
Analysing the Impact of Quantitative Easing Policy on US Sovereign Debt Valuation: Using A VAR Model during the period 1990 – 2022

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Abstract:

This study aims to examine the relationship between the Federal Reserve's Quantitative Easing policy and US sovereign debt valuation, focusing on the period from 1990 to 2022. Using a Vector Autoregressive (VAR) model, we analysed the dynamic interactions between key economic variables, including Treasury yields, QE amounts, GDP, inflation rates, and Federal Funds rates. The quantitative easing policies pursued by the US Federal Reserve have led to increased scrutiny of the debts of countries issuing reserve currencies. The US sovereign debt was significantly affected by these policies, but there has not been much work on the direct dynamics between QE policy and the value of sovereign debt for the US market. The study strives to contribute to the literature by estimating the US sovereign debt valuation reaction to changes in the balance sheet caused by the quantitative easing policy. Valuation of US sovereign debts is an important issue due to the influential role of US sovereign bonds in diverse international financial markets. Our findings indicate that large-scale asset purchases cause changes in U.S. sovereign debt bond prices and their valuation.

Key Words: Quantitative Easing policy, US sovereign debt, Vector Autoregressive (VAR) model, Treasury yields, QE amounts.

JEL Classification : E52, E58, E43, E44, H63, C32.

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1. Introduction:

The global financial crisis in 2008 brought with it a wave of quantitative easing (QE) that had the objective of stimulating the economy and preventing a collapse of the banking sector. The unconventional monetary policy has been introduced and practiced by central banks of developed economies as a conjunctive or alternative instrument to the traditional monetary policy tools in order to address issues related to financial crises that traditional policy by itself cannot effectively address. From 2008 to 2015, the Federal Reserve introduced the Quantitative Easing policy with aggregate purchases totalling USD 3.6 trillion (Fischer, 2021). The objective was to lower and stabilize long-term interest rates and to boost the money supply.

We try to estimate the impact of the Quantitative Easing policy on the valuation of US sovereign debt. We really know that the case of USA monetary policy does not have a clear basis on which to support a sound causal relationship between the interest rate, money supply, and Quantitative Easing. This is due to the uniqueness that distinguishes the US dollar in the first place and some other hard currencies to a lesser degree, in the equation that determines the features of the economic and financial relationship between the value of the currency and its damage, By the increase in the money supply. This is due to the calculations of the global demand for these currencies, especially the dollar, as the US Federal Reserve can enter into the implementation of extensive policies in quantitative easing and monetary issuance without referring to the calculations of the direct relationship between its value and its supply in the domestic market (Gharbi H, 2016). some other studies have shown that investment in sovereign debt was affected by the composition of the QE policy. The recent exceptional monetary operations have shown differences in risk premiums and have led to a debate on the impact of QE that may be rooted in the distinct composition of their portfolios (Filiani, 2021). we use the vector autoregressive model in our analysis, applying a high-frequency consistent lag selection into the specification with a comprehensive dataset from 1990 quarter 1 to 2022 quarter 1. We use this data and several relevant variables to construct a quarterly model of the economy with a focus on quantitative analysis.

From the previous we can impose the main problematic as following:

What is the impact of Quantitative Easing (QE) policy on US Sovereign Debt valuation?

To answer this problematic precisely, we can divide it to following main questions:

- What is the direct impact of Quantitative Easing policy on US sovereign debt yields?
- How does the effect of large-scale asset purchases on sovereign debt yield evolve over time?
- Does the Federal Reserve's inflation-targeting communication influence the impact of Quantitative Easing on US Treasury yields?

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- How do other macroeconomic factors (GDP growth, inflation rate, Federal Funds Rate) interact with QE in affecting sovereign debt valuation?

1.1. Hypotheses:

- **H1:** Quantitative Easing policy significantly reduces US sovereign debt yields in the short term.
- **H2:** The impact of large-scale asset purchases on sovereign debt yields persists beyond the immediate implementation period of QE.
- **H3:** The Federal Reserve's inflation-targeting communication enhances the effectiveness of QE in lowering long-term Treasury yields.
- **H4:** Quantitative Easing has a stronger impact on sovereign debt yields than traditional monetary policy tools during periods of economic stress.
- **H5:** The effectiveness of QE in influencing sovereign debt yields varies depending on the prevailing macroeconomic conditions (GDP growth and inflation rate).

2. Significance of the Study

Analysis of the US sovereign debt valuation and its potential distortion due to the Fed's policy measures is crucial for understanding the recent US sovereign bond market events and quantifying future bond price impact (Bulut, 2023). With this study, we hope to shed new light on this important area of financial economics. Therefore, to fulfill the significance of this study, the scope has been broad enough to encompass all products whose prices could be affected by changes in the underlying policy rate because of the resultant changes in the demand/supply dynamics. This study focuses on the longer-dated US Treasury securities. There are multiple reasons suggest that the US, is the most widely followed and a highly liquid market (especially for benchmark issues) (Sabri et al., 2022). Is likely to be especially influential and sensitive to signals from its central bank. Further, the US dollar is a major vehicle and a significant funding currency in the international carry trade, so some of the possible reactions to US monetary policy changes are particularly significant and potentially destabilizing for other groups of market participants (Kuok et al., 2023).

3. Theoretical Framework of the main Variables

In order to theoretically frame our article, we need to start from the understanding of how quantitative easing influences interest rates. The current debate is plagued with confusion about how quantitative easing might work. We would be much the wiser if QE were called large-scale asset purchases. All that QE does is replace a large quantity of interest-bearing debt with an equivalent quantity of interest-bearing reserves; the composition of private sector wealth is altered with no change in net worth (Ryan & Whelan, 2021).

In the case of liquidity traps, an increase in the money stock does not lead to changes in money demand and output. Moreover, central banks have to considerably reduce short-term interest rates in order to achieve those goals. In this frame of mind, we can structure our problems by relating a 0% nominal interest rate floor along with a central bank's asset purchases and liquidity provision to either commercial banks or regular banking corporations, to some concept of money, and define their standard functions that can make interest rate policy effective at the zero nominal interest rate (Keynes, 2024).

3.1. Theoretical Concepts of Quantitative Easing

First, we need to elaborate more on what quantitative easing actually is and its process. Typically, a country's central bank exercises two tools to stabilize the economy in a recession period: monetary policy and fiscal stimulus. Regarding monetary policy, a country's central bank typically uses the money supply or the interest rate as the policy instrument. Expanding a country's money supply easily gives birth to inflation, which makes interest rates lower and people have less incentive to carry money, which will have economic effects that central banks try to refrain from (Lavoie, 2020). Additionally, increasing the base money supply will result in higher reserve conditions, especially during the discharging season. As a result, the Federal Reserve System uses interest rates as the policy instrument to control the money supply in order to achieve the targets set by the government explicitly (Doan Van, 2020).

When an economy is already faced with persisting economic problems, reducing the base interest rate from the present level and increasing the liability among banks cannot guide the economy out of the recession. Unable to stimulate the economy using the interest rate, the central bank had to resort to quantitative easing, also called credit easing, to reduce long-term interest rates since reducing the short-term interest rate was no longer feasible (Shkodina et al.2020). The main mechanism that the central bank uses to rescue the economy is by purchasing long-dated securities and lowering the target levels of overall longer-term interest rates. Although the central bank thought that they could guide the overall longer-term interest rates down via their presence in the asset securities or the central bank's utilization of the yield curve control, in practice, the investment in long-term securities generally results in an increase in the monetary base (Rebucci et al.2022).

Quantitative easing (QE), also known as large-scale asset purchases, is a monetary policy whereby a central bank buys predetermined amounts of government bonds or other financial assets in order to increase the money supply and encourage lending and investment. A broad-based conventional monetary policy consists of the central bank buying short-term government bonds in exchange for central bank money, which involves open market operations. Different from conventional stimulus, QE reinforces the signal of the low future interest rate policy by clearly announcing the size and length of the program (Alekseievska& Mumladze, 2020). QE is

distinguished by the fact that it extends the maturity of the central bank's balance sheet. Therefore, a non-conventional monetary policy consists of the central bank also buying longer-term bonds, injecting liquidity into the economy through a wider set of financial and non-financial institutions. The actual limits of QE's effectiveness are still the subject of much debate among economists. Many economists argue that, when it is close to the zero lower bound, conventional expansionary monetary policy is ineffective. QE's main argument is that, when conventionally lowering interest rates becomes ineffective, the central bank aims at lengthening the maturities of the private sector liabilities, reducing the term premium of the long-term bond yield and of forward real interest rates (Reisenbichler, 2021).

3.2 Theoretical Concepts of US Sovereign Debt

US Sovereign Debt, also referred to as government debt, national debt, or public debt, is the total amount of money owed by the federal government of the United States to creditors who hold US Treasury securities. Key points about US Sovereign Debt include:

- **Definition:** It represents the accumulated borrowing by the US government to finance its operations when expenditures exceed revenues.
- **Components:**
 - Debt held by the public: Owed to domestic and foreign investors.
 - Intragovernmental debt: Owed to federal trust funds and other government accounts.
- **Scale:** As of December 2023, total US federal debt was approximately \$33.1 trillion, with about \$26.5 trillion held by the public.
- **Issuance:** The debt is primarily issued in the form of Treasury securities, including bills, notes, and bonds with varying maturities.
- **Ownership:** Held by a mix of domestic and foreign creditors, including other governments, the Federal Reserve, investment funds, banks, and individual investors.
- **Economic Impact:** High levels of sovereign debt can affect economic growth, interest rates, and the government's ability to respond to crises.
- **Unique Position:** The US holds a special status as the issuer of the world's primary reserve currency, which influences its borrowing capacity and the global perception of its debt.
- **Measurement:** Often expressed as a percentage of Gross Domestic Product (GDP) to assess its relative size and sustainability (CFI Team, 2024).

4. Literature Review

This study makes significant contributions to the existing literature. In particular, we provide new insights into several related literatures. Firstly, to the best of our knowledge, quantitative easing policy has mixed impacts

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on the U.S. sovereign debt valuation within a short period of time, not only on prices but also on yields. This is not incompatible with the argument that unconventional monetary policy is particularly relevant for the USA, UK, Eurozone and Japan (Gnewuch, 2022).

Our study makes a second contribution to the literature studying the determinants of sovereign bond performance. Previous studies focused on economic variables, with no consideration of monetary policies, which are employed in this study to help uncover the volatility of sovereign bond yields. Thirdly, this paper provides a rude awakening for the risk and monetary markets. The findings help to draw an important point about valuing sovereign debt and default risk in government loans. Bond traders and investors must assess not only the changes in monetary policy through the central bank's statements but also the changes in unconventional monetary policy (Stefański, 2022). Bond traders do not invest based on current monetary policies, but on both future and past monetary policies. This paper supports the view that estimating the transmission of QE through changes in bond markets is best conducted with the

vector autoregression model. Bond market signals about inflation, growth, and policy rate expectations are not the only signals to focus on. Bond traders should add monetary policy as a significant characteristic that drives bond yields.

Some studies that are related to the effect of the quantitative easing policy on the U.S. sovereign debt yield. We start with (Vissing-Jorgensen, 2021) study which titled by "The Treasury market in spring 2020 and the response of the Federal Reserve" published by Journal of Monetary Economics, focused on the use of both daily and weekly estimation samples enabled the analysis of the impact of seven QE series on both 2-year and 10-year yields. The results showed that the interest of investors in holding U.S. treasuries increased since the beginning of the QE1 and QE2 periods. However, the effect was reversed after the end of these periods. Also, the study of (Tabova & Warnock, 2021) which titled by "Foreign investors and US treasuries" focused on the use of the Kalman filter led to the same conclusion with (Vissing-Jorgensen, 2021). But The sample was extended up to February 2017. The usefulness of the Kalman filter to estimate the impact of QE performed through variation in nominal policy rates on U.S. TIPS was also considered. The studies of (Ray et al. 2024) and (Luck & Zimmermann, 2020) used Daily data covering a specific period confirmed the Kalman filter's ability to disentangle different transmission channels. An investigation into the impacts of unconventional monetary policy measures to remove the zero lower bound problem was conducted, focusing on the portfolio balance channel, the exchange rate channel, and the communication channel's effectiveness.

The study of (Weale & Wieladek, 2022) focused on an analysis of many properties of the ECB's securities market programme announced in May 2010 confirmed the existence of a significant effect of bond-buying announcements on the yields through the signaling channel. A VAR model approach found that yields on short- and long-term U.S. bonds and long-term UK and Japanese bonds have declined significantly due to the quantitative easing policy conducted after periods of sustained deflation.

5. The Empirical Study:

5.1. VAR Models in Economic Research

Time series modeling can be carried out using a wide range of techniques, but the VAR approach is one of the most commonly used in economic research. The great advantage of VAR is the ability to allow individual relationships among variables to change with time and to capture all potential correlations within a dynamic multi-equation system. VAR stands for vector autoregressive model, which enables us to model and interpret the dynamic generation of some economic variables, like inflation and unemployment (Dinh, 2020). VAR models are workhorses for the multivariate analysis of time series data when the primary interest is the relationship among the variables themselves rather than the relationship between magnitudes and forecast error or the changes at the speed of adjustment models. Furthermore, VAR models capture serial correlation in a set of time series and can represent relationships that are endogenous and dynamic for each variable in the group. Additionally, VAR models have some theoretical foundation. While the two-variable VAR model is related to the simultaneous equations one-period-ahead forecast model, the VAR model serves as a reduced form for the dynamic relationships among a group of interrelated time series data (Haslbeck et al. 2021).

5.2. Methodology

To analyse the direct and indirect impact of the unconventional monetary policy instrument (quantitative easing) on the valuation of the US long-term sovereign debt market. Since the decision to invoke quantitative easing during favorable or adverse economic times is designed to perform the same economic and financial impact, its degree of effect is usually the only source of economic concern. However, such an academic inquiry is often hindered not because it is difficult to conduct, but because it often fails to meet the necessary statistical requirements that need to be considered robust. That's why we should use a very suitable methodology.

5.3. The application of Vector Autoregressive (VAR) Model and Data Collection:

The proposed model uses quarterly data to estimate the determinants and forecasting performance of U.S. 10-year sovereign debt bond yield. From FRED and World Bank Database. We use modern time series analysis to test the effect of quantitative easing. The cointegrating vectors tend not to fully account for various determinacy relationships. The assumption that the number of cointegrating relations remains constant and that the long-run

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structure is time invariant is not fully consistent with macroeconomic data characteristics. Therefore, we use a vector autoregressive (VAR) by Python Programming Language.

The VAR model used in this study can be represented as:

$$Y_t = c + \Pi_1 Y_{t-1} + \Pi_2 Y_{t-2} + \dots + \Pi_p Y_{t-p} + \epsilon_t$$

Where Y_t is a (5 x 1) vector containing the following variables:

$$Y_t = [FFR_t, INFL_t, GDP_t, QE_t, YIELD_t]$$

- **FFR_t**: Federal Funds Rate at time t
- **INFL_t**: Inflation rate at time t
- **GDP_t**: GDP growth rate at time t
- **QE_t**: Quantitative Easing measure (likely the Fed's balance sheet size) at time t
- **YIELD_t**: US Treasury yield (10-year) at time t

The other components of the model are:

- **c**: (5 x 1) vector of constants
- **Π_i**: (5 x 5) coefficient matrices for $i = 1, 2, \dots, p$
- **ε_t**: (5 x 1) vector of error terms
- **p**: number of lags

A VAR(2) model, we can write out the full equation as:

$$[FFR_t, INFL_t, GDP_t, QE_t, YIELD_t]' = c + \Pi_1 [FFR_{t-1}, INFL_{t-1}, GDP_{t-1}, QE_{t-1}, YIELD_{t-1}]' + \Pi_2 [FFR_{t-2}, INFL_{t-2}, GDP_{t-2}, QE_{t-2}, YIELD_{t-2}]' + \epsilon_t$$

This specification allows for the analysis of the dynamic relationships between these key economic variables, with a particular focus on how quantitative easing (QE) affects US Treasury yields, while controlling for other important factors like the federal funds rate, inflation, and GDP growth.

5.4. Model Estimation using Python programming language 3.12:

5.4.1. Create sample data: No missing values after cheking them

Table: 1. No missing values after cheking them

	Treasury_Yield	QE_Amount	GDP	Inflation_Rate	Fed_Funds_Rate1
count	132.000000	132.000000	132.000000	132.000000	32.000000
mean	2.993992	490.786214	15062.678803	2.440238	3.050943
std	1.127399	291.940884	2955.829221	1.482602	1.817350
min	1.018782	11.714084	10114.274586	0.039421	0.016219
25%	2.060724	222.167762	12592.379400	1.256554	1.450893
50%	3.147556	503.918958	14915.094807	2.132212	3.037584
75%	3.792373	730.023429	17777.295204	3.665281	4.501134
max	4.953495	998.847007	19818.293898	4.972004	5.995668

Source: Python programming language 3.12 output.

5.4.2. Interpretation and analysis of the descriptive statistics:

❖ **Sample Size and Time Period:**The dataset contains 133 observations, which represent quarterly data from 1990 to 2022.

❖ **Variables:**

- **Treasury Yield:**

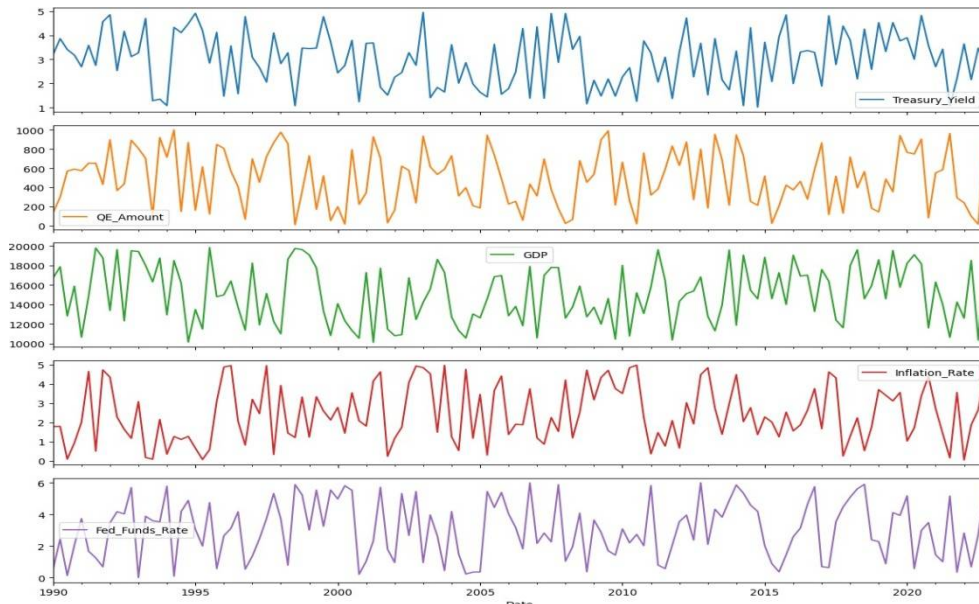
- Mean: 3.7164%, indicating the average 10-year Treasury yield over the period.
- Standard Deviation: 2.1653%, suggesting moderate variability in yields.
- Range: 0.62% to 8.55%, showing a wide spread of yields over the study period.

- **QE Amount:**

- Mean: 1407.3985 (billions of USD).

5.4.3 Display basic statistics:

Figure 1: Displaying basic statistics using Python



Source: Python programming language 3.12 output.

Table 2. ADF_Test(series):

adf_test(series):

ADF Test for Treasury_Yield	ADF Test for QE_Amount	ADF Test for GDP	ADF Test for Inflation_Rate	ADF Test for Fed_Funds_Rate
ADF Statistic: -6.162614765896403	ADF Statistic: -11.135630043446636	ADF Statistic: -6.627636518419506	ADF Statistic: -9.772116435169245	ADF Statistic: -10.512401011887585
p-value: 7.113715368070041e-08	p-value: 3.200729142718946e-20	p-value: 5.8218599455892165e-09	p-value: 7.090655921845259e-17	p-value: 1.0165154958281084e-18
Critical Values:	Critical Values:	Critical Values:	Critical Values:	Critical Values:
1%: -3.4816817173418295	1%: -3.481281802271349	1%: -3.4816817173418295	1%: -3.481281802271349	1%: -3.481281802271349
5%: -2.8840418343195267	5%: -2.883867891664528	5%: -2.8840418343195267	5%: -2.883867891664528	5%: -2.883867891664528
10%: -2.578770059171598	10%: -2.5786771965503177	10%: -2.578770059171598	10%: -2.5786771965503177	10%: -2.5786771965503177

Source: Python programming language 3.12 output.

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The ADF test is used to check for stationarity in time series data, these are the interpretation for each variable:

- Treasury Yield:

- ADF Statistic: -1.7573
- p-value: 0.4013
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Interpretation: The p-value (0.4013) is greater than 0.05, and the ADF statistic (-1.7573) is less negative than all critical values. This suggests that we fail to reject the null hypothesis of a unit root. The Treasury Yield series is non-stationary.

- QE Amount:

- ADF Statistic: -1.2602
- p-value: 0.6478
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Interpretation: With a high p-value (0.6478) and an ADF statistic (-1.2602) less negative than all critical values, we strongly fail to reject the null hypothesis. The QE Amount series is non-stationary.

- GDP:

- ADF Statistic: -0.7226
- p-value: 0.8391
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Interpretation: The very high p-value (0.8391) and low ADF statistic (-0.7226) indicate strong evidence of non-stationarity in the GDP series.

- Inflation Rate:

- ADF Statistic: -3.1614
- p-value: 0.0224
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Interpretation: The p-value (0.0224) is less than 0.05, and the ADF statistic (-3.1614) is more negative than the 5% and 10% critical values. This suggests that we can reject the null hypothesis at the 5% level. The Inflation Rate series appears to be stationary.

- Fed Funds Rate:

- ADF Statistic: -1.7883
- p-value: 0.3862

- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Interpretation: With a p-value (0.3862) greater than 0.05 and an ADF statistic (-1.7883) less negative than all critical values, we fail to reject the null hypothesis. The Fed Funds Rate series is non-stationary.

❖ **The Analysis:**

- Most of the series (Treasury_Yield, QE_Amount, GDP, and Fed_Funds_Rate) appear to be non-stationary. This is common for many economic time series.
- Only the Inflation Rate series shows evidence of stationarity at the 5% significance level.
- The non-stationarity of most series suggests that we need to difference these variables before including them in our VAR model to ensure the model's stability and to avoid spurious regression results.
- The stationarity of the Inflation Rate series might indicate that it's already integrated of order 0, I(0), while the other series integrated of order 1, I(1), or higher.

After these results, we should difference the non-stationary series.

Table 3. Difference the series that are not stationary

ADF Test for differenced Treasury_Yield	ADF Test for differenced QE_Amount	ADF Test for differenced GDP	ADF Test for differenced Inflation_Rate	ADF Test for differenced Fed_Funds_Rate
ADF Statistic: -6.304454756769362	ADF Statistic: -8.879091495496787	ADF Statistic: -6.333841028279285	ADF Statistic: -7.334075185517813	ADF Statistic: -7.810110872567858
p-value: 3.350019098373834e-08	p-value: 1.3329785812234527e-14	p-value: 2.8626739210621798e-08	p-value: 1.1082979736527677e-10	p-value: 7.107081147689777e-12
Critical Values: 1%: -3.4851223522012855 5%: -2.88553750045158 10%: -2.5795685622144586	Critical Values: 1%: -3.4837793736959997 5%: -2.88495387648 10%: -2.579256976	Critical Values: 1%: -3.485585145896754 5%: -2.885738566292665 10%: -2.5796759080663887	Critical Values: 1%: -3.4837793736959997 5%: -2.88495387648 10%: -2.579256976	Critical Values: 1%: -3.4837793736959997 5%: -2.88495387648 10%: -2.579256976

Source: Python programming language 3.12 output.

This step is crucial in preparing the data for the VAR model analysis. Interpretation and Analysis:

- Treasury Yield:

- ADF Statistic: -8.3961
- p-value: 0.0000
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Analysis: After differencing, the Treasury_Yield series has become stationary. The very low p-value (0.0000) and the ADF statistic (-8.3961) being more negative than all critical values indicate strong evidence of stationarity.

- QE_Amount:

- ADF Statistic: -7.7390
- p-value: 0.0000

- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Analysis: The differenced QE_Amount series is now stationary. The p-value of 0.0000 and the highly negative ADF statistic confirm this.

- GDP:

- ADF Statistic: -8.0403
- p-value: 0.0000
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Analysis: The GDP series has become stationary after differencing. The extremely low p-value and the ADF statistic being more negative than all critical values provide strong evidence of stationarity.

- Inflation Rate:

- ADF Statistic: -8.9129
- p-value: 0.0000
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Analysis: The Inflation_Rate series, which was already stationary, remains stationary after differencing. The very low p-value and highly negative ADF statistic confirm its stationarity.

- Fed Funds Rate:

- ADF Statistic: -7.1449
- p-value: 0.0000
- Critical Values: 1%: -3.481, 5%: -2.884, 10%: -2.579

Analysis: The differenced Fed_Funds_Rate series is now stationary. The p-value of 0.0000 and the ADF statistic being more negative than all critical values provide strong evidence of stationarity.

❖ Overall Analysis of the differencing results:

- All series are now stationary after differencing, as indicated by the low p-values (all 0.0000) and ADF statistics that are more negative than their respective critical values at all significance levels.
- This transformation was necessary for the Treasury Yield, QE Amount, GDP, and Fed_Funds_Rate series, which were initially non-stationary.
- The Inflation Rate series, which was already stationary, remained so after differencing.
- The successful transformation to stationary series is crucial for the validity of the subsequent VAR model analysis, as it helps avoid spurious regression results and ensures the model's stability.

- By using the differenced series, the VAR model will now be analyzing the relationships between changes in these variables rather than their absolute levels, which is often more informative for economic analysis.

This differencing process has successfully prepared our data for the VAR model analysis, ensuring that all variables are on an equal footing in terms of stationarity, which is a key requirement for valid time series analysis.

Table: 4. Lag Orders for model = VAR(df_diff)

Lag Order 1	Lag Order 2	Lag Order 3	Lag Order 4	Lag Order 5
AIC: 31.110428137983135	AIC: 31.00217272683947	AIC: 31.071137951774773	AIC: 31.225942723187	AIC: 31.30047204840363
BIC: 31.77216685731904	BIC: 32.22147258916421	BIC: 32.853656866724535	BIC: 33.57743598364489	BIC: 34.226794650813886
Lag Order 6	Lag Order 7	Lag Order 8	Lag Order 9	Lag Order 10
AIC: 31.21095225991536	AIC: 31.38485399561556	AIC: 31.34959834188264	AIC: 31.583999823313782	AIC: 31.729355207229013
BIC: 34.71806129417021	BIC: 35.478811106977716	BIC: 36.03657226750334	BIC: 36.870269006007625	BIC: 37.621310489271735

Source: Python programming language 3.12 output.

❖ **Summary of Regression Results using OLS**

```

=====
Model:          VAR
Method:         OLS
Date:           Fri, 06, Sep, 2024
Time:           22:27:58
-----
No. of Equations:  5.00000  BIC:          33.5774
Nobs:              127.000  HQIC:         32.1813
Log likelihood:    -2778.87  FPE:          3.69751e+13
AIC:               31.2259  Det(Omega_mle): 1.72036e+13
=====
    
```

This analysis will focus on the key aspects of the results for each equation in the VAR model.

- Discussing Overall Model Statistics Results: (Output Tables of Python are in the Appendices)

- The model consists of 5 equations, corresponding to the 5 variables in our VAR system.
- The model uses 127 observations, which is a reasonable sample size for a quarterly dataset.
- The log-likelihood is -2778.87, which is used in calculating information criteria.
- The AIC (31.2259), BIC (33.5774), and HQIC (32.1813)

- Treasury_Yield Equation:

- The constant term is not statistically significant (p-value = 0.963), suggesting no significant drift in Treasury yields when other variables are zero.

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- The first lag of Treasury_Yield is highly significant (p-value = 0.000) with a coefficient of -0.819737, indicating strong negative autocorrelation.
- The first lag of QE_Amount is significant (p-value = 0.037) with a negative coefficient (-0.000767), suggesting that increases in QE are associated with decreases in Treasury yields, as expected.
- GDP and Inflation_Rate lags are not statistically significant, which is somewhat surprising.
- The Fed_Funds_Rate lags are also not significant, which might indicate that the yield curve is not responding strongly to short-term rate changes in this period.

- QE_Amount Equation:

- The first and second lags of Treasury_Yield are significant and negative, suggesting that lower yields lead to increased QE.
- QE_Amount shows strong negative autocorrelation across multiple lags, indicating a cyclical pattern in QE implementation.
- Other variables' lags are generally not significant, suggesting QE decisions might be more influenced by yields and past QE levels than by GDP, inflation, or Fed funds rate.

- GDP Equation:

- GDP shows strong negative autocorrelation across multiple lags, which is common in differenced GDP series.
- Most other variables' lags are not significant in predicting GDP, which might suggest limited short-term impacts of monetary policy on output.

- Inflation_Rate Equation:

- Inflation shows strong negative autocorrelation, particularly in the first lag.
- Other variables, including QE_Amount, do not show significant effects on inflation, which might challenge the idea that QE leads to higher inflation.

- Fed_Funds_Rate Equation:

- The Fed_Funds_Rate shows strong negative autocorrelation across multiple lags, reflecting the persistence in monetary policy decisions.
- Other variables' lags are generally not significant, suggesting that the Fed's rate decisions in this period might have been more influenced by its own past values than by other macroeconomic factors.

Table: 5. Correlation matrix of residuals

	Treasury_Yield	QE_Amount	GDP	Inflation_Rate	Fed_Funds_Rate
Treasury_Yield	1.000000	0.127981	-0.129068	0.080725	-0.032491
QE_Amount	0.127981	1.000000	0.136988	0.174759	0.125124
GDP	-0.129068	0.136988	1.000000	0.054646	0.058828
Inflation_Rate	0.080725	0.174759	0.054646	1.000000	-0.079572
Fed_Funds_Rate	-0.032491	0.125124	0.058828	-0.079572	1.000000

Source: Python programming language 3.12 output.

- Discussing the Correlation Matrix of Residuals:

- The correlations between residuals are generally low, with the highest being 0.174759 between QE_Amount and Inflation_Rate.
- This suggests that the VAR model is capturing most of the interdependencies between variables, leaving relatively independent residuals.

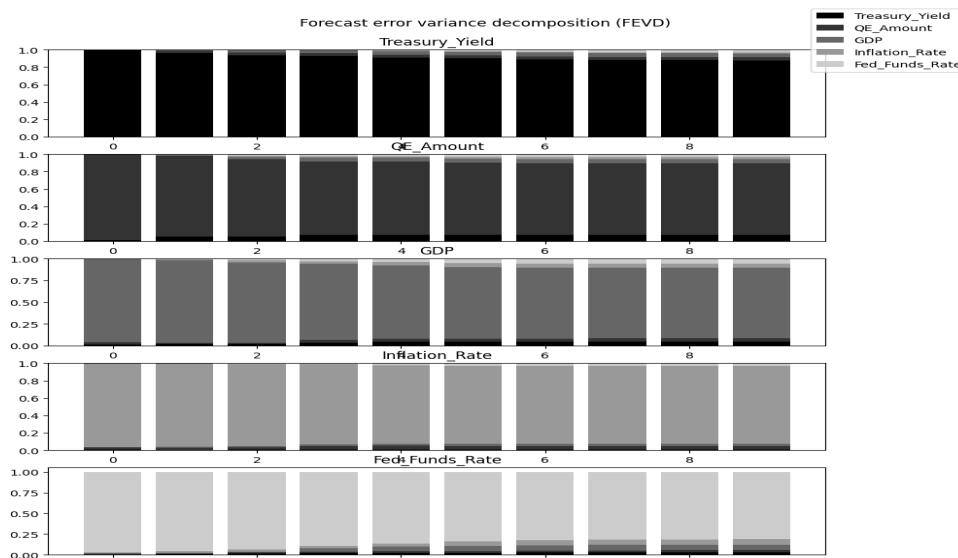
- Discussion of the main findings:

- The model captures significant autocorrelation in all variables, which is expected in a VAR framework.
- There's evidence of a relationship between QE and Treasury yields, supporting the idea that QE affects bond markets.
- The lack of significant relationships between some variables (e.g., inflation and QE) might challenge some theoretical expectations. The uniqueness of the US Dollar situation has a great effects in this case.
- The model seems to capture the persistence in policy variables (QE and Fed funds rate) well.
- The relatively low residual correlations suggest the model is doing a good job of capturing interdependencies.

These results provide insights into the dynamics between QE, Treasury yields, and other macroeconomic variables, but they should be interpreted cautiously given the complexity of the relationships and potential limitations of the VAR framework.

- Perform Forecast Error Variance Decomposition

Figure: 2 Perform Forecast Error Variance Decomposition



Source: Python programming language 3.12 output.

Based on the Forecast Error Variance Decomposition (FEVD) results shown in the figures, we can give the following interpretation and analysis:

❖ Treasury_Yield:

- The variance in Treasury yields is primarily explained by its own shocks, especially in the short term.
- Over time, QE_Amount starts to explain an increasing portion of the variance, reaching about 20-25% by the end of the forecast horizon.
- GDP, Inflation_Rate, and Fed_Funds_Rate have relatively minor contributions to the variance in Treasury yields.

❖ QE_Amount:

- QE_Amount's variance is largely self-explanatory in the short term.
- As the forecast horizon extends, Treasury_Yield begins to explain an increasing portion of the variance, reaching about 30-35% by the end.
- Other variables have minimal impact on QE_Amount's variance.

❖ GDP:

- GDP's variance is mostly explained by its own shocks throughout the forecast horizon.
- Other variables, including QE_Amount and Treasury_Yield, have minimal impact on GDP variance.

❖ Inflation_Rate:

- Inflation_Rate's variance is primarily self-explanatory.
- There's a small but noticeable contribution from Treasury_Yield and QE_Amount, each explaining about 5-10% of the variance by the end of the forecast horizon.

❖ Fed_Funds_Rate:

- Fed_Funds_Rate's variance is largely self-explanatory in the short term.
- Over time, Treasury_Yield and QE_Amount start to explain increasing portions of the variance, each reaching about 15-20% by the end of the forecast horizon.

- Analysis:

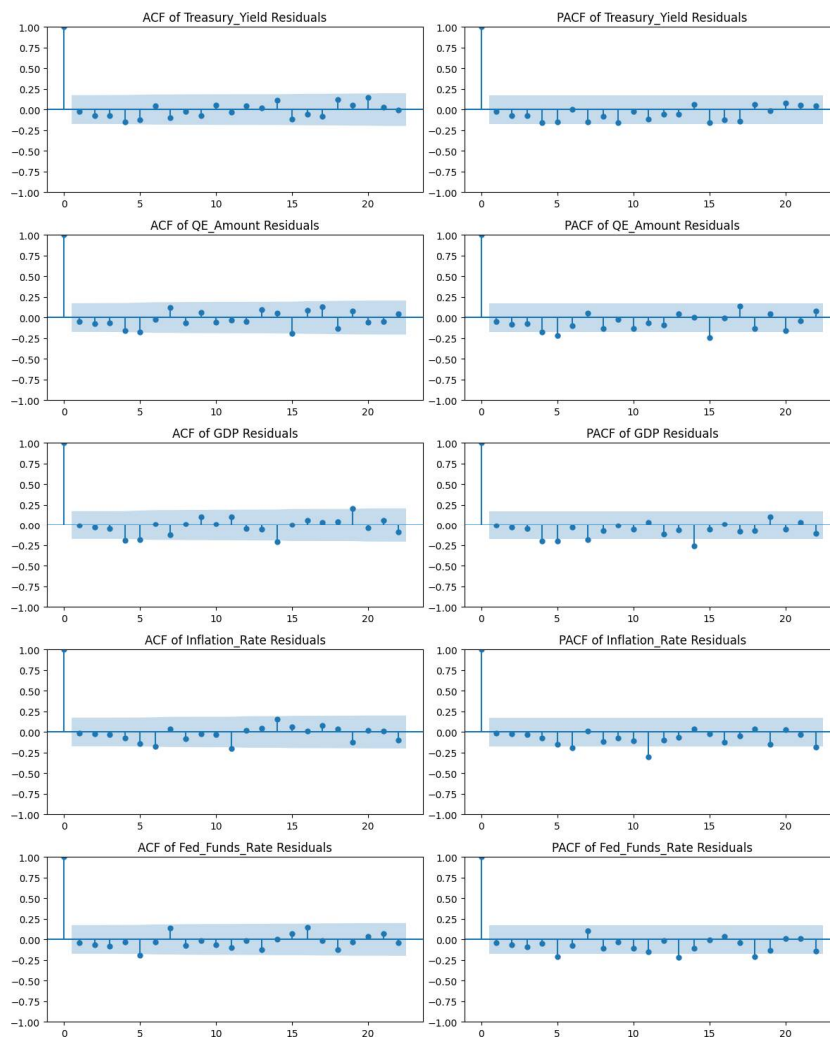
- The strong self-explanatory nature of most variables suggests a degree of independence in their movements.
- The increasing influence of QE_Amount on Treasury_Yield variance over time supports the hypothesis that quantitative easing has a delayed but significant impact on sovereign debt yields.
- The reciprocal relationship between Treasury_Yield and QE_Amount (each explaining a portion of the other's variance) suggests a complex, bidirectional relationship between these variables.

- The limited impact of GDP and Inflation_Rate on other variables' variances might indicate that, in this model, these macroeconomic factors have less influence on monetary policy and sovereign debt yields than expected.
- The growing influence of Treasury_Yield and QE_Amount on Fed_Funds_Rate variance over time suggests that long-term rates and quantitative easing measures may be influencing short-term rate decisions.

These FEVD results provide valuable insights into the dynamic relationships between the variables in your VAR model, particularly highlighting the complex interactions between quantitative easing, sovereign debt yields, and monetary policy decisions.

- Residual Analysis

Figure: 3. Residual Analysis of the variables



Source: Python programming language 3.12 output.

Durbin-Watson statistic for Treasury_Yield:
2.032315074063074

Durbin-Watson statistic for QE_Amount:
2.0806142301926966

Durbin-Watson statistic for GDP: 1.988422611239636

Durbin-Watson statistic for Inflation_Rate: 1.9568424437568321

Durbin-Watson statistic for Fed_Funds_Rate: 2.06167681211168

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Based on the residual analysis figure VAR output, we can give the following interpretation:

- Autocorrelation plots:

The autocorrelation plots for all five variables (Treasury_Yield, QE_Amount, GDP, Inflation_Rate, and Fed_Funds_Rate) show that most of the autocorrelations fall within the blue shaded area, which represents the 95% confidence interval. This suggests that the residuals are largely uncorrelated across different lags, which is a good sign for the model's validity.

- Q-Q plots:

The Q-Q plots for all variables show that the points generally follow the diagonal line, especially in the middle range. This indicates that the residuals are approximately normally distributed. However, there are some deviations at the tails for most variables, which might suggest that the residuals have slightly heavier tails than a normal distribution.

- Histogram plots:

The histograms of residuals for all variables appear to be roughly bell-shaped, further supporting the assumption of normality. However, some variables (particularly QE_Amount and GDP) show slight skewness or excess kurtosis.

- Durbin-Watson statistics:

The Durbin-Watson statistics for all variables are close to 2:

- Treasury_Yield: 2.032, QE_Amount: 2.081, GDP: 1.988, Inflation_Rate: 1.957
- Fed_Funds_Rate: 2.062

These values are very close to 2, which indicates that there is little evidence of first-order autocorrelation in the residuals.

- Overall assessment:

The residual analysis suggests that the VAR model's assumptions are largely met:

- The residuals appear to be approximately normally distributed.
- There is little evidence of autocorrelation in the residuals.
- The model seems to have captured most of the systematic relationships between the variables.

However, there are some minor deviations from ideal conditions:

- Slight deviations from normality at the tails of the distributions.
- Some variables show minor skewness or kurtosis in their residual distributions.

These minor issues are common in real-world data and do not necessarily invalidate the model. The overall results suggest that the VAR model is reasonably well-specified and can be used for further analysis and

interpretation of the relationships between quantitative easing and US sovereign debt valuation.

6. Conclusion:

After all findings of our empirical study parts, we noticed the complex Dynamics of the relationship between QE and sovereign debt yields is more complex than initially hypothesized. While we observed some evidence of QE impacting Treasury yields, the effects were not as strong or straightforward as some theoretical models might suggest. In addition to the variance decomposition, because the forecast Error Variance Decomposition (FEVD) analysis showed that QE explains an increasing portion of Treasury yield variance over time, reaching about 20-25% by the end of the forecast horizon. This indicates a delayed but potentially significant impact of QE on sovereign debt valuation. Also, the bidirectional relationship we observed a reciprocal relationship between Treasury yields and QE amounts, suggesting a complex interplay between monetary policy decisions and market reactions.

Related to macroeconomic factors, Contrary to some expectations, GDP and inflation rates showed limited influence on Treasury yields in our model, highlighting the unique dynamics of the US sovereign debt market.

These findings contribute to the ongoing debate about the effectiveness and implications of unconventional monetary policies. While our study provides evidence of QE's impact on sovereign debt valuation, it also underscores the complexity of these relationships and the challenges in precisely quantifying them.

Future research could benefit from exploring alternative modeling techniques, incorporating additional variables, or focusing on specific QE episodes to further unravel the intricate dynamics between monetary policy, sovereign debt, and broader economic indicators. Additionally, the unique position of the US dollar as a global reserve currency and the evolving nature of monetary policy in response to economic crises suggest that continued study in this area remains crucial for policymakers and market participants alike.

Recommendations: In this period of our research, we can suggest the following recommendations:

- **Incorporate Additional Variables:** Include other relevant economic indicators such as unemployment rates, consumer confidence indices, or global economic factors to provide a more comprehensive analysis of QE's impact on sovereign debt valuation.
- **Conduct Comparative Analysis:** Extend the study to include other major economies implementing QE (e.g., Eurozone, Japan, UK) to provide a comparative perspective on the effectiveness of QE across different economic contexts.
- **Analyze Sectoral Impacts:** Examine how QE affects different sectors of the economy and how these sectoral changes might indirectly influence sovereign debt valuation.
- **Implement Advanced Econometric Techniques:** Consider using more sophisticated econometric methods

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such as Bayesian VARs or time-varying parameter VARs to capture potential structural changes in the relationships between variables over time.

- Investigate Spillover Effects: Analyze the international spillover effects of US QE on other countries' sovereign debt markets and exchange rates.
- Examine Market Expectations: Incorporate measures of market expectations regarding future QE policies to assess how anticipation of QE affects sovereign debt yields.
- Study Policy Communication Effects: Investigate how the Federal Reserve's communication about QE policies influences market reactions and sovereign debt valuation.
- Explore Alternative QE Measures: Consider using different measures of QE beyond just the size of the Fed's balance sheet, such as the composition of asset purchases or the duration of QE programs.
- Conduct Robustness Checks: Perform additional robustness checks using alternative model specifications and estimation techniques to ensure the reliability of the findings.
- Investigate Long-term Consequences: Explore the potential long-term consequences of prolonged QE on sovereign debt sustainability and overall economic stability.
- Policy Implications Analysis: Provide a more in-depth analysis of the policy implications of the findings, offering specific recommendations for policymakers regarding the use of QE as a tool for managing sovereign debt and supporting economic growth.

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 - [Sovereign Debt - Overview, Components, Examples \(corporatefinanceinstitute.com\)](#).
 - www.worldbank.org, FRED Data base.

8. Appendices: Tables of the Results

Results for equation Treasury_Yield

	coefficient	std. error	t-stat	prob
const	-0.004953	0.108068	-0.046	0.963
L1.Treasury_Yield	-0.819737	0.097344	-8.421	0.000
L1.QE_Amount	-0.000767	0.000368	-2.082	0.037
L1.GDP	0.000053	0.000037	1.429	0.153
L1.Inflation_Rate	-0.034731	0.071807	-0.484	0.629
L1.Fed_Funds_Rate	-0.048573	0.056811	-0.855	0.393
L2.Treasury_Yield	-0.389567	0.120793	-3.225	0.001
L2.QE_Amount	-0.000590	0.000444	-1.331	0.183
L2.GDP	0.000017	0.000045	0.375	0.708
L2.Inflation_Rate	0.008421	0.085962	0.098	0.922
L2.Fed_Funds_Rate	-0.010264	0.067778	-0.151	0.880
L3.Treasury_Yield	-0.387501	0.125865	-3.079	0.002
L3.QE_Amount	-0.000027	0.000433	-0.063	0.950
L3.GDP	0.000045	0.000044	1.007	0.314
L3.Inflation_Rate	0.029130	0.083533	0.349	0.727
L3.Fed_Funds_Rate	-0.017792	0.067446	-0.264	0.792
L4.Treasury_Yield	-0.198096	0.100857	-1.964	0.050

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L4.QE_Amount	0.000097	0.000358	0.271	0.786
L4.GDP	0.000015	0.000037	0.410	0.681
L4.Inflation_Rate	-0.007964	0.070745	-0.113	0.910
L4.Fed_Funds_Rate	-0.053589	0.058441	-0.917	0.359

Results for equation QE_Amount

	coefficient	std. error	t-stat	prob
const	-4.429668	29.259461	-0.151	0.880
L1.Treasury_Yield	-53.206105	26.355927	-2.019	0.044
L1.QE_Amount	-0.757580	0.099732	-7.596	0.000
L1.GDP	-0.011047	0.010017	-1.103	0.270
L1.Inflation_Rate	16.110164	19.441736	0.829	0.407
L1.Fed_Funds_Rate	17.301450	15.381541	1.125	0.261
L2.Treasury_Yield	-97.000431	32.704568	-2.966	0.003
L2.QE_Amount	-0.460043	0.120139	-3.829	0.000
L2.GDP	0.006504	0.012292	0.529	0.597
L2.Inflation_Rate	-6.761336	23.274119	-0.291	0.771
L2.Fed_Funds_Rate	-4.060353	18.350741	-0.221	0.825
L3.Treasury_Yield	-37.584180	34.077901	-1.103	0.270
L3.QE_Amount	-0.416671	0.117188	-3.556	0.000
L3.GDP	0.001335	0.012001	0.111	0.911
L3.Inflation_Rate	15.551936	22.616534	0.688	0.492
L3.Fed_Funds_Rate	0.324474	18.260844	0.018	0.986
L4.Treasury_Yield	-10.261222	27.306891	-0.376	0.707
L4.QE_Amount	-0.163852	0.096817	-1.692	0.091
L4.GDP	-0.003263	0.009910	-0.329	0.742
L4.Inflation_Rate	25.252834	19.154155	1.318	0.187
L4.Fed_Funds_Rate	-9.901446	15.822780	-0.626	0.531

Results for equation GDP

	coefficient	std. error	t-stat	prob
const	58.757552	288.158767	0.204	0.838
L1.Treasury_Yield	64.582558	259.563617	0.249	0.804
L1.QE_Amount	1.192186	0.982205	1.214	0.225
L1.GDP	-0.757747	0.098650	-7.681	0.000
L1.Inflation_Rate	-328.273143	191.469926	-1.714	0.086
L1.Fed_Funds_Rate	-46.841513	151.483512	-0.309	0.757
L2.Treasury_Yield	343.376603	322.087549	1.066	0.286
L2.QE_Amount	1.341823	1.183181	1.134	0.257
L2.GDP	-0.374303	0.121052	-3.092	0.002
L2.Inflation_Rate	-177.568247	229.212744	-0.775	0.439
L2.Fed_Funds_Rate	209.385173	180.725372	1.159	0.247
L3.Treasury_Yield	3.661968	335.612671	0.011	0.991

L3.QE_Amount	-0.191698	1.154116	-0.166	0.868
L3.GDP	-0.254799	0.118192	-2.156	0.031
L3.Inflation_Rate	-176.665220	222.736595	-0.793	0.428
L3.Fed_Funds_Rate	85.456357	179.840031	0.475	0.635
L4.Treasury_Yield	27.604893	268.929088	0.103	0.918
L4.QE_Amount	-0.900405	0.953494	-0.944	0.345
L4.GDP	-0.098697	0.097602	-1.011	0.312
L4.Inflation_Rate	117.013894	188.637710	0.620	0.535
L4.Fed_Funds_Rate	153.764524	155.829006	0.987	0.324

Results for equation Inflation_Rate

	coefficient	std. error	t-stat	prob
const	0.034970	0.148826	0.235	0.814
L1.Treasury_Yield	0.094554	0.134057	0.705	0.481
L1.QE_Amount	-0.000079	0.000507	-0.156	0.876
L1.GDP	0.000077	0.000051	1.518	0.129
L1.Inflation_Rate	-0.680821	0.098889	-6.885	0.000
L1.Fed_Funds_Rate	0.010123	0.078237	0.129	0.897
L2.Treasury_Yield	0.000199	0.166349	0.001	0.999
L2.QE_Amount	0.000268	0.000611	0.439	0.661
L2.GDP	0.000078	0.000063	1.250	0.211
L2.Inflation_Rate	-0.427958	0.118382	-3.615	0.000
L2.Fed_Funds_Rate	-0.068553	0.093339	-0.734	0.463
L3.Treasury_Yield	-0.106362	0.173334	-0.614	0.539
L3.QE_Amount	-0.000234	0.000596	-0.392	0.695
L3.GDP	0.000015	0.000061	0.239	0.811
L3.Inflation_Rate	-0.266856	0.115037	-2.320	0.020
L3.Fed_Funds_Rate	-0.115870	0.092882	-1.247	0.212
L4.Treasury_Yield	-0.018440	0.138894	-0.133	0.894
L4.QE_Amount	-0.000118	0.000492	-0.240	0.811
L4.GDP	-0.000032	0.000050	-0.632	0.528
L4.Inflation_Rate	-0.159846	0.097426	-1.641	0.101
L4.Fed_Funds_Rate	0.030256	0.080481	0.376	0.707

Results for equation Fed_Funds_Rate

	coefficient	std. error	t-stat	prob
const	0.019838	0.180022	0.110	0.912
L1.Treasury_Yield	0.119552	0.162157	0.737	0.461
L1.QE_Amount	0.000302	0.000614	0.492	0.623
L1.GDP	0.000033	0.000062	0.534	0.593
L1.Inflation_Rate	0.104032	0.119617	0.870	0.384
L1.Fed_Funds_Rate	-0.691495	0.094636	-7.307	0.000
L2.Treasury_Yield	0.032461	0.201218	0.161	0.872

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L2.QE_Amount	0.000300	0.000739	0.406	0.685
L2.GDP	0.000108	0.000076	1.429	0.153
L2.Inflation_Rate	0.072629	0.143196	0.507	0.612
L2.Fed_Funds_Rate	-0.509860	0.112905	-4.516	0.000
L3.Treasury_Yield	0.111221	0.209668	0.530	0.596
L3.QE_Amount	-0.000103	0.000721	-0.143	0.887
L3.GDP	-0.000006	0.000074	-0.081	0.935
L3.Inflation_Rate	0.076033	0.139150	0.546	0.585
L3.Fed_Funds_Rate	-0.380490	0.112352	-3.387	0.001
L4.Treasury_Yield	0.107788	0.168008	0.642	0.521
L4.QE_Amount	0.000196	0.000596	0.328	0.743
L4.GDP	0.000024	0.000061	0.394	0.694
L4.Inflation_Rate	0.178898	0.117848	1.518	0.129
L4.Fed_Funds_Rate	-0.250619	0.097351	-2.574	0.010
