployment. The Fed must commit to inflation to get out of the liquidity trap, which Krugman claims is possible through quantitative easing.

In regards to her second interpretation, Tropeano (2012) claims quantitative easing is a way to restore asset prices and consumption out of wealth. The central bank wants to only restore the asset values of shares and bonds to save the balance sheets of financial institutions. It wants to protect wealth of most citizens rather than support investment led growth that may expand wealth. This is not encouraging if we look at long term sustainability of policies because there would continue to be the same unequal distribution of wealth that already exists.

Blinder (2010), opens on his thought of quantitative easing in his article, *"Quantitative Easing: Entrance and Exit Strategies."* The early stages of the quantitative easing policy were ad hoc, reactive, and institution based. It was basically just a reaction to the financial crisis and a plan on how to attack it. The Fed was making things up on the fly, often acquiring assets in the context of rescue operations for specific companies on very short notice. However, the Fed's purchasing, lending, and guarantee programs took on a more systematic, thoughtful, and market-based approach. The goal became to push down risk premiums rather than save faltering institutions. As evidence will show, the Fed's quantitative easing attack on interest rate spreads appears to have been successful, at least in part. Once the Fed embarked on quantitative easing in a major way, spreads tumbled dramatically.

Why it shouldn't/didn't work?

Yu (2016) offers reasons why quantitative easing may not work in his article, "*Did Quantitative Easing Work?*" He claims it should not work because traditional theories claim the term structure of interest rates are determined by investor expectations about the path and volatility of future interest rates and the degree of avoiding risk. Therefore, buying large quantities of long-term bonds should not affect long-term rates. This strategy did work, however.

Thornton (2010) discusses the hazards of quantitative easing throughout, *"The Downside of Quantitative Easing."* The first potential danger of quantitative easing is it increases the likelihood that long-run inflation could increase above the Fed's objective of 2%. The high level of excess reserves can create a large increase in the money supply if banks increase their lending/investing. A second reason is the considerable disagreement among economists and policymakers about whether, and to what extent, money growth is inflationary. A third reason for concern is that employment growth is uncharacteristically slow during this recovery. The Fed will be tempted to purchase more securities, which could have an inflationary effect on the economy. A fourth reason, related to the third, the FOMC (Federal Open Market Committee) may be concerned about the adverse effects on the financial market from selling large amounts of government securities quickly, if needed to fight inflation. This concern will make the FOMC less likely to engage in large-scale asset sales and is likely to be intensified if employment growth is slow and the unemployment rate high.

Why it should/did work?

There are several different interpretations of quantitative easing discussing the Fed's motives and whether this plan should work. Yu (2016) claims quantitative easing might work by affecting the expectations about future rates. The Federal Reserve might be able to commit to carrying out its policy of holding the federal funds rate at zero. Buying large amounts of assets might worry investors that the Fed will raise the federal funds rate if inflation rises above its target. This will not lower long-term rates because investors would not trust the Fed. Yu believes quantitative easing will make the Fed's promise more convincing.

Yu (2016) believes quantitative easing significantly lowered long-term rates in the short-run and longer term by changing investor's expectations about future fed funds rates. Over the 2-day window that QE1 was announced, the expected federal funds rate fell, indicating that QE1 did actually lower investor's expectations of future short-term rates. QE1 and QE2 had the largest effects, followed by a small effect from Operation Twist and QE3. Later programs did not shift expectations as much as earlier programs. (Krishnamurthy and Vissing-Jorgensen, 2011) Quantitative Easing worked by lowering the supply of bonds of particular maturities. The yields on Treasury bonds of the same maturity as those purchased through QE1 fell the most, signaling market segmentation (Michael Cahill). Quantitative easing lowered mortgage rates on announcement dates (showed by Krishnamurthy and Vissing-Jorgensen) and reduced mortgage rates (Andreas Fuster and Paul Willen). Risks of quantitative easing include uncertainty if QE will lead to too much liquidity and high inflation. The economy might grow so fast that it is difficult for Fed to raise interest rates in time to avert inflation. With yields on long-term assets very low, investors may allot a greater share of their portfolios to riskier assets. This leaves investors' portfolios more sensitive to interest rate changes and market volatility.

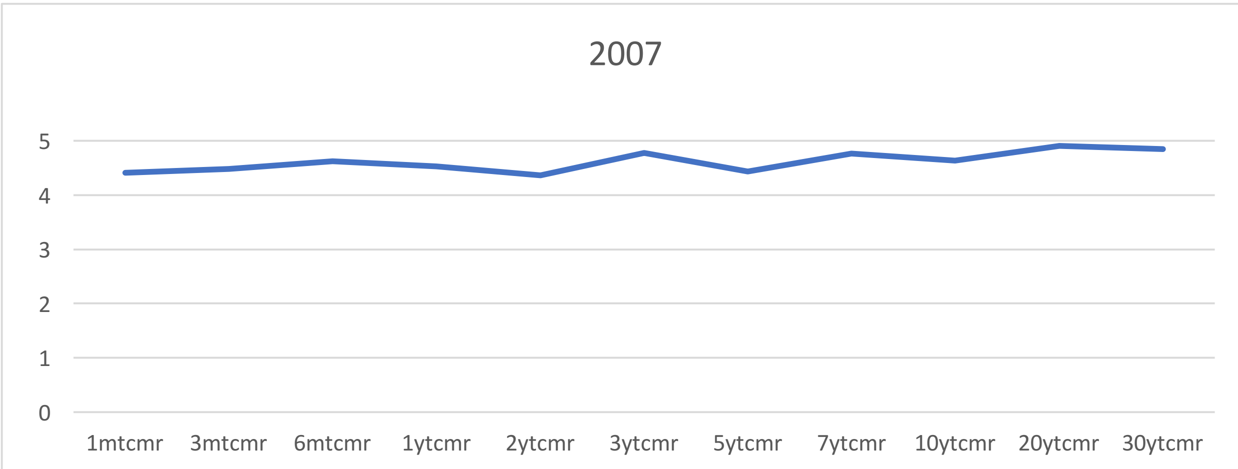
Quantitative easing may also work if markets are segmented. Yu explains that, in this case, bonds of different maturities are no longer perfect substitutes. Therefore, the supply of maturities can affect their yields. Quantitative easing will reduce the supply of long-term bonds, causing prices to increase and yields to fall. Yu also claims quantitative easing can affect the term premium by reducing investors' risk tolerance. The term premium is the compensation that investors require for bearing the risk that short-term yields do not grow as expected. Reducing the quantity of riskier long-term assets will reduce the total amount of risk held by investors. Therefore, they will require less compensation to hold risky bonds, dropping the risk premium.

Arvind Krishnamurthy and Annette Vissing-Jorgensen (2011) explain what they believe the results quantitative easing were in, *"The Effects of Quantitative Easing on Interest Rates."* QE1 and QE2 significantly lower nominal interest rates on Treasuries, Agencies and highly-rated corporate bonds. This was driven mainly by an increase in the safety price premium of assets with near-zero default. QE1 and QE2 purchases of long-term Treasuries have had a smaller effect on lower-grade corporate bonds. The impact of quantitative easing on MBS rates is large when QE involves MBS purchases (QE1), but not when it involves only Treasury purchases (QE2). Evidence from inflation swap rates and TIPS (Treasury Inflation Protected Securities) show that expected inflation increased substantially due to QE1 and modestly due to QE2. This implies reductions in real rates were larger than reductions in nominal rates. They found only small effects on nominal (default-adjusted) interest rates on less safe assets such as Baa corporate rates.

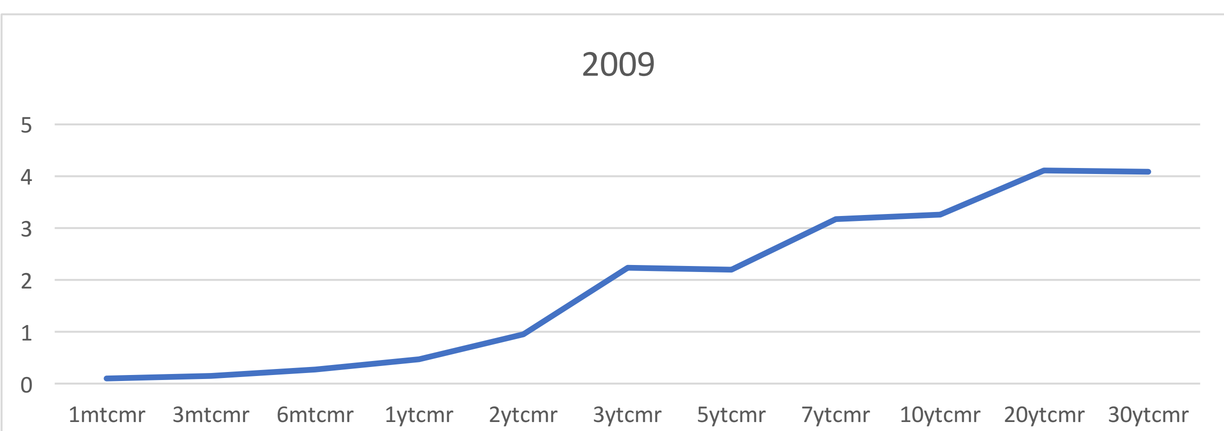
V. Data: Evidence of Quantitative Easing

The empirical portion of this research used data to show evidence of quantitative easing. Data was downloaded from FRED Database to compare term structures before and after the recession starting in 2001 and ending in 2015. At first the yearly term structures of 1 month to 30 year U.S. Treasury Securities were used. This data was for Treasury securities with a constant maturity rate was used. The constant maturity rate is an average yield on United States Treasury securities adjusted to a constant maturity of 1 year by the Federal Reserve. This rate exemplifies the Expectations Theory of the Term Structure of Interest Rates, which says an interest rate on a bond that matures in 'n' years is equal to the average expected short-term rates over 'n' years. Yields are incorporated by the United States Treasury from the daily yield curve.

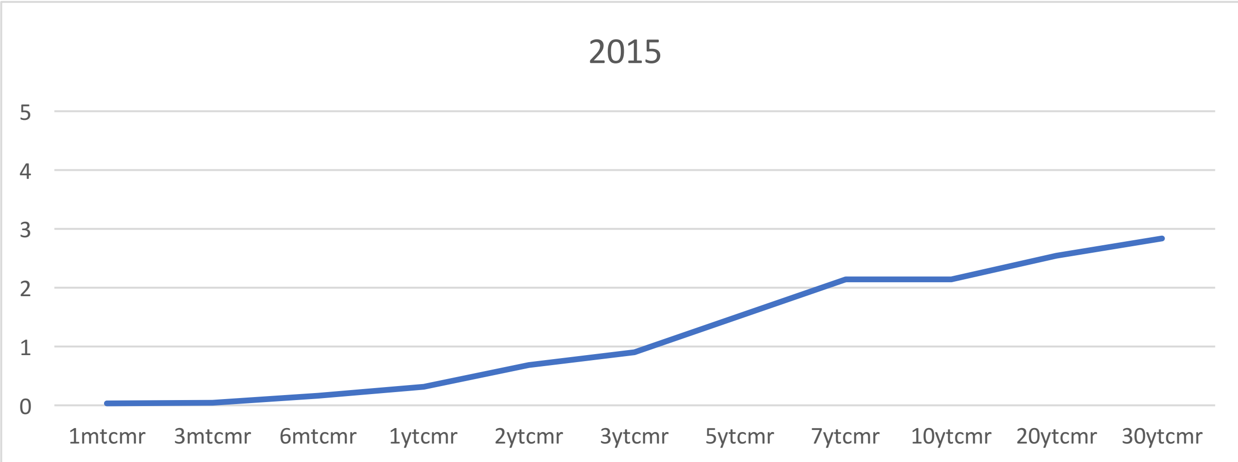
The course of change in of the yield curve can be described in three steps. During stable economic times, the yield curve is upward sloping. However, as short term interest rates rise, the yield curve starts to flatten out. A flat yield curve, where short term rates are level with long term rates, is a strong indicator of a recession.



When the yield curve inverts (where the spreads are negative), the Fed attempts to lower the short-term rates. If there is an increase in expected inflation in the market, the demand on long-term bonds will drop. The higher the inflation rate, the more interest rates are likely to rise because lenders will demand a higher compensation for the decrease in purchasing power. Investors view long-term assets as undesirable because of falling profits. High interest rates mean the cost of borrowing is very expensive, therefore reducing economic activity. Therefore, the Fed slashes interest rates to encourage spending. By doing this, however, the Fed cut short-term interest rates. This increased the interest rate spreads between short and long-term securities, causing the yield curve to be very steep.



This is where quantitative easing truly starts to come into effect. The Fed tries to encourage lending to bring down those long-term rates by purchasing long-term securities.

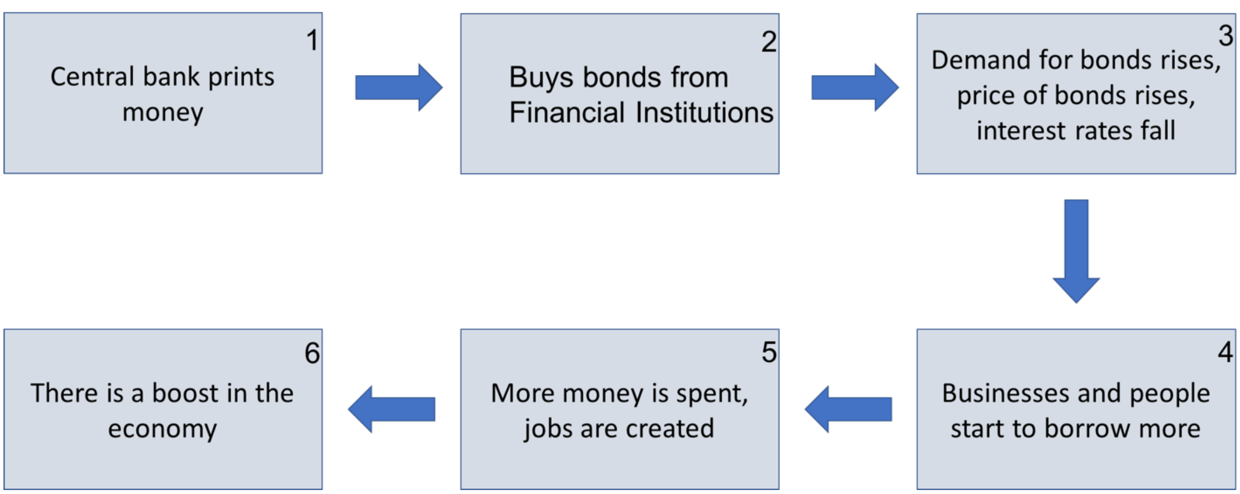


VI. A Statistical Illustration of the Effects of Quantitative Easing on the Relationship Between Long-Term and Short-Term Yields

While the data used above was helpful in producing graphs to show variations of the yield curve over time, it is evident from Table A that the yearly rates do not allow for an in-depth view of exactly where quantitative easing occurred. In this next portion, quarterly data was used to correct for that issue. As shown in Table B, the closing gap between 1 and 10 year bonds prior to the recession is a strong indicator of a potential inverted yield curve. From 2006 Q4 to 2007 Q1 the spread is negative, showing the short-term yields are higher than long term yields, thus creating the inverted yield curve. From the end of QE2 into QE3, the spreads began to tumble dramatically.

This data was used to calculate the spread between the 1 year and 10 year bonds. The spread was used to determine whether there was any correlation between the two maturities that might allow us to use one to predict the other. A ten-year range seemed to be an appropriate choice because anything less would have been too short. Using Stata software and the data collected from FRED database, regression tests were conducted to develop two equations. The first was to calculate the 10-year yield as a function of the 1-year yield. The second was to calculate the 10-year yield as a function of the 1-year yield with quantitative easing.

Before any equations could be developed, a stationary test was conducted for the three variables in question: 1-Year Yield, 10-Year Yield, Employment Growth Rate. The employment growth rate was being used to represent the impact of quantitative easing because the Fed was looking at employment when setting its policies. Right before this policy was introduced, interest rates on long-term assets were very high. This meant that it was too costly to borrow. When QE was initiated, more money was introduced into the economy because the Fed was purchasing these assets. The increase in cash flow drove up prices and lowered interest rates. Since it was now less costly to borrow, demand for assets increased. This led to more borrowing and more investment, which further drove up prices. As wealth from capital gains and investment increased, more money was being spent, thus increasing the GDP. Eventually the higher spending and investment lead businesses to create more jobs in an attempt to keep up with the demand for their offerings.



Two regression tests were used to ensure the use of these three variables. Data had to be used starting in the second quarter of 2007 because it did not pass the tests in the years prior. The first test was a stationarity test. A variable is stationary if its change, over time is not a random walk. The stationarity test for the 1-year yield variable can be seen in Tables 1 and 2.

Table 1: Stationarity Test for 1-Year Yield Without Constant (Source: Stata)

```
-------------------------------------------------------------------------------
dfuller yield1 in 26/63, noconstant regress lags(0)

Dickey-Fuller test for unit root                   Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -5.541            -2.639            -1.950            -1.605

------------------------------------------------------------------------------
    D.yield1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      yield1 |
         L1. |  -.1482075    .026747    -5.54   0.000    -.2024021   -.0940129
------------------------------------------------------------------------------
```

Table 2: Stationarity Test for 1-Year Yield With Constant (Source: Stata)

```
-------------------------------------------------------------------------------
. dfuller yield1 in 26/63, regress lags(0)

Dickey-Fuller test for unit root                   Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -4.795            -3.662            -2.964            -2.614
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0001

------------------------------------------------------------------------------
    D.yield1 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      yield1 |
         L1. |  -.1543905   .0322008    -4.79   0.000    -.2196968   -.0890842
             |
       _cons |   .0185146   .0522245     0.35   0.725    -.0874017    .1244309
```

The test statistic is greater than the critical value at the 1% level in both tests. This shows that the variable for the yields on 1-year bonds is not a random walk with and without a constant.

Table 3 and Table 4 show results from testing the 10-year yield.

Table 3: Stationarity Test for 10-Year Yield With Constant (Source: Stata)

```
--------------------------------------------------------------------------------

dfuller yield10 in 26/63, regress lags(0)


Dickey-Fuller test for unit root                   Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -1.664            -3.662            -2.964            -2.614
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.4499

------------------------------------------------------------------------------
   D.yield10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     yield10 |
         L1. |  -.1003709   .0603292    -1.66   0.105    -.2227242    .0219825
             |
       _cons |   .2063025   .1814746     1.14   0.263    -.1617451      .57435
```

Table 4: Stationarity Test for 10-Year Yield Without Constant (Source: Stata)

```
--------------------------------------------------------------------------------
. dfuller yield10 in 26/63, noconstant regress lags(0)

Dickey-Fuller test for unit root                   Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -1.945            -2.639            -1.950            -1.605

------------------------------------------------------------------------------
   D.yield10 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     yield10 |
         L1. |  -.0348578   .0179182    -1.95   0.059    -.0711636    .0014479
```

The yield on a 10-year bond is not stationary around a constant; the test statistic in Figure 6 is not greater than any critical value. However, this yield is very close to stationary, at the 5% level, without the constant. This may imply that this variable is a random walk. Based on the Expectations Theory, the 10-year yield should be correlated to the 1-year yield. Therefore, because it was borderline stationary, according to this test, it was used for the sake of argument. The change in employment growth rate is stationary, as seen in Table 5 with the test statistic also greater than all critical values.

Table 5: Stationarity Test for Change in Employment Growth Rate (Source: Stata)

```
------------------------------------------------------------------------------
. dfuller d.emplgrowthrate in 26/63, regress lags(0)

Dickey-Fuller test for unit root                   Number of obs   =        38

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -4.811            -3.662            -2.964            -2.614
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0001

------------------------------------------------------------------------------
D2.            |
emplgrowthrate |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
emplgrowthrate |
           LD. |  -.7826087   .1626808    -4.81   0.000    -1.112541   -.4526768
               |
         _cons |   4.60e-10   .0438429     0.00   1.000    -.0889175    .0889175
```

The other test was to check for serial correlation. Serial correlation is when the residuals of the regression across time are correlated, not random. Usually time series regressions suffer from serial correlation. Serial correlation doesn't bias the estimates of the coefficients. The first correlation test was between the two yield maturities. Looking at Table 7, The adjusted R-squared value tells us that 54% of the variation in the dependent variable is explained by variation in the independent variable. The t-values show that each coefficient is statistically different from zero, therefore these two variables are correlated. This should imply that they can be studied together. The second tested the correlation between all three variables (Table 8). The adjusted R-squared value tells us that 57% of the variation in the dependent variable is explained by variation in the independent variable. The t-values show that each coefficient is statistically different from zero, therefore these three variables are correlated. This should imply that they can be studied together.

Assuming the validity of these tests was accurate, the two equations were formulated. The algebra below contains the step-by-step process to how the equations were developed and examples of them in use.

This model follows a heuristic approach similar to that of Michal Kalecki in his essay, *Theory of Economic Dynamics*. This is a technique that uses a practical method, not guaranteed to work perfectly, but is sufficient for immediate goals. This was the most reasonable approach due to time constraints limiting the possibility of finding an optimal solution.

We begin by assigning some basic variables to be used throughout the model. The letter 'i' denotes the yield on 10-year bonds. The average yield on 1-year bonds during 2007 QE2 through 2016 will be defined as '$\bar{r}$.' There is a risk parameter associated with holding 10-year bond, such as interest rate risk. This will be denoted by the letter 'g.' Finally, we also have an inconvenience factor, 'e', associated with holding 1-year bond. This is the risk that the yield falls as opposed to staying constant or rising, as the bond matures every year; inconvenience in that transaction cost associated (brokerage fees) involved in purchasing a new bond every year.

We are going to assume the interest rate spread is defined as the yield on 10-year bonds less the yield on 1-year bonds. This gives us the following: $i - \bar{r}$. Lets suppose, based on the Fed's actions, the interest rate spread is modified through quantitative easing, defined as qe. We end up with the following equation:

(1) $i – \bar{r} = g – e + qe$

We will need to assume the risk component 'g' is, in fact, proportional to the risk that the price of the 10-year bond will decrease. Suppose investors have a sense, based on past fluctuations, as to what the minimum price of the 10-year bond is. We are able to develop an equation that defines the risk component, 'g,' as being related to fluctuations in 10-year bond price. Fluctuations in the ten-year bond price are measured as the price of the bond minus the minimum price of the 10-year bond, divided by the price; i.e:

(2) $g=a[(P-Pmin)/P]$ or $g=a[(1-Pmin/P)]$;

where the parameter "a" is the long-term risk coefficient.

Given that yields and prices are inversely related, the long-term risk component can be rewritten as:

(2') $g = a(1 - i/imax)$;

where imax is the maximum observable 10-year yield. By substituting 2' into 1, the interest rate spread is rewritten as:

(3) $i - \bar{r} = a[(1- i/imax)] - e + qe$

Letting qe, quantitative easing, be a function of the employment growth rate (ER), and by solving for the ten-year yield, i, in (3) yields:

(4) $i = 1/[1+ (a/imax)](\bar{r}) + (a - e)/[1 + (a/imax)] + f(ER)/[1 + (a/imax)]$

To estimate equation 4, we make some heuristic assumptions to approximate $\bar{r}$, and f(ER). We assume that $\bar{r}$, the average short term yield, is just some linear function of a 1-year yield' i.e:

(5) $\bar{r}=Bo+B1*r1$, where $0<B1$ $B1=0$ $B1>0$;

and that:

(6) $qe = \alpha o + \alpha 1*\Delta EG$, where $\alpha 0, \alpha 1 < 0$[1]

Substituting (5) and (6) into (4) yields:

(7) $i=(\alpha o+a-e+Bo)/(1+a/imax) + (B1/(1+(a/imax))*r1 + [\alpha 1/(1 + a/imax)]*\Delta EG$

We estimate two versions of equation 7 to understand the relationship between the ten-year treasury yield and one-year treasury yield, and to measure the effect of quantitative easing on the 10-year treasury yield. All estimates utilized STATA's Prais-Winston technique to

[1] Various FOMC statements refer to the labor market.

correct for serial correlation. The version assumes no quantitative easing, and the estimates are summarized in Table 6. The second allows for quantitative easing, and the estimates are summarized in Table 7.

Table 6: Estimates of the Relationship Between 10-Year and 1-Yields: Without Quantitative Easing (2007: Q2 to 2016:Q3)

Prais-Winsten AR(1) regression -- iterated estimates

Source	SS	df	MS		
				Number of obs =	38
				F(1, 36) =	44.56
Model	3.97802914	1	3.97802914	Prob > F =	0.0000
Residual	3.2137549	36	.08927097	R-squared =	0.5531
				Adj R-squared =	0.5407
Total	7.19178405	37	.194372542	Root MSE =	.29878

yield10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
yield1	.5069326	.1208779	4.19	0.000	.261781	.7520843
_cons	2.20632	.4537749	4.86	0.000	1.286022	3.126618
rho	.905904					

Durbin-Watson statistic (original) 0.267952
Durbin-Watson statistic (transformed) 1.468922

The constant and slope coefficients has the expected signs are statistically different from zero. The slope indicates that for every 1 percentage point change in the one-year yield, the ten-year yield changed by half of a percentage point.

When include our proxy variable for quantitative easing, we get similar results. See Table 7.

Table 7: Estimates of the Relationship Between 10-Year and 1-Yields: With Quantitative Easing (2007: Q2 to 2016:Q3)

Prais-Winsten AR(1) regression -- iterated estimates

Source	SS	df	MS		
				Number of obs =	38
				F(2, 35) =	25.74
Model	4.05183172	2	2.02591586	Prob > F =	0.0000
Residual	2.75483741	35	.07870964	R-squared =	0.5953
				Adj R-squared =	0.5721
Total	6.80666913	37	.183964031	Root MSE =	.28055

yield10	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
yield1	.4646968	.1172951	3.96	0.000	.226575	.7028186
emplgrowthrate						

```
          D1. |    .3447807   .1424723     2.42   0.021     .0555465    .6340148
              |
        _cons |    2.244954   .4853623     4.63   0.000     1.259616    3.230292
--------------+----------------------------------------------------------------
          rho |     .920609
-------------------------------------------------------------------------------
Durbin-Watson statistic (original)    0.321417
Durbin-Watson statistic (transformed) 1.545598
```

All the coefficients have the expected signs and are statistically different from zero. The inclusion of the change in the employment growth rate reduces the one-year yield coefficient to .464. The change in the employment growth rate coefficient is about .34—meaning that for a 1 percentage point change in the *change* employment growth rate, the 10-year yield increased by .34 percentage points.

Other indicators of quantitative easing were used, such as the GDP growth rate, the change in GDP growth rate and a dummy variable for the quantitative easing years. None of these variables provided coefficients statistically different from zero. These results are available upon request. The statistical significance of the change in the growth rate of employment is indicative of the effect of quantitative easing on the 10-year yield.

The estimates provided in Tables 6 and 7 can be used to provide a rough approximation to the long-term yield risk coefficient, a, and the expected average short-term yield slope coefficient, B1. To illustrate, we assume imax is equal to 4.85, the highest long-term yield during 2007 Q2 - 2016 Q3. Recall from equation (7') and Table 1 that the constant and the slopes are: (a - e+Bo)/(1+a/imax) = 2.21, and B1/(1+a/imax) = .507, assuming no quantitative easing. To solve for a, assume that e = 0 = Bo, thus:

(8) a/(1+a/imax) =2.24, or a = 4.0625.

The expression for the slope coefficient from equation 7 is:

(9) B1/(1+a/(4.85)) = .507, or B1 = .93

So the average yield on 1-year bonds is equal to the following:

(10) $\bar{r} = 0 + 0.93r1$ (where r1 is the current yield on a 1-year bond)

Similar results are generated when we use the estimates that account for quantitative easing. Recall from equation (7) and Table 2 that the constant and the slopes are: $(\alpha o+a-e+Bo)/(1+a/imax) = 2.24$, $B1/(1+a/imax) = .465$, and $\alpha 1/(1 + a/imax) = .345$ an assuming. To solve for a, assume that $e = 0 = Bo = \alpha o$, thus:

(11) $a/(1+a/imax) =2.24$, or $a = 4.16$.

The expression for the slope coefficient from equation 7 is:

(12) $B1/(1+a/(4.85)) = .465$, or $B1 = .86$

So the average yield on 1-year bonds is equal to the following:

(13) $\bar{r} = 0 + 0.86r1$ (where r1 is the current yield on a 1-year bond).

Likewise, the quantitative easing slope coefficient (which indicates how changes in the employment growth rate affect the interest rate spread) is:

(14) $\alpha 1/(1 + a/imax) = .345$, or $= .641$,

which indicates that for every 1 percentage point change in the change in employment growth rate, the change in (10-year-1-year) yield spread is .641.

VII. Conclusion

Upon completion of this project, the main goal was met. Understanding the history and rationale of quantitative easing, as well as empirically showing evidence of its success, has helped support the motives of the Federal Reserve in trying to pull the country out of the financial crisis. While there are many differing opinions on whether this was the correct policy to use, the data reinforces the facts and theories behind the term structure of interest rates. The original hypothesis of this paper was that quantitative easing was successful. Based on these findings, this would appear to remain true.

Unfortunately, these findings are not complete, and this has turned into a working project. There are still many things that need to be corrected for. In the algebra used to formulate the equations, heuristic assumptions were made to estimate the forward looking average short-term yield. This assumption was sufficient for the immediate goals of this project, but is not accurate for a long-term assessment of this topic. Also, different regression tests could have been implemented, but a lack of econometrics tightened the limits of use. It may have been better to use a longer maturity, such as 20 or 30 years to compare to 1 year, since the 20-year yield was borderline stationary. With all of this being said, this project has definitely opened up new paths for further research of this policy.

References

Blinder, A. S. (2010). Quantitative Easing: Entrance and Exit Strategies (Digest Summary). *Federal Reserve Bank of St. Louis Review*, *92*(6), 465-479.

Board of Governors of the Federal Reserve System (US), Treasury Constant Maturity Rate [DGS1], retrieved from FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/, December 2, 2016.

Forbes (2015). *What is quantitative easing?*

Kalecki Michal (1965). *Theory of Economic Dynamics*

Krishnamurthy, A., & Vissing-Jorgensen, A. (2011). *The effects of quantitative easing on interest rates: channels and implications for policy* (No. w17555). National Bureau of Economic Research.

Mishkin, F. S. (2015). *The economics of money, banking and financial markets* (11th ed.). Boston, MA: Pearson.

Talton, Jon (2014). *How did Federal Reserve do handling Great Recession?* Seattle Times

The Economist (2015). *Quantitative Easing in Focus: The U.S. Experience*

Thornton, D. L. (2010). The downside of quantitative easing. *Economic Synopses*, *2010*.

Tropeano, D. (2012). 11. Quantitative easing in the United States after the crisis: conflicting views. *Monetary Policy and Central Banking: New Directions in Post-Keynesian Theory*, 227.

Yu, Edison (2016). *Did Quantitative Easing Work?* Federal Reserve Bank of Philadelphia Research Department

Appendix

Table A: Yearly Interest Rates for Various Maturities (Source: FRED Database)

year	1mtcmr	3mtcmr	6mtcmr	1ytcmr	2ytcmr	3ytcmr	5ytcmr	7ytcmr	10ytcmr	20ytcmr	30ytcmr	10yr 1 yr spread
2001	2.47	3.48	3.45	3.49	3.83	6.22	4.56	6.2	5.02	5.63	5.49	1.53
2002	1.63	1.64	1.72	2	2.64	4.09	3.82	4.88	4.61	5.43	5.43	2.61
2003	1.02	1.03	1.08	1.24	1.65	3.1	2.97	4.3	4.01	4.96	.	2.77
2004	1.27	1.4	1.61	1.89	2.38	2.1	3.43	3.52	4.27	5.04	.	2.38
2005	3	3.22	3.5	3.62	3.85	2.78	4.05	3.87	4.29	4.64	.	0.67
2006	4.75	4.85	5	4.94	4.82	3.93	4.75	4.15	4.8	5	4.91	-0.14
2007	4.41	4.48	4.62	4.53	4.36	4.77	4.43	4.76	4.63	4.91	4.84	0.1
2008	1.29	1.4	1.66	1.83	2.01	4.35	2.8	4.51	3.66	4.36	4.28	1.83
2009	0.1	0.15	0.28	0.47	0.96	2.24	2.2	3.17	3.26	4.11	4.08	2.79
2010	0.11	0.14	0.2	0.32	0.7	1.43	1.93	2.82	3.22	4.03	4.25	2.9
2011	0.04	0.05	0.1	0.18	0.45	1.11	1.52	2.62	2.78	3.62	3.91	2.6
2012	0.07	0.09	0.13	0.17	0.28	0.75	0.76	2.16	1.8	2.54	2.92	1.63
2013	0.05	0.06	0.09	0.13	0.31	0.38	1.17	1.22	2.35	3.12	3.45	2.22
2014	0.03	0.03	0.06	0.12	0.46	0.54	1.64	1.74	2.54	3.07	3.34	2.42
2015	0.04	0.05	0.17	0.32	0.69	0.9	1.53	2.14	2.14	2.55	2.84	1.82

Table B: Quarterly Interest Rates for Various Maturities (Source: FRED Database)

Quarter	1mcmtr	3mcmtr	6mcmtr	1ycmtr	2ycmtr	3ycmtr	5ycmtr	7ycmtr	10ycmtr	20ycmtr	30ycmtr	1 yr vs 20 yr
2001 Q4	2.00	1.95	1.98	2.25	2.87	3.32	4.08	4.52	4.76	5.48	5.30	3.23
2002 Q1	1.73	1.75	1.90	2.32	3.20	3.75	4.46	4.88	5.08	5.74	5.43	3.42
2002 Q2	1.73	1.75	1.91	2.35	3.23	3.77	4.45	4.85	5.11	5.77	#N/A	3.42
2002 Q3	1.69	1.67	1.67	1.81	2.24	2.63	3.36	3.90	4.27	5.19	#N/A	3.38
2002 Q4	1.37	1.37	1.39	1.53	1.89	2.27	3.01	3.60	4.00	5.02	#N/A	3.49
2003 Q1	1.18	1.17	1.19	1.30	1.65	2.07	2.91	3.47	3.92	4.90	#N/A	3.60
2003 Q2	1.07	1.06	1.07	1.15	1.42	1.77	2.57	3.13	3.62	4.59	#N/A	3.44
2003 Q3	0.92	0.95	1.02	1.22	1.68	2.20	3.14	3.72	4.23	5.17	#N/A	3.95
2003 Q4	0.91	0.94	1.02	1.30	1.86	2.38	3.24	3.78	4.29	5.16	#N/A	3.86
2004 Q1	0.91	0.93	1.00	1.22	1.69	2.16	2.98	3.50	4.01	4.89	#N/A	3.67
2004 Q2	0.95	1.10	1.36	1.78	2.45	2.97	3.72	4.18	4.60	5.36	#N/A	3.58
2004 Q3	1.37	1.51	1.79	2.08	2.56	2.92	3.51	3.92	4.30	5.07	#N/A	2.99
2004 Q4	1.84	2.05	2.30	2.47	2.82	3.06	3.49	3.86	4.18	4.87	#N/A	2.40
2005 Q1	2.36	2.59	2.88	3.07	3.45	3.62	3.89	4.10	4.30	4.76	#N/A	1.69
2005 Q2	2.71	2.93	3.18	3.34	3.65	3.73	3.87	3.98	4.16	4.55	#N/A	1.21
2005 Q3	3.23	3.44	3.71	3.79	3.96	3.99	4.04	4.11	4.22	4.51	#N/A	0.72
2005 Q4	3.70	3.91	4.25	4.29	4.36	4.37	4.39	4.43	4.49	4.77	#N/A	0.48
2006 Q1	4.36	4.51	4.66	4.64	4.60	4.58	4.55	4.56	4.58	4.76	4.66	0.12
2006 Q2	4.67	4.83	5.03	5.02	5.00	4.99	4.99	5.02	5.07	5.29	5.14	0.27
2006 Q3	4.95	5.04	5.17	5.09	4.93	4.87	4.84	4.85	4.89	5.09	4.99	0.00
2006 Q4	5.02	5.03	5.11	4.99	4.74	4.65	4.60	4.60	4.63	4.83	4.74	-0.16
2007 Q1	5.11	5.11	5.13	5.01	4.76	4.68	4.64	4.65	4.68	4.90	4.80	-0.11
2007 Q2	4.78	4.87	5.00	4.93	4.80	4.76	4.76	4.78	4.85	5.07	4.99	0.14
2007 Q3	4.28	4.43	4.61	4.54	4.39	4.42	4.51	4.60	4.74	5.01	4.95	0.47
2007 Q4	3.46	3.49	3.71	3.64	3.49	3.51	3.80	3.99	4.27	4.65	4.61	1.01
2008 Q1	2.13	2.10	2.16	2.11	2.03	2.17	2.75	3.15	3.67	4.40	4.41	2.29
2008 Q2	1.51	1.65	1.87	2.07	2.42	2.66	3.16	3.46	3.88	4.59	4.57	2.52
2008 Q3	1.39	1.52	1.86	2.13	2.36	2.63	3.11	3.44	3.86	4.49	4.45	2.36
2008 Q4	0.14	0.31	0.74	0.99	1.22	1.48	2.17	2.62	3.23	3.97	3.66	2.98
2009 Q1	0.12	0.21	0.40	0.57	0.90	1.27	1.76	2.24	2.74	3.69	3.46	3.12
2009 Q2	0.11	0.17	0.32	0.52	1.02	1.50	2.24	2.89	3.32	4.19	4.17	3.67
2009 Q3	0.11	0.16	0.25	0.45	1.03	1.56	2.47	3.12	3.52	4.28	4.32	3.83
2009 Q4	0.04	0.06	0.16	0.35	0.88	1.39	2.30	2.99	3.46	4.27	4.34	3.92
2010 Q1	0.07	0.11	0.19	0.36	0.92	1.47	2.43	3.16	3.72	4.49	4.62	4.13
2010 Q2	0.13	0.15	0.22	0.38	0.87	1.38	2.25	2.94	3.49	4.20	4.37	3.82
2010 Q3	0.14	0.15	0.20	0.27	0.54	0.83	1.55	2.19	2.78	3.60	3.86	3.33
2010 Q4	0.12	0.14	0.18	0.26	0.49	0.75	1.50	2.19	2.88	3.84	4.17	3.58
2011 Q1	0.10	0.13	0.17	0.27	0.69	1.16	2.12	2.82	3.46	4.32	4.56	4.05
2011 Q2	0.02	0.05	0.10	0.20	0.56	0.94	1.85	2.54	3.20	4.07	4.34	3.87
2011 Q3	0.02	0.03	0.06	0.13	0.28	0.47	1.14	1.76	2.41	3.34	3.69	3.21
2011 Q4	0.01	0.01	0.05	0.11	0.26	0.42	0.95	1.50	2.05	2.75	3.04	2.64
2012 Q1	0.05	0.07	0.11	0.16	0.29	0.42	0.90	1.44	2.04	2.80	3.14	2.64
2012 Q2	0.06	0.09	0.14	0.19	0.29	0.40	0.79	1.24	1.83	2.55	2.94	2.36
2012 Q3	0.08	0.10	0.14	0.18	0.26	0.35	0.67	1.08	1.64	2.37	2.74	2.19
2012 Q4	0.09	0.09	0.14	0.17	0.27	0.36	0.69	1.12	1.71	2.46	2.86	2.29
2013 Q1	0.07	0.09	0.12	0.15	0.26	0.39	0.82	1.32	1.95	2.75	3.13	2.60
2013 Q2	0.03	0.05	0.09	0.13	0.27	0.43	0.91	1.38	1.99	2.78	3.14	2.65
2013 Q3	0.03	0.03	0.06	0.12	0.37	0.71	1.50	2.12	2.71	3.44	3.71	3.32
2013 Q4	0.06	0.06	0.09	0.13	0.33	0.63	1.44	2.12	2.74	3.50	3.79	3.37
2014 Q1	0.04	0.05	0.08	0.12	0.37	0.76	1.60	2.23	2.77	3.42	3.68	3.30
2014 Q2	0.02	0.03	0.06	0.10	0.42	0.87	1.66	2.19	2.62	3.18	3.44	3.08
2014 Q3	0.02	0.03	0.05	0.11	0.52	0.98	1.70	2.16	2.50	3.01	3.27	2.90
2014 Q4	0.03	0.02	0.08	0.15	0.54	0.97	1.60	1.99	2.28	2.69	2.97	2.54
2015 Q1	0.02	0.02	0.09	0.23	0.60	0.97	1.46	1.77	1.97	2.32	2.55	2.09
2015 Q2	0.01	0.02	0.09	0.25	0.61	0.97	1.53	1.91	2.16	2.62	2.88	2.37
2015 Q3	0.02	0.04	0.17	0.35	0.69	1.02	1.56	1.94	2.22	2.65	2.96	2.30
2015 Q4	0.09	0.13	0.32	0.47	0.84	1.14	1.58	1.94	2.19	2.60	2.96	2.13
2016 Q1	0.25	0.29	0.45	0.58	0.84	1.02	1.37	1.69	1.91	2.32	2.72	1.74
2016 Q2	0.21	0.26	0.40	0.57	0.77	0.92	1.24	1.54	1.75	2.15	2.57	1.58
2016 Q3	0.24	0.30	0.44	0.56	0.73	0.85	1.13	1.40	1.56	1.91	2.28	1.35

Table C: Summary of Table A (Source: Stata)

```
--------------------------------------------------------------------------------
. summarize yield10 yield1 emplgrowthrate d.emplgrowthrate in 26/63

    Variable |        Obs        Mean    Std. Dev.       Min        Max
-------------+---------------------------------------------------------
     yield10 |         38    2.791316    .8745475       1.56       4.85
      yield1 |         38    .7613158     1.19845         .1       4.93
             |
emplgrowth~e |
        --. |          38    .1342105    .5619831       -1.7         .6
       D1.   |         38    5.88e-10    .2731201        -.7         .7
```