FA 541 FINAL PROJECT REPORT

Analysis of Treasury Yield Curve in Relation to Macroeconomic Indicators

FINAL PROJECT REPORT

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Project By:

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Abstract

This report examines the relationship between the U.S. Treasury yield curves and key macroeconomic in-dicators across four critical economic periods: the dot-com bubble (1997–2004), the economic crisis (2006–2010), and the COVID-19 pandemic (2019–2024). By analyzing how major events and monetary policies influenced yield trends, the study provides insights into the interactions between Treasury yields and macroeconomic indicators such as GDP, inflation, unemployment, the Federal Funds rate, and stock market performance. The findings highlight the role of government interventions and investor behavior in shaping economic stability and market dynamics during these periods.

1. INTRODUCTION

Treasury yields serve as critical benchmarks in financial markets, often referred to as risk-free rates due to the backing of the U.S. government. They provide valuable insights into investor sentiment, economic conditions, and monetary policy dynamics. Understanding these yields and their interplay with macroeconomic indicators is essential for economists, policymakers, and investors alike.

1.1 Overview of Treasury yields and their significance

- Treasury yields reflect the cost of borrowing for the U.S. government and are widely used as benchmarks for other interest rates, including corporate bonds and mortgage rates.
- Short-term yields are highly sensitive to Federal Reserve policies, while long-term yields incorporate expectations for inflation, economic growth, and risk premiums. • Analyzing the yield curve, which plots yields across different maturities, offers insights into market expectations about future economic conditions and potential recession risks.

1.2 Purpose and Scope:

- Objective: This study aims to analyze the relationships between Treasury yields and key macroeconomic indicators, exploring how these variables interact during various economic cycles.
- Scope: The analysis focuses on key historical periods, including the Dot-Com Bubble (1997–2004), The financial crisis of 2008 , the Post-Financial Crisis recovery (2013–2018), and the COVID-19 pandemic (2019–2024), to understand the influence of macroeconomic changes on yield trends.

2. MATERIALS AND METHODS

2.1 Data Collection

The data used in this study were collected from reputable sources such as Federal Reserve Economic Data (FRED) and Yahoo Finance. The selected macroeconomic indicators and Treasury yields provide a comprehensive dataset for analysis.

1) Data Sources:
    a) Federal Reserve Economic Data (FRED) for macroeconomic indicators and Treasury yields.
    b) Yahoo Finance for S&P 500 data.
2) Macroeconomic Indicators:
    a) Gross Domestic Product (GDP): A measure of overall economic activity and growth.
    b) Consumer Price Index (CPI): An indicator of inflation levels.
    c) Federal Funds Rate: A key monetary policy tool influencing short-term interest rates.
    d) Unemployment Rate: Reflecting labor market conditions and economic health.
    e) S&P 500 Index: Representing equity market performance.
3) Treasury Yields:
    a) 6-Month Treasury Yields: Reflecting short-term interest rates.
    b) 5-Year Treasury Yields: Representing medium-term rates.
    c) 10-Year Treasury Yields: A benchmark for long-term interest rates and economic expectations.

2.2 Methodology

A systematic approach was employed to investigate the relationships between Treasury yields and macroeconomic indicators. The methodology includes the following steps:

• Exploratory Data Analysis (EDA): Descriptive statistics and visualizations were used to identify trends, distributions, and anomalies in the data.

• Correlation Analysis: Examined the strength and direction of relationships between Treasury yields and macroeconomic indicators.

• Regression Analysis: Applied linear regression models, including regularized methods like Lasso regression, to quantify the predictive power of macroeconomic indicators on Treasury yields.

• Model Evaluation: R-squared, error metrics, and variable importance measures were used to assess model performance and interpret key predictors.

• Decision Tree Models: Evaluated non-linear relationships and feature importance for predicting yields across different maturities.

3. Historical Period Analysis

Summary for normal period (2013-2018)

In our study we compared each of the crisis studies with a relative neutral period, i.e., From 2013 to 2018, where the U.S. economy experienced steady growth, with GDP expanding at an average annual rate of 2.5% to 3%, reflecting a stable post-crisis recovery. Inflation remained moderate, hovering near the Federal Reserve's 2% target, gradually increasing as economic conditions improved. The unemployment rate showed significant improvement, dropping from 7.9% in 2013 to 3.9% by 2018, driven by consistent job creation and a tightening labor market. The stock market flourished, with the S&P 500 index gaining over 70%, supported by strong corporate earnings, low-interest rates, and economic optimism. Meanwhile, the Federal Reserve began a gradual normalization of monetary policy, increasing the federal funds rate from near-zero in 2015 to 2.5% by 2018, balancing inflation control with sustained economic growth. This period was marked by recovery, stability, and cautious monetary adjustments.

3.1 Dot-com Bubble (1997–2004)

The dot-com bubble and its subsequent collapse had a profound impact on the U.S. Treasury yields, highlighting market uncertainty and the influence of government monetary policies during a period of technological euphoria and financial volatility.

3.1.1 Economic Events

During the period 1997 to 2004, key events that influenced Treasury yields were:

• **Dot-Com Bubble (1997–2000):** The rapid rise and subsequent collapse of technology stock prices created significant market volatility. As the bubble burst, investors shifted from equities to safer assets like Treasuries, leading to a decline in yields.

• **Y2K Concerns (1999):** Leading up to the year 2000, fears about potential widespread technological failures (Y2K) prompted precautionary actions by businesses and governments, driving liquidity into short-term Treasuries and temporarily suppressing yields.

• **9/11 Terrorist Attacks (2001):** The September 11 attacks caused a spike in geopolitical risk and uncertainty. In the aftermath, investors sought safety in Treasuries, driving yields lower.

• **Recession of Early 2000s (2001–2002):** A mild recession, partly exacerbated by the dot-com collapse, led the Federal Reserve to cut interest rates significantly, reducing Treasury yields further.

• **Monetary Policy Shifts (2003–2004):** In response to economic recovery and fears of inflation, the Federal Reserve began to raise the federal funds rate. This resulted in an increase in Treasury yields, particularly at the shorter end of the curve.

3.1.2 Yield Trends Over Time

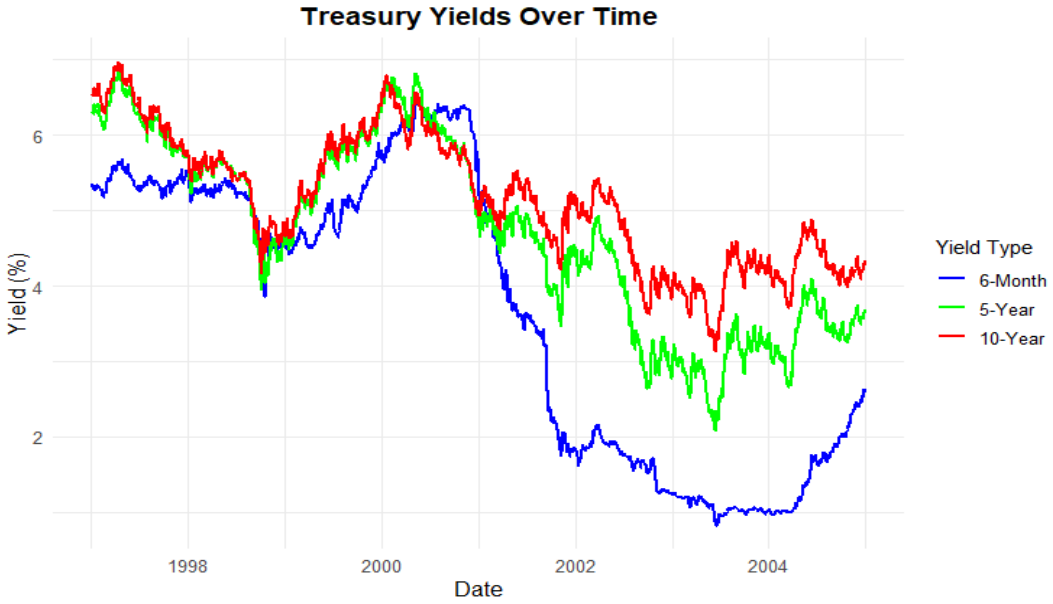


Figure 1: Treasury Yields Over Time During the Dot-Com Bubble

As shown in Figure 1, the Treasury yields for 6-month, 5-year, and 10-year terms experienced significant fluctuations during this period:

• **Short-term yields (6-month)** showed notable volatility, dropping sharply during the peak of the dot-com bubble and the subsequent market correction. This reflected the Federal Reserve's accommodative monetary policy, which lowered short-term rates to support economic recovery. Toward the end of this period, yields began to stabilize as the economy showed signs of improvement.

• **Mid-term yields (5-year)** and Long-term yields (10-year) exhibited a similar pattern, closely tracking each other. Both yields fell substantially during the initial phase of the economic downturn, driven by investor flight to safe-haven assets. Over the next two years, they gradually recovered, but at a slower pace compared to short-term yields, reflecting lingering uncertainty about long-term economic prospects and the impact of monetary policy.

3.1.3 Macroeconomic Indicator Changes

The graphs in Figures illustrate the dynamic changes in key macroeconomic indicators over the period from 1997 to 2004. These indicators reflect the direct impact of the dot-com bubble, subsequent market correction, and broader economic events.

1. Gross Domestic Product

    • **Peak and Decline (2000–2001):** During the peak of the dot-com bubble, GDP growth was strong, driven by rapid expansion in the technology sector. However, as the bubble burst, GDP growth slowed significantly, reflecting reduced investment and consumer confidence.
    • **Recovery Phase (2002–2004):** Following the recession, GDP gradually recovered as monetary easing and government policies supported economic stabilization.

2. Unemployment Rate

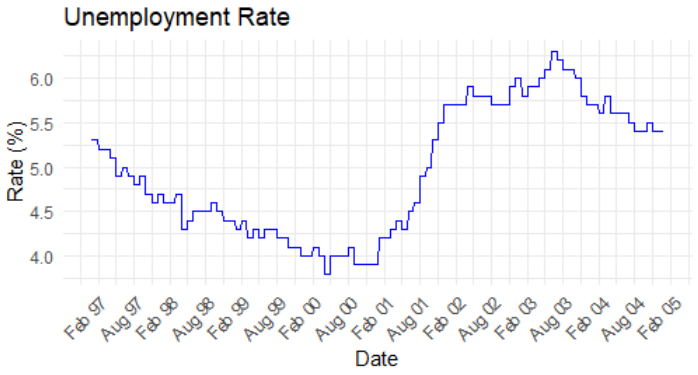


Figure 2: Unemployment v/s time

• **Gradual Increase (2000–2002)**: Unemployment rose steadily after the bubble burst, reflecting layoffs in the tech sector and broader economic slowdown.
• **Stabilization (2003–2004):** By mid-2003, unemployment began to stabilize, reflecting modest recovery in the labor market.

3. Consumer Price Index

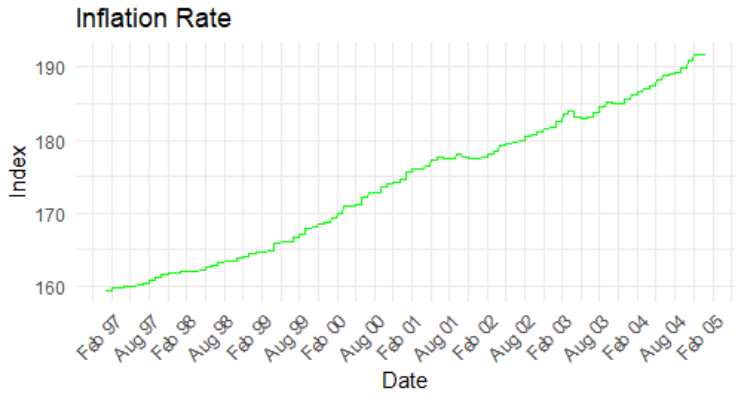


Figure 3: Inflation Rate v/s time

• **Moderate Inflation (1997–2004):** Inflation remained relatively stable throughout the period, as subdued economic growth following the bubble burst offset potential inflationary pressures.

4. S&P 500 Index

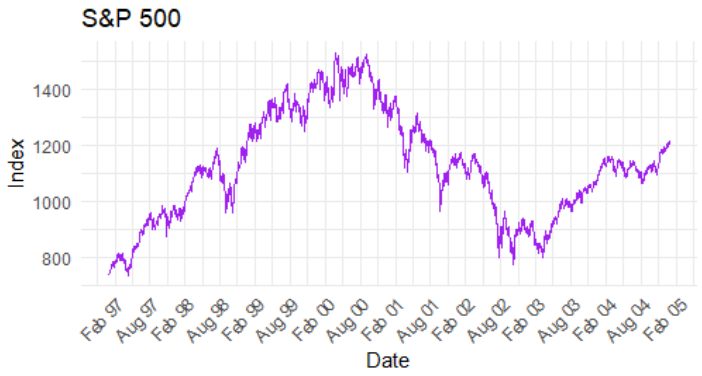


Figure 4: S&P v/s time

• **Sharp Decline (2000–2002):** The S&P 500 experienced a significant downturn as the dot-com bubble burst, leading to substantial losses in the stock market, particularly for tech stocks.
• **Gradual Recovery (2003–2004):** By 2003, the market began to recover, supported by improving corporate earnings and investor sentiment.

5. Federal Funds Rate

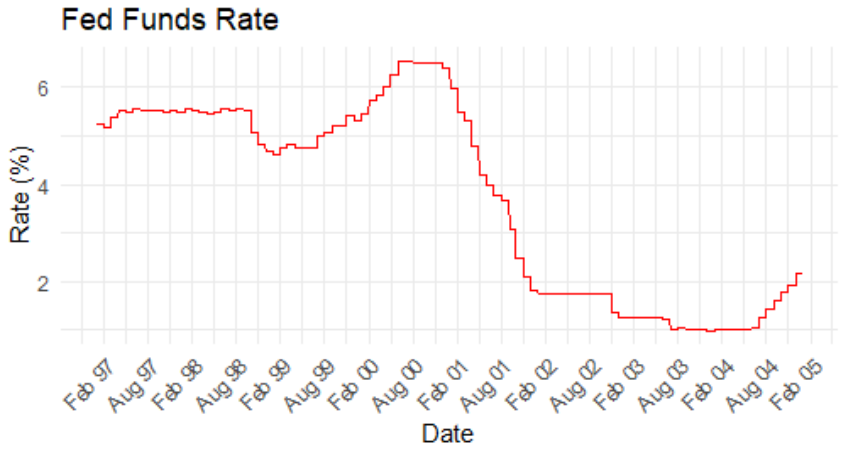


Figure 5: Fed Fund Rates v/s time

• **Rate Cuts (2001–2003):** In response to the economic slowdown, the Federal Reserve implemented aggressive rate cuts to stimulate growth, driving rates to historically low levels.
• **Stabilization (2004):** By 2004, rates began to stabilize as the economy showed signs of recovery, signaling a shift toward a more neutral monetary policy stance.

3.1.4 Correlation

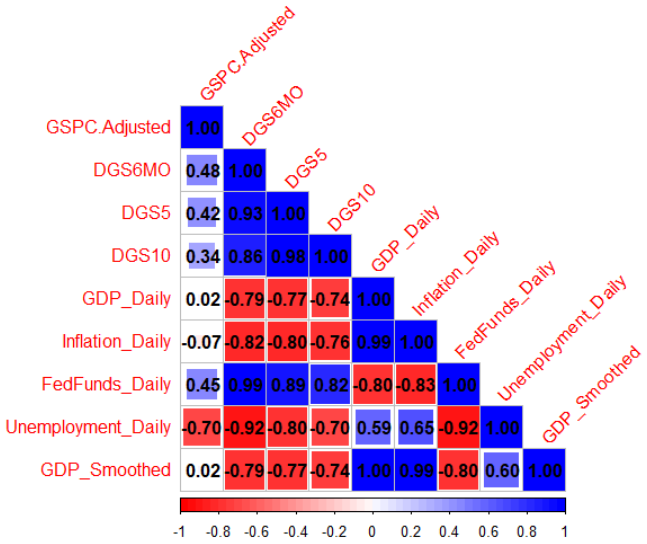


Figure 6 : Correlation Matrix (1997 - 2004)

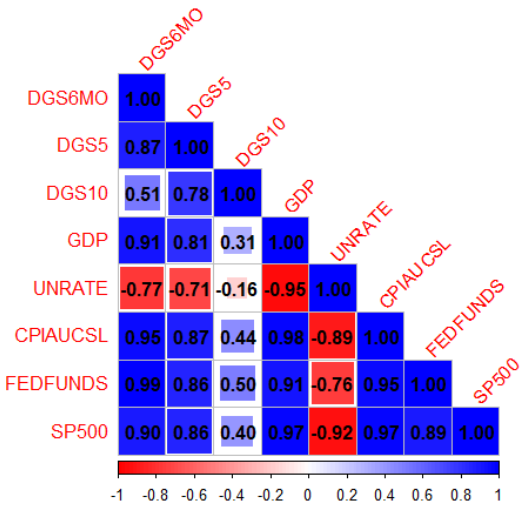


Figure 7: Correlation Matrix (2013 - 2018)

Treasury Yields Correlation: Strong positive correlations exist among short-term (DGS6MO), mid-term (DGS5), and long-term (DGS10) Treasury yields, indicating they move together in response to market conditions.

Fed Funds Rate Link: Treasury yields, particularly short-term ones, show near-perfect positive correlations with the Fed Funds rate, underscoring the influence of Federal Reserve policy.

Unemployment and Growth: Unemployment (UNRATE) has a strong negative correlation with GDP and Treasury yields, reflecting its inverse relationship with economic activity.

Inflation Dynamics: Inflation metrics (e.g., CPIAUCSL) are positively correlated with Treasury yields, suggesting that inflation expectations influence interest rates.

3.1.5 Regression Models

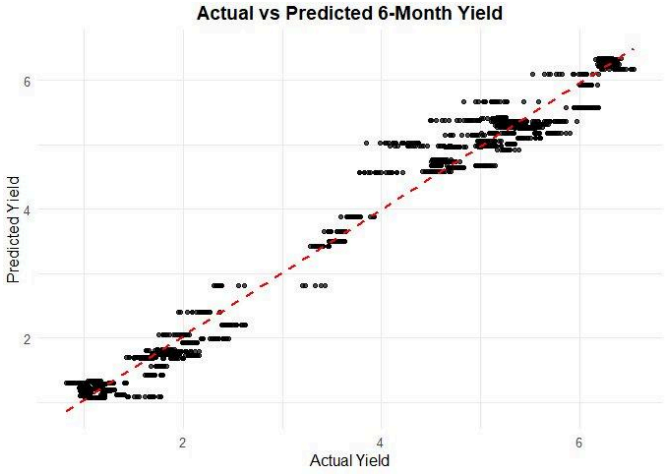
Linear Model

Summary of Models:

- **Model Accuracy (R-Squared)**:
  - The 6-Month Treasury Yield model has the highest R-squared (0.9828), indicating excellent explanatory power.
  - The 5-Year model shows a moderate fit with an R-squared of 0.817.
  - The 10-Year model has the lowest R-squared (0.7015), suggesting that it captures less variability in the data compared to shorter maturities.
- **Residual Standard Error (RSE)**:

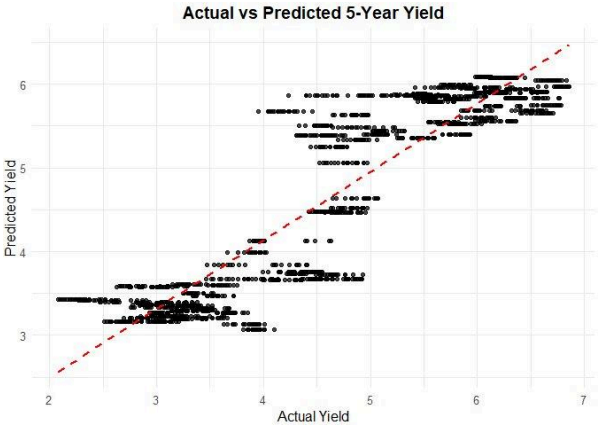
- The 6-Month model has the smallest RSE (0.2512), implying tighter residuals around the predicted values.
- The 5-Year and 10-Year models exhibit higher RSE (0.5353 and 0.4775, respectively), reflecting greater variability in residuals.

- **Impact of Predictor Variables**:
  - Across all models, FedFunds_Daily has the highest t-value and significant impact, indicating its critical role in predicting Treasury yields.
  - Inflation_Daily and GDP_Daily show variable impacts, with Inflation_Daily having a negative and significant effect across all maturities.
- **Graphical Observations**:
  - Actual vs. Predicted plots show linear alignment for shorter maturities but slightly more spread for longer maturities.
  - Residual plots and histograms indicate normality and randomness, with increased variability and potential heteroscedasticity in longer maturities.



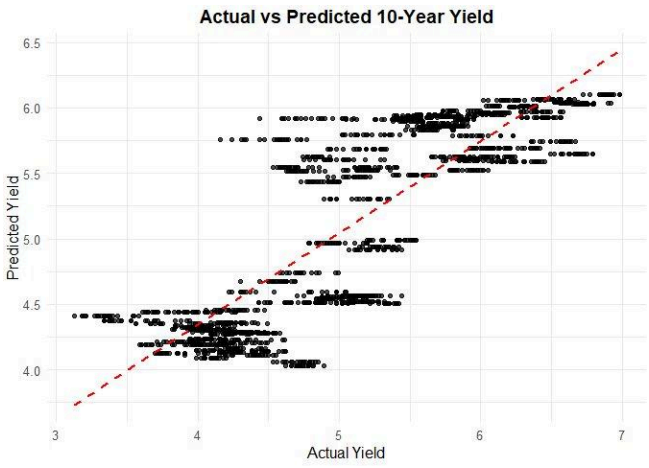

```
Call:
lm(formula = DGS6MO ~ GDP_Daily + Inflation_Daily + FedFunds_Daily +
    Unemployment_Daily, data = regression_data)

Residuals:
     Min       1Q   Median       3Q      Max
-1.18427 -0.12601 -0.01136  0.13305  0.71458

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)         8.267e+00  5.458e-01  15.147  < 2e-16 ***
GDP_Daily           8.293e-04  5.254e-05  15.784  < 2e-16 ***
Inflation_Daily    -1.012e-01  6.332e-03 -15.985  < 2e-16 ***
FedFunds_Daily      9.735e-01  1.182e-02  82.364  < 2e-16 ***
Unemployment_Daily  1.589e-01  2.692e-02   5.903 4.19e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2512 on 1991 degrees of freedom
Multiple R-squared:  0.9828,    Adjusted R-squared:  0.9828
F-statistic: 2.852e+04 on 4 and 1991 DF,  p-value: < 2.2e-16
```

Figure 8: Regression Model & Plot Summary - 6 months yields




```
5-Year Treasury Yield Regression Summary:
> print(summary_5yr)

Call:
lm(formula = DGS5 ~ GDP_Daily + Inflation_Daily + FedFunds_Daily +
    Unemployment_Daily, data = regression_data)

Residuals:
     Min       1Q   Median       3Q      Max
-1.72325 -0.33364 -0.00605  0.36805  1.24536

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        12.8143156  1.1630330  11.018  < 2e-16 ***
GDP_Daily           0.0006561  0.0001120   5.860 5.41e-09 ***
Inflation_Daily    -0.1040467  0.0134940  -7.711 1.96e-14 ***
FedFunds_Daily      0.5272810  0.0251861  20.935  < 2e-16 ***
Unemployment_Daily  0.2536438  0.0573667   4.421 1.03e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5353 on 1991 degrees of freedom
Multiple R-squared:  0.817,     Adjusted R-squared:  0.8166
F-statistic:  2222 on 4 and 1991 DF,  p-value: < 2.2e-16
```

Figure 9: Regression Model & Plot Summary -5 year yields




```
10-Year Treasury Yield Regression Summary:
> print(summary_10yr)

Call:
lm(formula = DGS10 ~ GDP_Daily + Inflation_Daily + FedFunds_Daily +
    Unemployment_Daily, data = regression_data)

Residuals:
    Min      1Q  Median      3Q     Max
-1.6002 -0.3109 -0.0023  0.3555  1.1392

Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)         9.422e+00  1.038e+00   9.081  < 2e-16 ***
GDP_Daily           3.615e-04  9.988e-05   3.620 0.000302 ***
Inflation_Daily    -6.360e-02  1.204e-02  -5.284 1.41e-07 ***
FedFunds_Daily      3.775e-01  2.247e-02  16.800  < 2e-16 ***
Unemployment_Daily  3.309e-01  5.118e-02   6.466 1.26e-10 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.4775 on 1991 degrees of freedom
Multiple R-squared:  0.7015,    Adjusted R-squared:  0.7009
F-statistic:  1170 on 4 and 1991 DF,  p-value: < 2.2e-16
```

Figure 10: Regression Model & Plot Summary - 10 year yields

Random Forest Tree:

6 Months - Yield

- **Model Performance:** The Random Forest model explains 99.79% of the variance in the 6-month Treasury yield, with a low mean squared residual of 0.007561, showcasing exceptional accuracy.
- **Key Predictors**: Inflation_Daily is the most significant predictor, followed by FedFunds_Daily and GDP_Daily, while Unemployment_Daily contributes the least.
- **Comparison to Regression:** The Random Forest model outperforms linear regression by capturing non-linear relationships and providing improved variance explanation and lower residual error.

5-Year Treasury Yield

- **Model Performance: The Random Forest model explains 98.91% of the variance in the** 5-Year Treasury yield, with a mean squared residual of 0.016943, indicating high accuracy.
- **Key Predictors:** Inflation_Daily is the most significant predictor, closely followed by Unemployment_Daily and FedFunds_Daily, while GDP_Daily has the least contribution.
- **Comparison to Regression:** The Random Forest model improves upon the linear regression by better capturing nonlinear interactions, providing higher variance explanation, and reducing the residual error.

10-Year Treasury Yield

- **Model Performance:** The Random Forest model explains 98.10% of the variance in the 10-Year Treasury yield, with a mean squared residual of 0.014512, reflecting strong predictive performance.
- **Key Predictors:** Inflation_Daily and Unemployment_Daily are the most significant predictors, with FedFunds_Daily and GDP_Daily contributing slightly less.
- **Comparison to Regression:** The Random Forest model demonstrates improved predictive accuracy compared to the linear regression, particularly by capturing complex, non-linear relationships and reducing residual errors.

Results for Tree Model

Maturity	% Variance Explained	Mean Squared Residual
6-Month	99.79	0.007561
5-Year	98.91	0.016943
10-Year	98.1	0.014512

As compared to regression

- **Higher Variance Explanation**: The Random Forest models consistently explain more variance in the Treasury yields (e.g., 99.79% for 6-month vs. 98.28% in regression), demonstrating their superior ability to capture complex relationships.
- **Improved Error Metrics**: Random Forest models achieve lower mean squared residuals (e.g., 0.007561 for 6-month vs. 0.2512 in regression), indicating better accuracy and precision in predictions.
- **Capturing Non-linear Relationships**: Unlike regression, Random Forest models effectively account for non-linear interactions and variable importance, making them more robust in handling complex data dependencies.

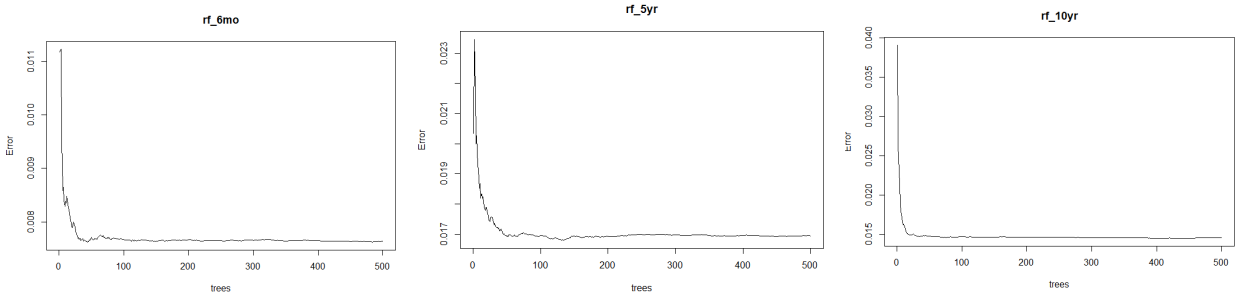


Figure 11: Random Forest Model

3.1.6 Results

6-months Treasury Yield Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
1997-2004	0.9828	0.9828	0.2512
2013-18 (Neutral Period)	0.9896	0.9896	0.07799

5-years Treasury Yield Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
1997-2004	0.817	0.8166	0.5353
2013-2018 (Neutral period)	0.7976	0.7971	0.2496

10-years Treasury Yield Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
1997-2004	0.7015	0.7009	0.4775
2013-2018 (Neutral period)	0.5422	0.541	0.2785

3.1.7 Residual Analysis Summary

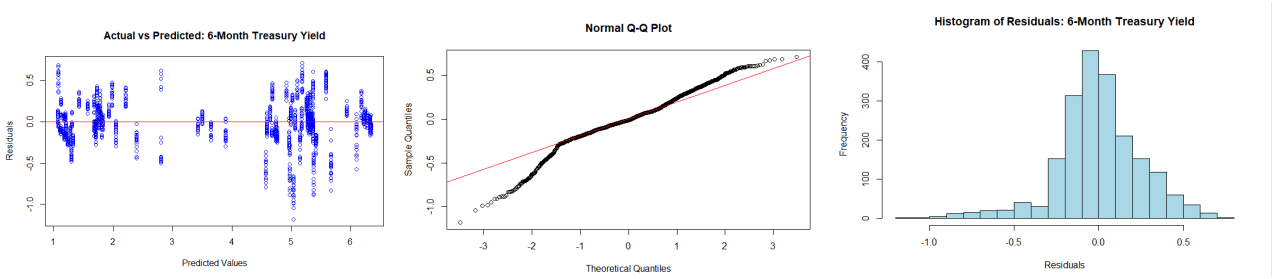


Figure 12: Residual Analysis - 6 months yields

6-Month Maturity:

- The Q-Q plot shows that the residuals closely align with the red reference line, indicating a near-normal distribution, with minor deviations at the tails suggesting slight skewness or heavier tails.
- The histogram reveals a symmetric distribution centered around zero, supporting the assumption of normality. However, the slight presence of outliers can be observed at the extremes.
- The residuals are scattered randomly around the zero line, indicating no clear pattern and suggesting that the model does not suffer from heteroscedasticity or bias.

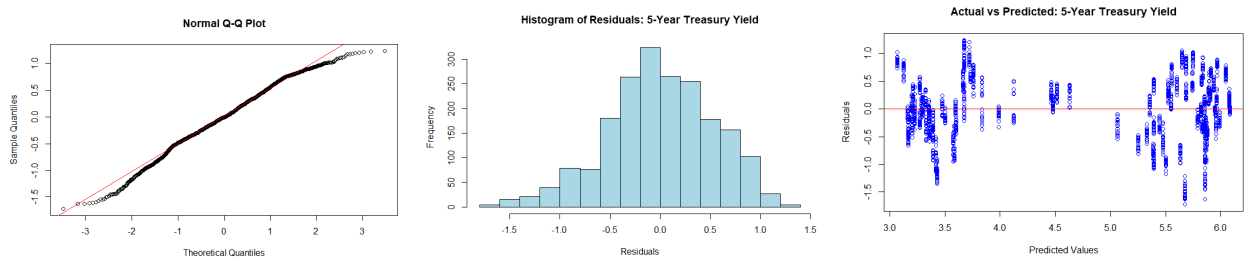


Figure 13: Residual Analysis - 5 year yields

5-Year Maturity:

- The Q-Q plot similarly displays an alignment with the reference line, though there are some noticeable deviations at both ends, indicating potential outliers or non-normality in the extremes.
- The histogram is also centered around zero, with a similar symmetric distribution. However, there is a more pronounced spread compared to the 6-month maturity, indicating increased variability in residuals.
- Similar to the 6-month plot, the residuals are randomly scattered, with some larger deviations at specific predicted values. This indicates a slight increase in heteroscedasticity compared to shorter maturities.

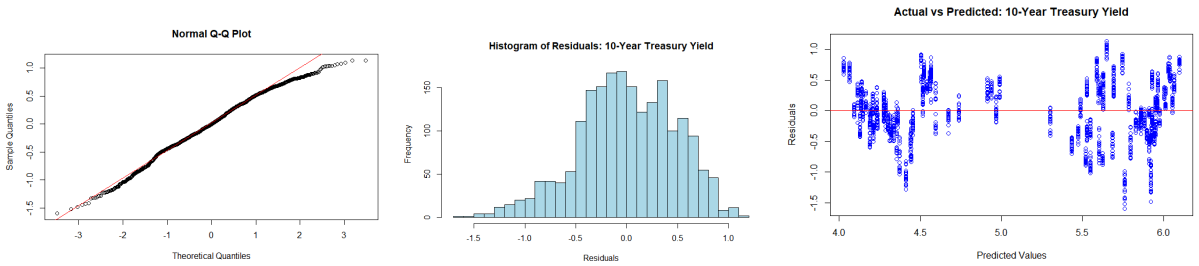


Figure 14: Residual Analysis - 10 year yields

10-Year Maturity:

- The Q-Q plot also aligns well with the theoretical quantiles, with slightly more prominent deviations in the tails compared to the other maturities, signaling heavier tails or skewness.
- The histogram for the 10-year maturity displays a symmetric but wider spread distribution, suggesting greater variability and potential for outliers compared to the shorter maturities.
- The residuals show greater variability and dispersion around the zero line, especially at higher predicted values, suggesting increased heteroscedasticity and reduced accuracy of the model at longer maturities.

3.2 Financial Crisis 2008 (2006–2010)

The 2008 financial crisis, driven by the collapse of the U.S. housing market and subprime mortgage industry, caused global economic turmoil. It led to major bank failures, a credit freeze, and skyrocketing unemployment. Emergency interventions like rate cuts, quantitative easing, and bailouts eventually stabilized markets and spurred recovery by 2010.

3.2.1 Economic Events

During the period from 2006 to 2010, several key events influenced Treasury yields:

1. **Housing Bubble Peak (2006):** Over-inflated housing prices showed signs of instability, eventually leading to the collapse of the subprime mortgage market.
2. **Subprime Mortgage Crisis (2007):** Rising mortgage defaults and the failure of mortgage-backed securities caused stress in financial markets, leading to early yield declines as investors sought safer assets.
3. **Lehman Brothers Collapse (2008):** The bankruptcy of Lehman Brothers created panic and a global liquidity crisis, pushing Treasury yields to historic lows.
4. **Global Financial Meltdown (2008–2009):** Credit markets froze, and global economies entered deep recessions, further driving demand for safe-haven assets like U.S. Treasuries.
5. **Emergency Monetary Policies (2008–2010):** The Federal Reserve slashed the Fed Funds Rate to near zero and initiated quantitative easing to stabilize markets and spur recovery.

3.2.2 Yield Trends Over Time

Treasury yields experienced significant fluctuations during this period:

- **Short-term Yields (6-month):** Declined sharply starting in 2007 due to Federal Reserve rate cuts aimed at boosting liquidity and reached near-zero levels by 2009 under the zero-interest-rate policy.
- **Mid-term and Long-term Yields (5-year and 10-year):** Declined steadily as risk aversion increased and investors moved funds to long-term Treasuries. The yield curve flattened, reflecting prolonged uncertainty. Gradual recovery began in late 2009 and 2010 as market confidence improved.

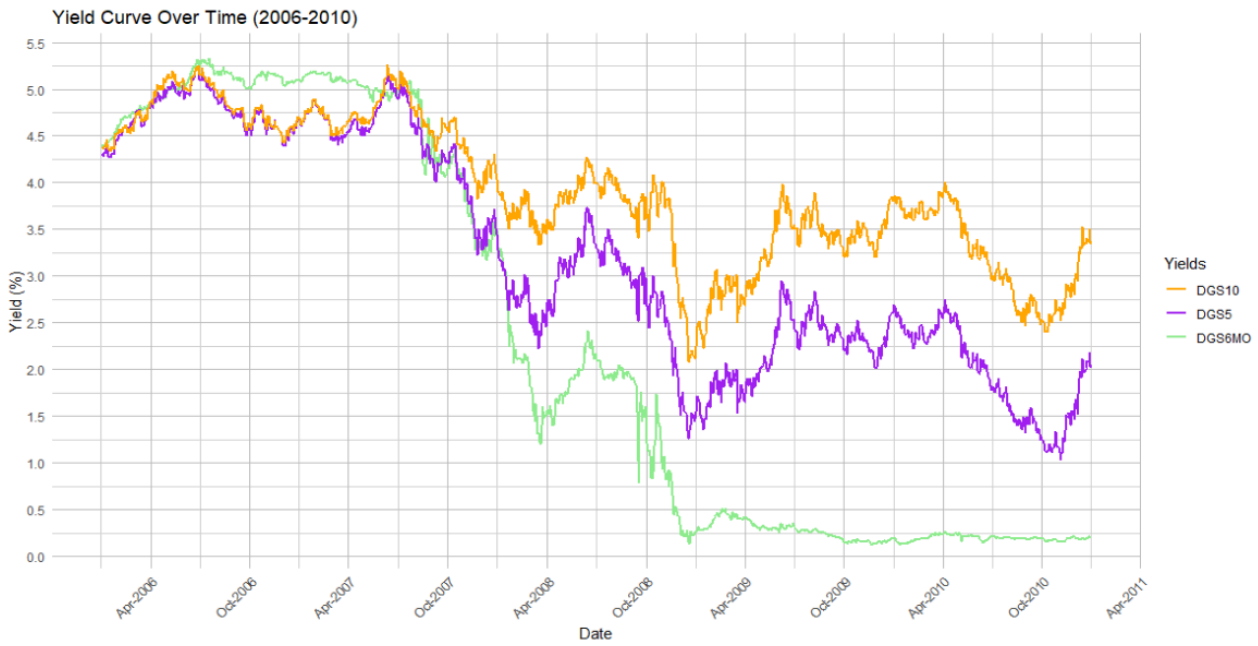


Figure 15 : treasury over time (2006 - 10)

3.2.3 Macroeconomic Indicator Changes

Several macroeconomic indicators showed dynamic changes:

1. **Gross Domestic Product (GDP):**
   - Moderate growth during the housing boom (2006–2007).
   - Sharp contraction during 2008–2009, reflecting reduced consumer spending and business investment.
   - Gradual recovery in 2010, fueled by fiscal stimulus and improved global conditions.
2. **Unemployment Rate:**
   - Rose sharply to over 10% by 2009, reflecting widespread layoffs.
   - Stabilized at around 9.6% in 2010 as the economy began recovering.
3. **Consumer Price Index (CPI):**
   - Deflationary pressures emerged in 2008 during the crisis.
   - Inflation stabilized during 2009–2010 as economic activity resumed.
4. **S&P 500 Index:**
   - Declined dramatically, losing nearly 50% of its value from 2007 to 2009.
   - Rebounded significantly in 2010, driven by improved investor sentiment.
5. **Federal Funds Rate:**
   - Aggressively reduced to near-zero levels from 2007 to 2009 to stimulate borrowing.
   - Remained low in 2010 under accommodative monetary policy.

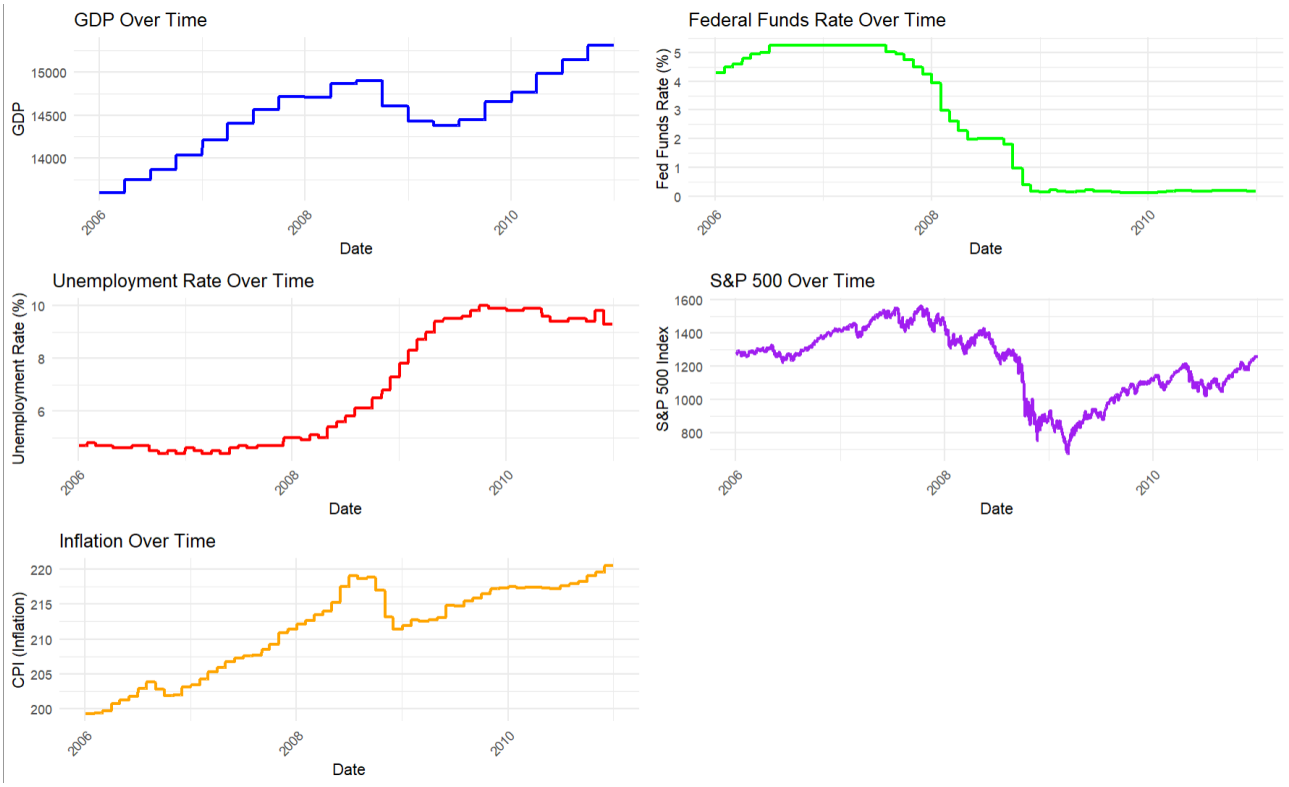


Figure 16: Macroeconomic data over time (2006-10)

3.2.4 Correlation

The correlation matrix during this period highlights:

Crisis Period (2006–2010)

- Treasury Yields: Strong positive correlations across maturities (DGS6MO, DGS5, DGS10) reflect synchronized movements during economic turbulence.
- Federal Funds Rate: Highly correlated with short-term yields, emphasizing its role in crisis management.
- Inflation (CPI): Strong positive correlation with medium- and long-term yields, reflecting heightened inflation expectations.
- Unemployment Rate: Strong negative correlation with GDP, CPI, and yields, indicating its counter-cyclicality during the downturn.

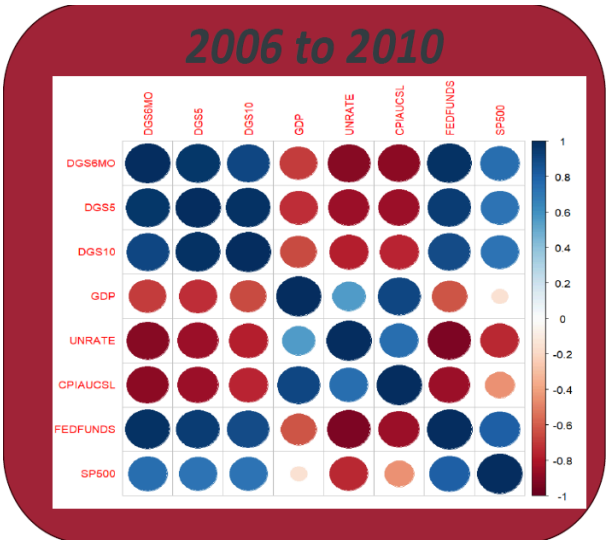


Figure 17: Correlation Matrix (2006 - 2010)

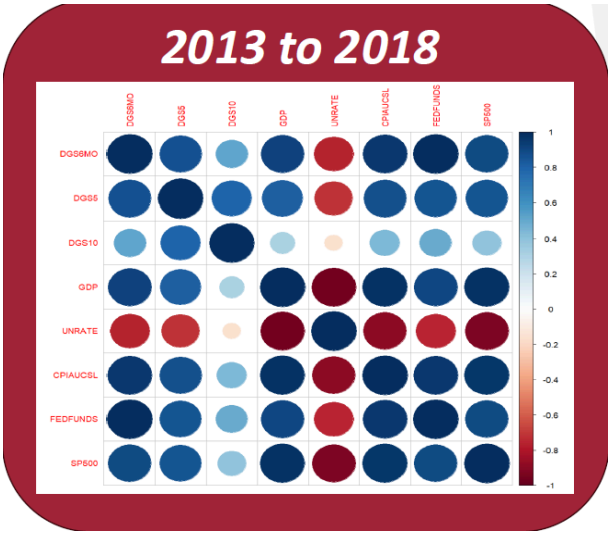


Figure 18: Correlation Matrix (2013 - 2018)

Neutral Period (2013–2018)

- Treasury Yields: Positive correlations persisted but with less volatility compared to the crisis.
- Federal Funds Rate: Continued to influence short-term yields but with weaker effects on medium- and long-term yields.
- Inflation (CPI): Correlations with yields were weaker, reflecting reduced inflation concerns.
- Unemployment Rate: Showed a weaker negative relationship with GDP and yields, consistent with economic stability.

3.2.5 Regression Models

Regression models were developed to analyze 6-month Treasury yields during the financial crisis (2006–2010) and the neutral period (2013–2018). The models incorporated lagged variables to evaluate delayed effects of macroeconomic indicators and were compared to non-lagged models for their predictive power and relevance.

Key Results

1. **2006–2010 (Without Lagged Variables):**
    - The baseline model showed significant relationships between Treasury yields and key macroeconomic indicators such as the Federal Funds Rate, GDP, and CPI.
    - The unemployment rate exhibited an inverse relationship with yields, reflecting its counter-cyclical nature during the crisis.
2. **2006–2010 (With Lagged Variables):**
    - Incorporating lagged variables improved the model's ability to capture delayed responses of yields to macroeconomic changes.
    - Lagged GDP and inflation were particularly influential, highlighting the temporal impact of economic shocks on yield trends.
    - The inclusion of lagged variables resulted in higher predictive accuracy compared to the non-lagged model.

3. **2013–2018 (Neutral Period):**
    - During this period of economic stability, the models showed weaker relationships between yields and macroeconomic indicators compared to the crisis period.
    - The Federal Funds Rate remained the most significant predictor, while the effects of other variables like GDP and CPI were less pronounced.

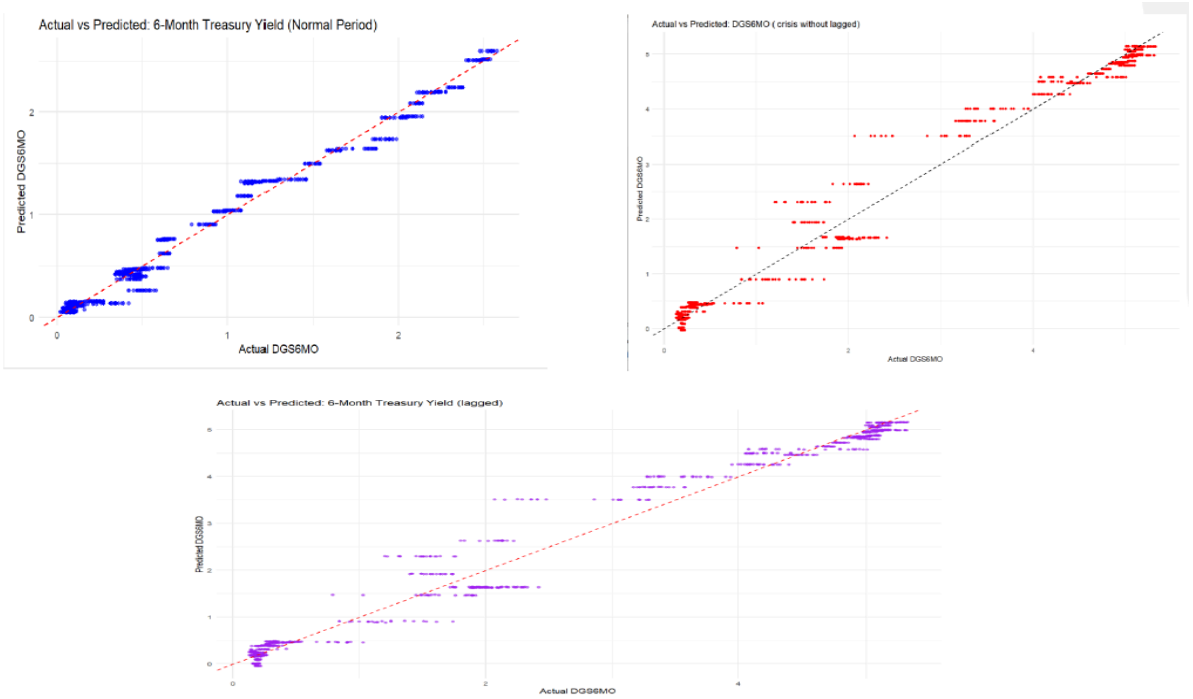


Figure 19: regression plot (6 months)

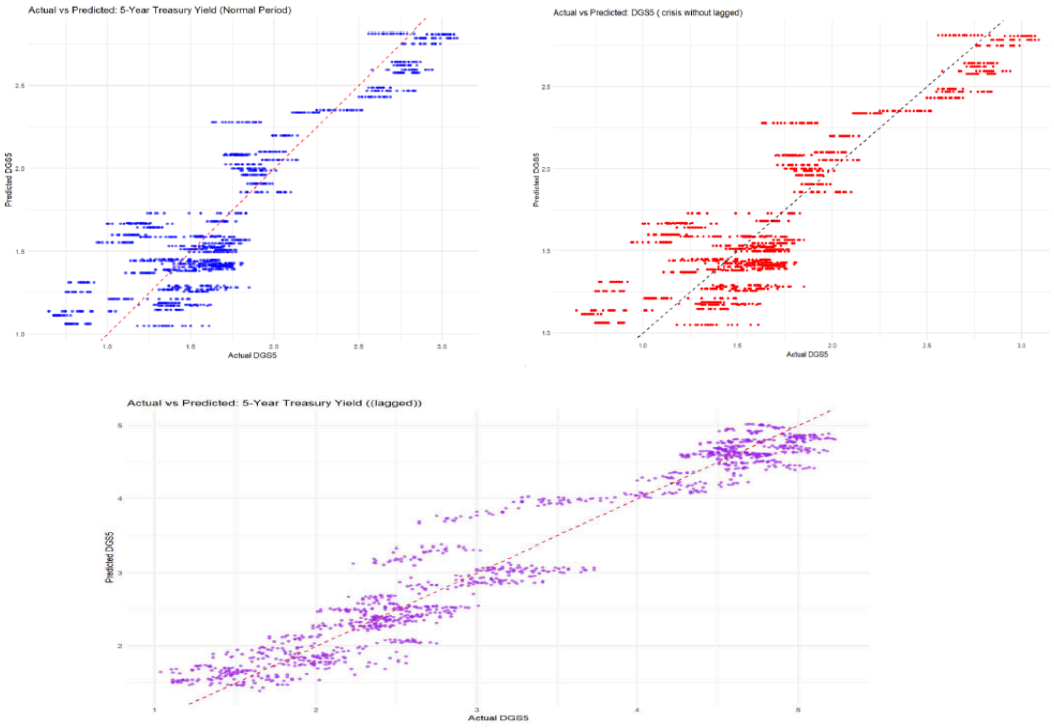


Figure 20: regression plot (5 years)

Figure 21: regression plot (10 years)

3.2.6 Results

The regression analysis highlights that short-term Treasury yields (6-month) are highly predictable, with the best model fit across all periods, especially during the stable 2013–2018 neutral period. Mid-term yields (5-year) show improved performance with lagged variables during the crisis, reflecting delayed macroeconomic effects. Long-term yields (10-year) are harder to predict, with lower R^2 values, especially during stable periods, as they are influenced by broader market expectations and external factors. Including lagged variables generally enhances model performance during volatile periods.

6-Month Treasury Yield Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
2006-10 (without lag)	0.9852	0.9852	0.2577
2006-10 (lagged)	0.9848	0.9848	0.2612
2013-18 (Neutral Period)	0.9896	0.9896	0.07799

5-years Treasury Yield Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
2006-10 (without lag)	0.9343	0.9341	0.3162
2006-10 (lagged)	0.9413	0.9411	0.299
2013-2018 (Neutral period)	0.7976	0.7971	0.2496

10-years Treasury Yields Results

TIME PERIOD	R-SQUARED	ADJ. R-SQUARED	RESIDUAL STD. ERROR
2006-10 (without lag)	0.8613	0.8608	0.2885
2006-10 (lagged)	0.8795	0.879	0.2691
2013-2018 (Neutral period)	0.5422	0.541	0.2785

3.2.7 Residual Analysis Summary

Residuals vs. Fitted Plots

- **Patterns:** Slight patterns in residuals for DGS6MO, DGS5, and DGS10 suggest the models do not fully capture all underlying relationships between predictors and response variables. However, the overall consistency indicates an acceptable fit for the majority of the data.
- **Heteroscedasticity:** The spread of residuals remains relatively uniform across fitted values, with minor deviations, showing that heteroscedasticity is not a significant concern for the models.

- **Centering:** Residuals are generally centered around zero, demonstrating no significant bias in the predictions, which supports the adequacy of the models.

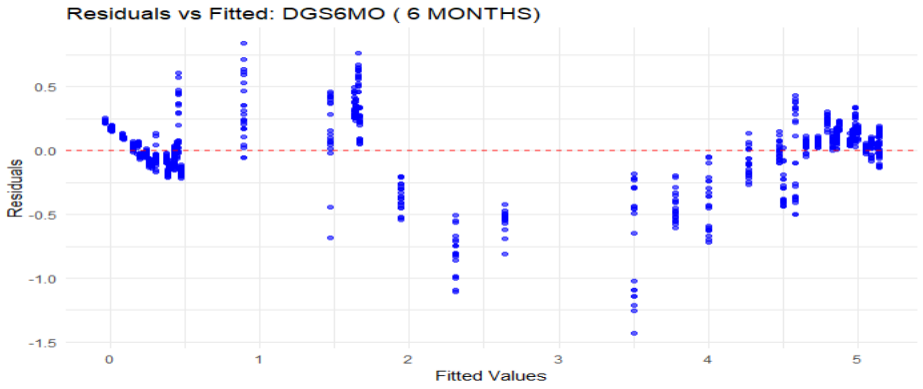


Figure 22: residual vs fitted (6 months)

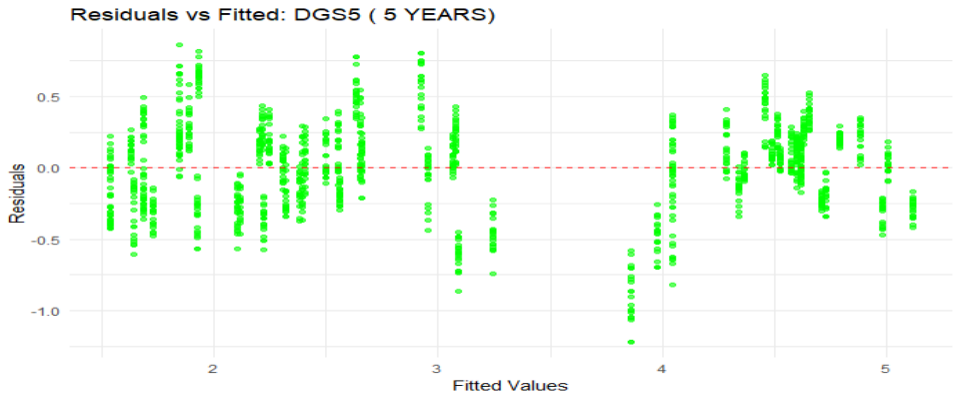


Figure 23: residual vs fitted (5 years)

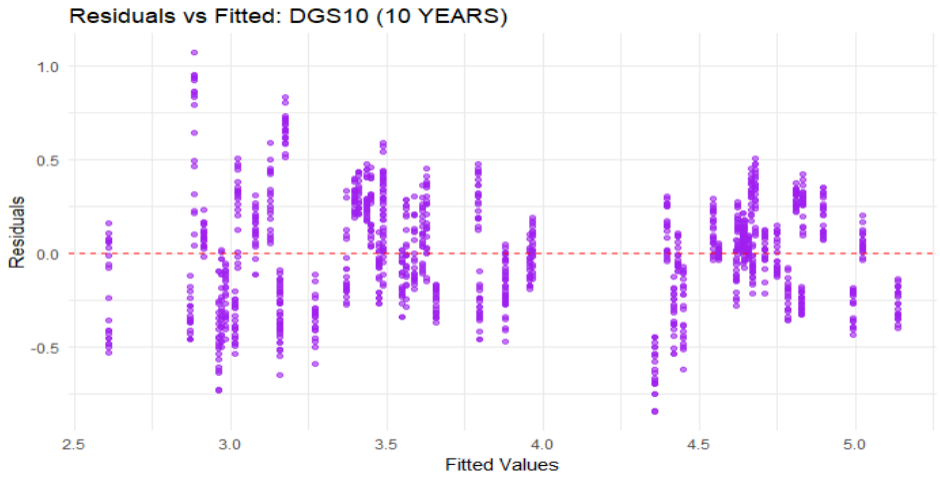


Figure 24: residual vs fitted (10 years)

Histograms of Residuals

- **Normality:** The residuals for DGS5 and DGS10 roughly follow a normal distribution, though slight deviations are observed in the tails. This indicates the models satisfy the normality assumption reasonably well for most observations.
- **Concentration:** The high concentration of residuals near zero suggests that the models fit well for the majority of the data, capturing the central trends effectively.

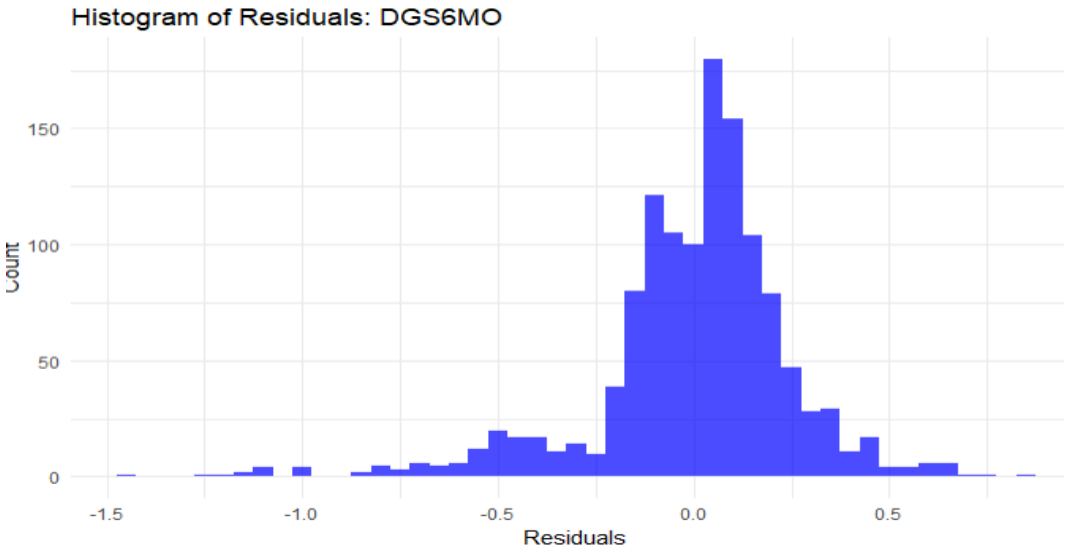


Figure 25: Residuals Analysis histogram 6 months

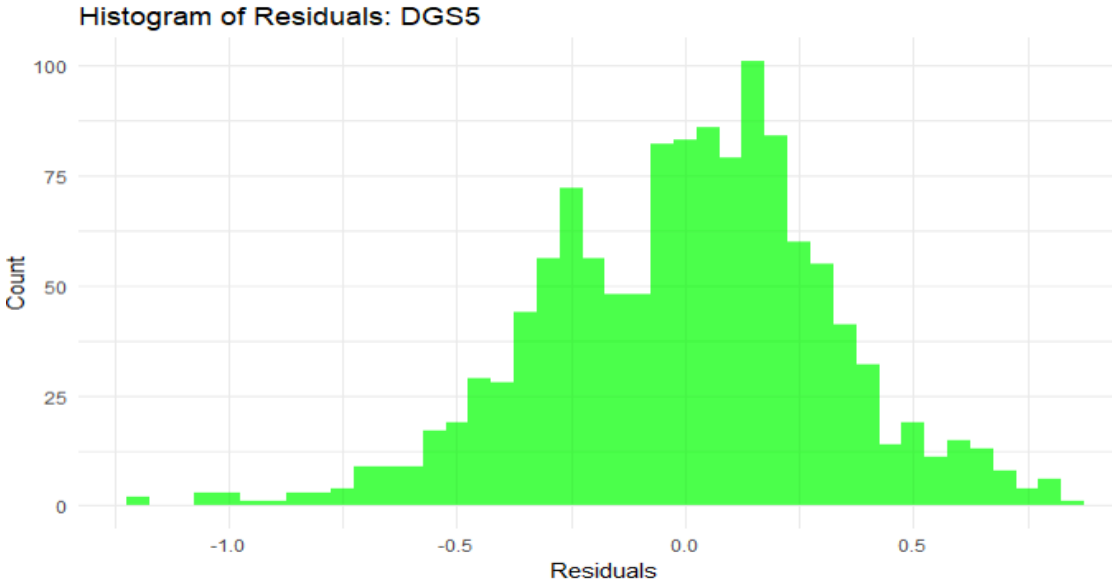


Figure 26: Residuals Analysis histogram 5 years

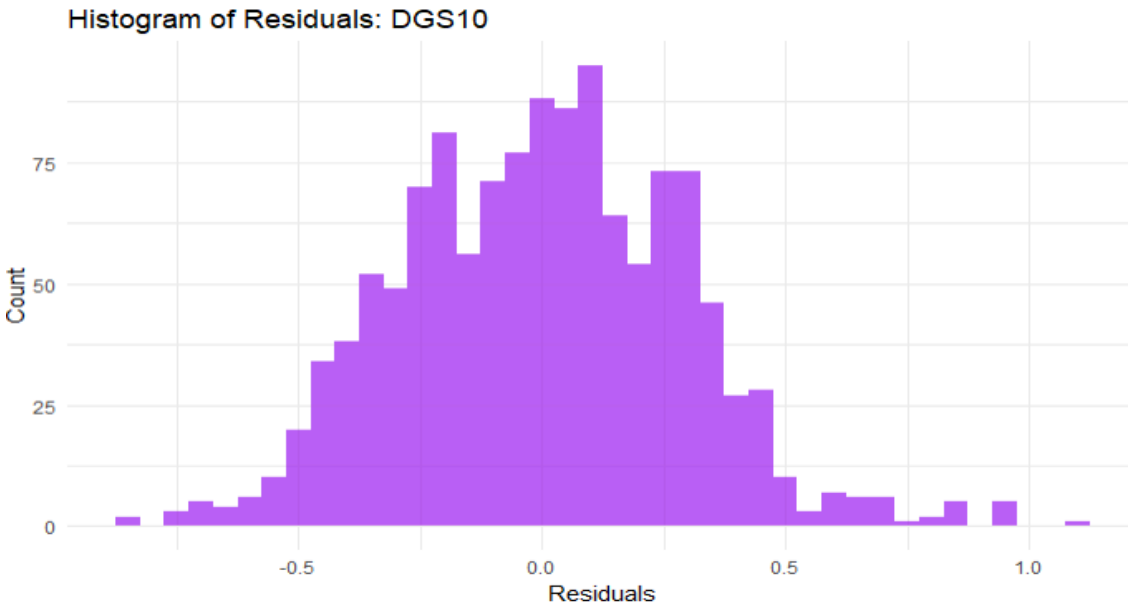


Figure 27: Residuals Analysis histogram 10 years

Q-Q Plots of Residuals

- **Alignment with Theoretical Quantiles:** Q-Q plots for DGS6MO, DGS5, and DGS10 show residuals aligning closely with the diagonal (theoretical quantiles), confirming the normality assumption for most of the residuals.
- **Deviations:** Minor deviations in the tails of the Q-Q plots indicate the presence of outliers or extreme values, which may be linked to specific data points or non-linear effects not fully captured by the current models.

The models show reasonable performance, with residuals demonstrating normality and being centered around zero. Minor patterns and deviations observed in the residuals suggest that while the models are generally well-fitted, there is room for further refinement in capturing complex relationships or handling extreme values.

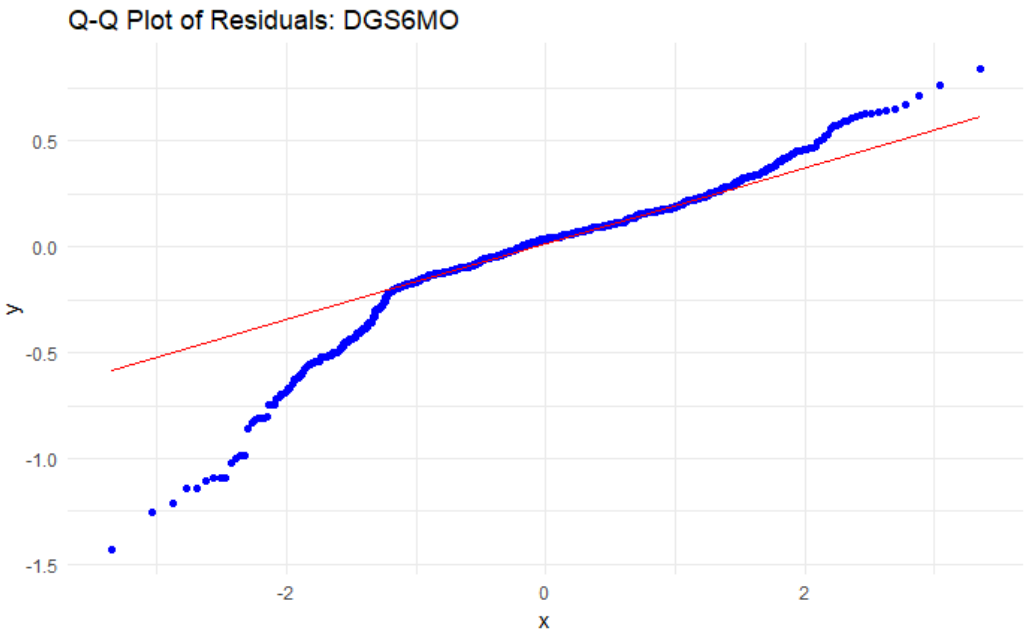


Figure 28: QQPlot 6 months

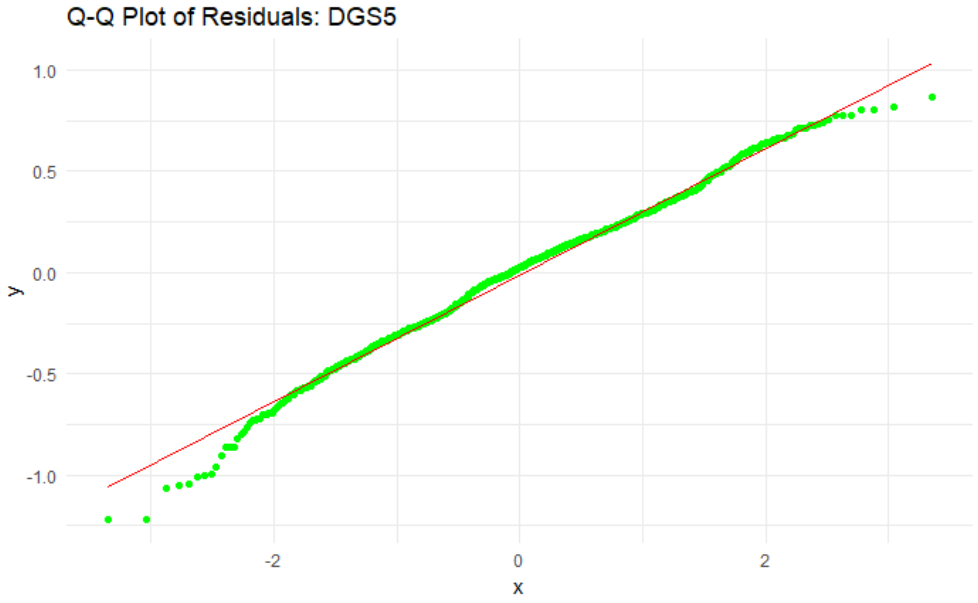


Figure 29: QQPlot 6 month

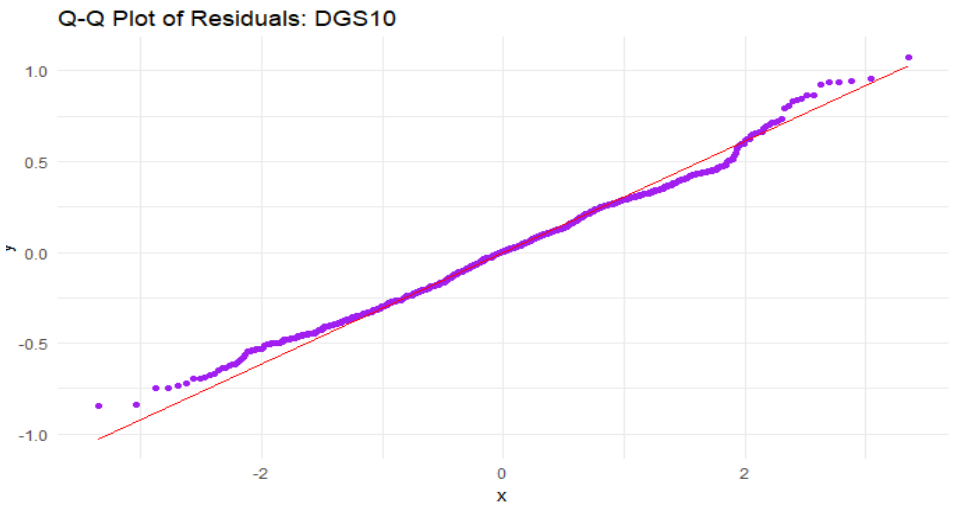


Figure 30: QQPlot 6 month

3.3 COVID-19 Pandemic (2019–2024)

The COVID-19 pandemic and subsequent global economic events had a significant impact on the U.S. Treasury yields, reflecting market uncertainty and government monetary policies.

3.3.1 Economic Events

During the period 2019-2024, key events that influenced Treasury yields included:

• COVID-19 Pandemic: The global pandemic triggered widespread economic uncertainty and downturn, causing central banks globally lowered interest rates to stimulate the economy. Further leading to a drop in Treasury yields as investors sought safe-haven assets.

• March 2020 Russia–Saudi Arabia Oil Price War: The oil price war added another layer of volatility, driven energy prices up and further depressing yields.

• February 2022 Russian Invasion of Ukraine: The invasion of Ukraine led to increased geopolitical risk and potential inflationary pressures.

• March 2023 Banking Crisis: With the failure of Silicon Valley Bank, Signature Bank and First Republican Bank, the banking crisis triggered a surge in risk aversion. Yields decrease, reflecting this shift as investors flocked to safe assets.

• August 2023 Fed Funds Rate Increase: As the Federal Reserve implemented aggressive rate hikes to combat increasing inflation, there is a substantial rise in yields, particularly for short-term Treasuries, which are highly sensitive to Fed policy.

3.3.2 Yield Trends Over Time

As shown in Figure 31, the Treasury yields for 6-month, 5-year, and 10-year terms experienced substantial fluctuations during this period:

• Short-term yields (6-month) are more volatile and reached near zero during COVID. After which, it showed a rapid recovery as the inflation kept increasing. It surpassed the yields of longer maturity, meaning there is possibly recession. It reached a record high of over 5%.

• Mid-term yields (5-year) and Long-term yields (10-year) exhibit a close relation as they move together over the past five years. Influenced by the pandemic, They drop rapidly but soon gradually recover to previous levels in two years. After which, they show wider dispersion and slower adjustments, indicating uncertainty about long-term economic conditions.

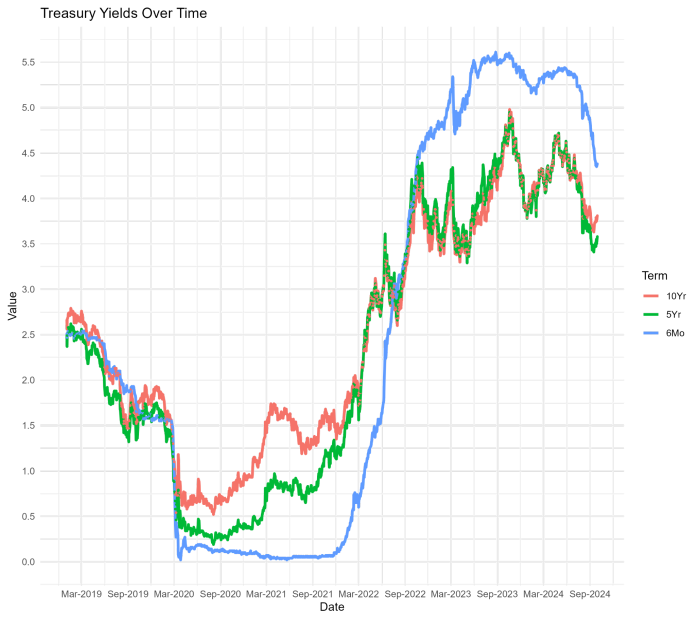


Figure 31: Treasury over time

3.3.3 Macroeconomic Indicator changes

The graphs in Figures 32 illustrate the dynamic changes in key macroeconomic indicators over the period from 2019 to 2024. These indicators reflect the direct impact of global and domestic economic events.

1. Gross Domestic Product

• Initial Decline (2020): The COVID-19 pandemic triggered a sharp contraction in GDP as economies globally implemented lockdowns and reduced economic activity.

• Recovery Phase (2021–2024): After the initial shock, GDP shows a steady upward trend. This recovery is attributed to the gradual reopening of economies, government stimulus packages, and vaccine rollouts. The smoothed GDP highlights consistent long-term growth following the recovery.

2. Unemployment Rate

• Spike in 2020: A significant spike in unemployment is observed in early 2020, coinciding with widespread layoffs and economic shutdowns due to the pandemic.

• Gradual Decline (2021–2024): From mid-2021 onwards, the unemployment rate steadily decreases as the labor market recovers. By 2024, the unemployment rate stabilizes close to pre-pandemic levels, reflecting improved economic conditions.

3. Consumer Price Index

• Rise in Inflation (2021–2024): The Consumer Price Index shows a sharp upward trend post-2020. This inflationary pressure can be linked to supply chain disruptions, increased consumer demand during recovery, and higher energy prices, particularly after geopolitical events such as the Russia-Ukraine conflict.

4. S&P 500 Index

• Volatility in 2020: The stock market experienced sharp declines in early 2020 due to pandemic-induced uncertainty but rebounded quickly with stimulus measures and investor optimism.

• Sustained Growth (2021–2024): The index reflects strong performance, driven by economic recovery and a focus on technology and growth sectors.

5. Federal Funds Rate

• Near-Zero Levels in 2020: To combat the economic downturn, the Federal Reserve reduced the interest rate to near-zero levels, stimulating borrowing and investment.

• Gradual Increase (2022–2024): As inflation rose, the Fed responded by incrementally increasing the rate, culminating in a sharp rise by 2024 to control price stability and manage economic overheating.

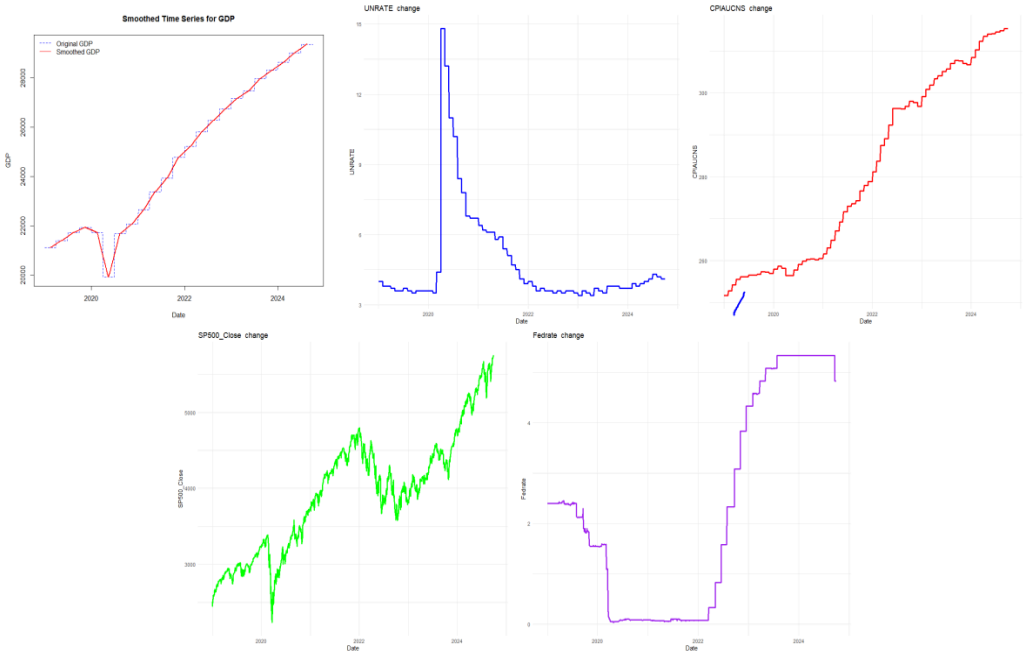


Figure 32: Macroeconomics Indicators change

3.3.4 Correlation

The correlation matrix on the right, shown in Figure 33, depicts the relationships between percentage changes in macroeconomic indicators:

• Treasury Yields: Short-term Treasury yields (6-Mo) exhibit a strong positive correlation with medium-and long-term yields (5-Year: r = 0.90, 10-Year: r = 1.00), reflecting synchronized movements across maturities.

• GDP: Gross Domestic Product correlates moderately with CPI (r = 0.42) and S&P 500 (r = 0.88), indicating economic growth is intertwined with inflation levels and market performance. A strong inverse relationship is observed with unemployment (r = −0.61), consistent with economic theory.

• Unemployment: Unemployment negatively correlates with CPI (r = −0.26) and short-term yields, highlighting its role as a counter-cyclical indicator.

The correlation matrix on the left focuses on absolute values of macroeconomic indicators and yields:

• Strongest Correlations: Near-perfect correlations are observed between short-term and medium-/long-term Treasury yields (6-Mo vs. 5-Year: r = 0.96, 6-Mo vs. 10-Year: r = 0.95). The Fed Funds rate correlates highly with 6-Mo yields (r = 0.98), underscoring its critical influence on short-term market dynamics.

• GDP: Strong positive correlations between GDP and CPI (r = 0.99) and GDP and S&P 500 (r = 0.86) highlight the alignment of economic output with inflation and equity performance.

• Unemployment: As expected, unemployment exhibits a negative correlation with GDP (r = −0.59), reinforcing its counter-cyclicality.

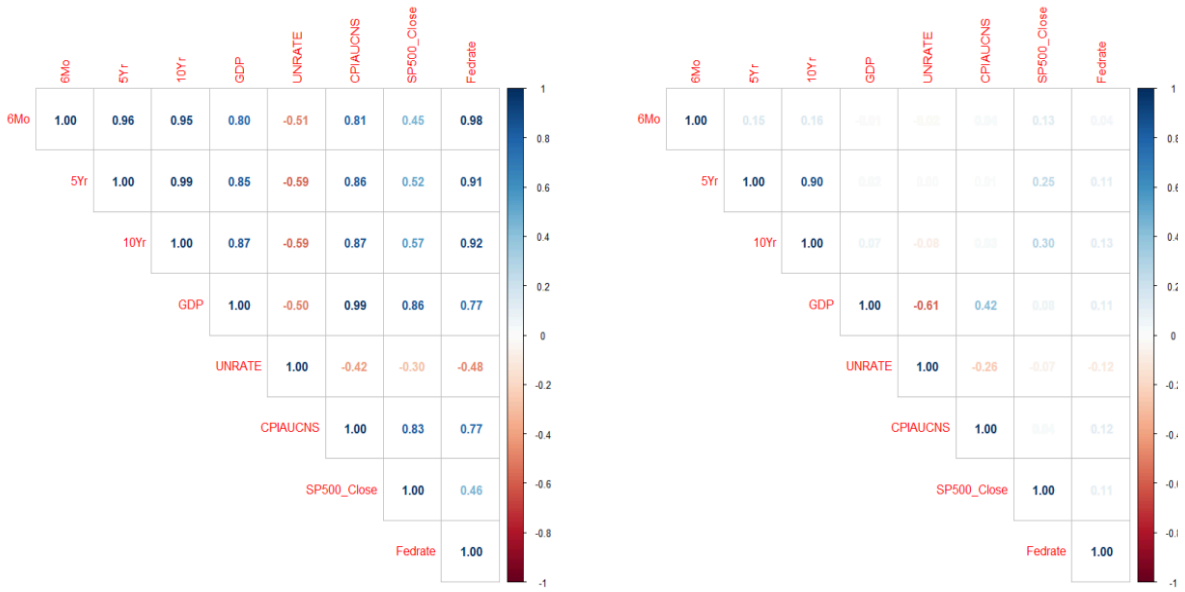


Figure 33: Correlation Matrices

3.3.5 Regression Models

1. Linear Regression: The relationship between 6-month Treasury yields and macroeconomic indicators was analyzed using multiple linear regression. Table 1 summarizes the regression results, including using both raw and standardized data.

(a) The linear regression model on raw data indicates the direct effect of each macroeconomic indicator on Treasury yields:

• Negative Impact: GDP, unemployment rate, Stock market performance.

• Positive Impact: Inflation, Federal funds rate.

(b) To compare the relative influence of predictors, coefficients obtained from standardized data were analyzed:

• Fed Funds Rate: The most influential predictor (1.66), reflecting its critical role in short-term market dynamics.

• CPI (Inflation): A strong contributor (1.22) to yield changes, indicating its economic significance.

• GDP, UNRATE, S&P500: Moderate but consistent effects, demonstrating their relevance to treasury yield movements.

(c) Model Fit: The model explains 99.12% of the variance in Treasury yields (R2 = 0.9912), indicating an excellent fit. The regression residuals reveal a standard error of 0.023, and an F -statistic of 3.23×10^4 (p-value < 0.001), confirming the model's accuracy and robustness.

Predictor	Coeff.	Scaled Coeff.
Intercept	-8.61	2.47
GDP	$-1.5 \cdot 10^{-4}$	-0.44
Unemployment rate	$-5.79 \cdot 10^{-2}$	-0.13
Inflation	$5.57 \cdot 10^{-2}$	1.22
S&P500	$-5.83 \cdot 10^{-4}$	-0.46
Fed Funds Rate	0.786	1.69
R^2	0.9912	
Residual Std. Error	0.202	
F-Statistic	3.23×10^4	
P-value	<0.001	

Table 1: Regression Results for 6-Month Treasury Yields.

(d) Residual Analysis

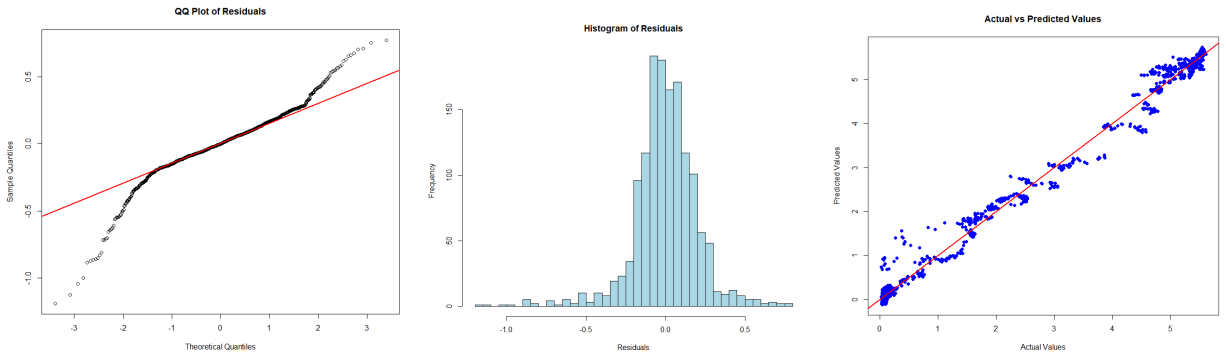


Figure 34: Residual Analysis on 6 month treasury yield

For linear regression on 6 month treasury yields:

1. The QQ-plot indicates that the residuals are approximately normally distributed, with most points lying close to the reference line, though slight deviations are observed at the tails.
2. The histogram of residuals shows a bell-shaped distribution centered around zero, but shows slightly skew.
3. The actual vs. predicted values plot demonstrates good predictive accuracy, with points closely aligned along the 45-degree line. While some scatter is evident at the extremes, it remains minimal and does not significantly impact the overall model performance.

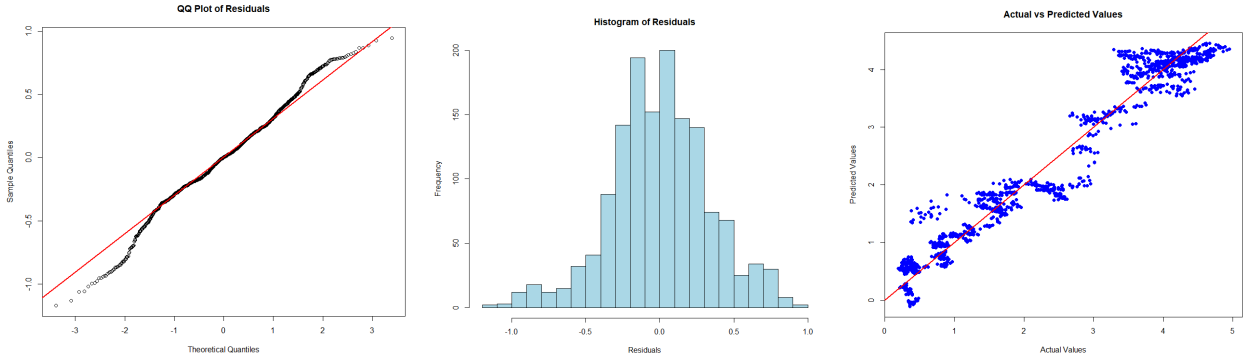


Figure 35: Residual Analysis on 5 Yr treasury yield

For linear regression on 5 years treasury yields:

4. The QQ-plot shows an improved normality of residuals, with most points closely following the reference line and only minimal deviations at the tails.
5. The histogram of residuals exhibits a more symmetric and well-defined bell-shaped curve centered around zero,.
6. The actual vs. predicted plot displays some predictive accuracy, with points tightly aligned along the 45-degree line but are more dispersed compared to the previous model, showing a lower precision in predicting yields with longer maturity.

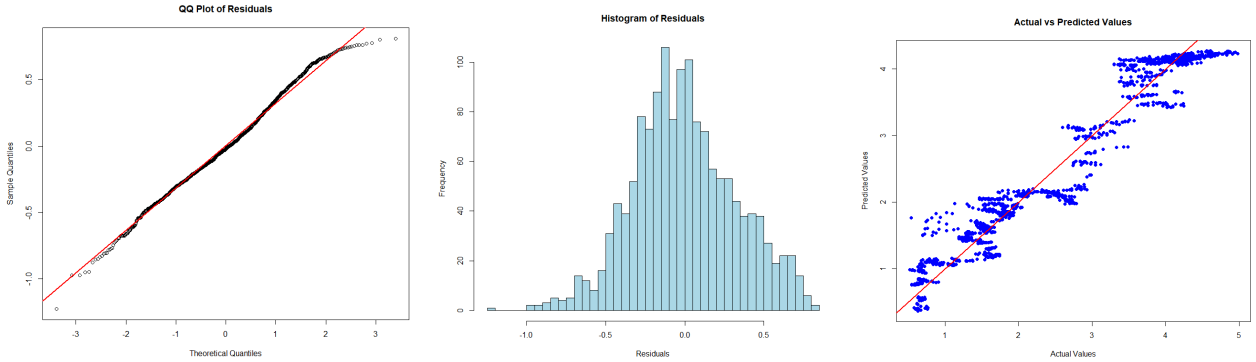


Figure 36: Residual Analysis on 10Yr treasury yield

For linear regression on 5 years treasury yields:

7. The QQ-plot shows strong evidence in normal distribution, where near all points tightly follow the 45 degree line.
8. The histogram of residuals exhibits a normal distribution with slight fat in the right tail.
9. The actual vs. predicted plot displays minimal predictive accuracy among all three, showing the lowest precision in predicting yields with longest maturity.

2. Lasso Regression: This section presents the coefficients of predictors from a Lasso regression model applied to Treasury yields across different maturities: 10-Year, 5-Year, and 6-Month. The results, visualized in Figure 7, highlight the influence of key macroeconomic variables and the effect of L1-regularization.

• Inflation: - Inflation demonstrates a strong influence on long-term yields (10-Year), with coefficients decreasing for medium-term (5-Year) and short-term (6-Month) maturities. This reflects the role of inflation in shaping expectations about future interest rates, particularly for longer maturities.

• Fed Funds Rate: - The Fed rate shows an increasing coefficient trend from long-term to short-term maturities, becoming the dominant factor for short-term yields. This aligns with the direct influence of monetary policy on shorter-term Treasury yields.

• GDP: - GDP exhibits relatively stable and near-zero coefficients across all maturities, suggesting it is not a significant predictor in this Lasso regression model.

• Stock Market: - The S&P500's influence remains negative across all maturities, particularly for medium- and short-term yields. This reflects the inverse relationship between equity markets and yields due to risk-on/risk-off dynamics.

• Unemployment Rate: - The unemployment rate has a consistent negative influence on yields across all maturities, consistent with its inverse relationship with economic health and bond market Demand.

Lasso regression applies L1-regularization, which penalizes less relevant predictors and shrinks their coef-ficients toward zero. This effect is evident in the small coefficients for GDP, while significant predictors like CPI and Fed Funds Rate retain larger coefficients due to their stronger relationship with Treasury yields.

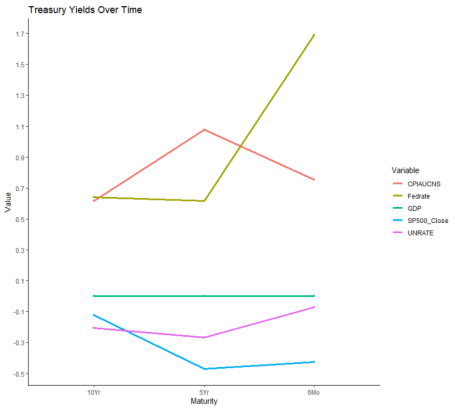


Figure 37: Coefficient changes

3. Decision Tree Regression: The variable importance metrics for predicting 6-month and 10-year Treasury yields were obtained from decision tree models. Table 2 summarizes the relative importance of each macroeconomic predictor.

(a) 6-Month Treasury Yields

• Fed Funds Rate (39%): Most significant, reflecting direct monetary policy impact.

• CPI (38%): A critical factor shaping short-term expectations.

• S&P500 (15%): Moderate influence, linked to equity market trends.

• Unemployment (9%): Least important, weaker immediate market effect.

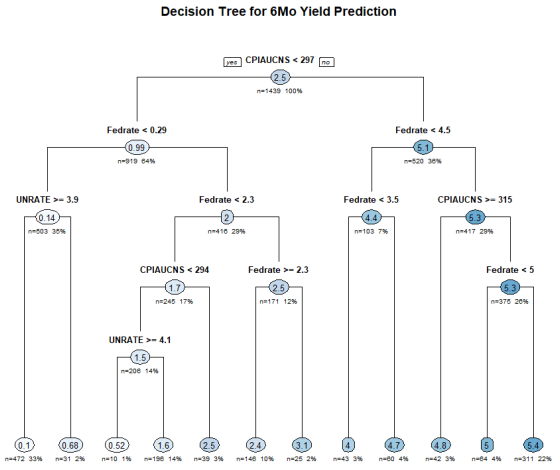
(b) 10-Year Treasury Yields

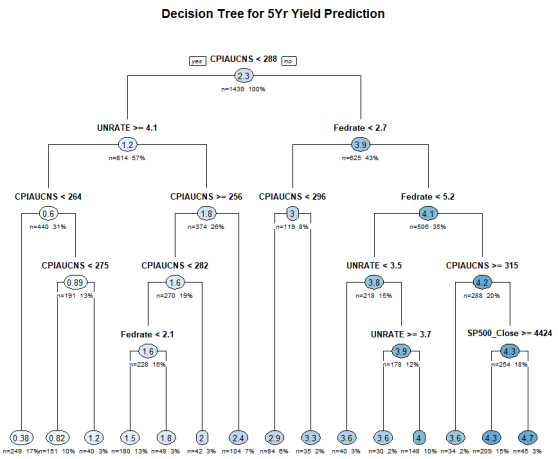
- CPI (36%): Dominates long-term yield predictions.
- Fed Funds Rate (30%): Significant but less than CPI.
- S&P500 (18%): Greater influence than for 6-month yields.
- Unemployment (16%): More relevant for long-term trends.

Variable	6-Month (%)	10-Year (%)
Fed Funds Rate	39	30
CPI (Inflation)	38	36
S&P500 Close	15	18
Unemployment Rate	9	16

Table 2: Variable Importance for Predicting Treasury Yields.

(c) Decision tree hierarchy: The decision trees for predicting 6-month, 5-year, and 10-year treasury yields illustrate the hierarchical importance of macroeconomic variables across different maturities. For all maturities,Consumer Price Index is the primary determinant, reflecting its dominant influence on yield prediction. Short-term yields, such as the 6-month maturity, rely heavily on Federal Funds Rate and unemployment rates, showcasing a strong relationship with immediate economic indicators. As the maturity increases, additional variables like stock market performance become more relevant, highlighting the interplay of long-term economic trends and investor sentiment. However, models on longer maturity yields show greater complexity and dispersion in the splits, indicating increased variability and challenges in predicting longer-term yields. This progression demonstrates that while inflation remains a consistent predictor, the predictive complexity grows with maturity, necessitating more nuanced models for accurate forecasting.





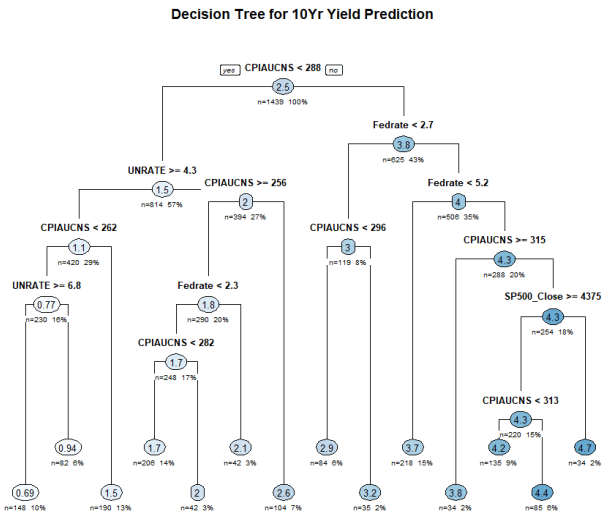


Figure 38: Decision Tree Hierarchy

3.3.6 Conclusion

The analysis of treasury yields during the COVID-19 pandemic (2019-2024) highlights the significant impact of unprecedented global economic events on financial markets. The COVID-19 pandemic initiated a rapid decline in yields, driven by a flight to safety as investors sought refuge in government securities. This trend was further exacerbated by the Russia-Saudi Arabia oil price war in early 2020, which added additional instability to global markets.

Throughout the period, the Federal Reserve's interventions played a crucial role in stabilizing the economy. The reduction of the Federal Funds Rate to near-zero levels provided liquidity and bolstered investor confidence, while large-scale asset purchases supported financial markets and maintained low borrowing costs. However, these measures also resulted in a sharp decline in short-term treasury yields, reflecting heightened uncertainty and reduced economic activity.

As the pandemic progressed, treasury yields began to rise steadily, driven by economic recovery, vaccine rollouts, and the easing of restrictions. The Russian invasion of Ukraine in 2022 and the banking crisis of 2023 caused temporary disruptions, highlighting the sensitivity of treasury yields to geopolitical and macroeconomic shocks. By mid-2023, the Federal Reserve's policy pivot towards raising rates to combat inflation led to a notable increase in yields, particularly for longer-term securities.

Model performance analysis during this period revealed that linear regression, lasso, and decision tree models all achieved good R-squared values for short-term maturities, reflecting strong predictive accuracy. However, as the maturity of treasury yields increased, the R-squared values declined across all models. This highlights the growing complexity and reduced predictability of longer-term yields in the face of evolving economic conditions.

In conclusion, the COVID-19 pandemic period underscored the vulnerability of treasury yields to external shocks and the critical role of monetary policy in stabilizing markets. While the early phase was marked by rapid declines, the subsequent recovery showcased the resilience of financial systems in adapting to extraordinary challenges. The period also emphasized the importance of dynamic, data-driven strategies for predicting yield movements amidst economic uncertainty.

4. Conclusion

The analysis of treasury yields in relation to macroeconomic indicators across different timeframes has provided valuable insights into their behavior and predictive relationships. For all crisis periods and 2013-2018 periods, the Federal Funds Rate emerged as the most influential predictor across all maturity models, showcasing its central role in monetary policy's impact on treasury yields. During the crisis period, the models demonstrated higher predictive power, with consistently higher R-squared values compared to the 2013-2018 period. This indicates stronger and more stable relationships between predictors and yields during the strong economic environment.

Short-term yields, such as the 6-month maturity, exhibited the strongest alignment between predicted and actual values, reflecting robust model performance and minimal variability. Medium-term yields (5 years) showed moderate predictive accuracy but required further refinement due to increased scatter and clustered deviations. Long-term yields (10 years), however, displayed wider dispersion and systematic patterns of deviation, indicating potential biases in the model's long-term projections and highlighting the challenges of accurately modeling extended maturities.

Additionally, the analysis of the 2013-2018 period revealed a steady post-crisis recovery reflected in rising treasury yields. The gradual increase in Federal Funds Rates during this time aligned with the economic recovery and the Federal Reserve's normalization of monetary policy. However, the predictive power for long-term yields in this period was notably weaker compared to the crisis period , suggesting that the relationships between macroeconomic indicators and treasury yields have become more complex in the post-crisis economic environment.

In conclusion, this analysis underscores the dynamic interplay between macroeconomic factors and treasury yields, emphasizing the need for continued refinement of predictive models, particularly for medium and long-term maturities. These findings contribute to a deeper understanding of market dynamics and provide a basis for informed monetary policy and investment decision-making. To analyze the deeper relation between treasury yield we would require to run more advanced analysis by taking into account other factors. Also, the relationship between these treasury and macroeconomic variables is quite complex which would require more advanced models to predict the right results.

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