

**Analyzing the U.S. Federal Reserve’s Dual Mandate – Final Draft**

**DATA 698 Analytics Master’s Research Project**

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# Abstract

The role of a Central Bank is a balancing act between competing monetary policy objectives. In the United States, the Federal Reserve System articulates this goal as its dual mandate of price stability and full employment. The official stated position of the Federal Reserve is that it weighs both components of the dual mandate equally when conducts monetary policy. This analysis provides insight into the Federal Reserve's deliberation process when setting the target range for the Federal Funds Rate. The paper explores models based on the concepts behind the Economic Discomfort Index (EDI) and the Taylor Rule to quantify the predictive power of each component of Federal Reserve’s dual mandate.

# Introduction

On December 23, 1913, the United States Congress passed the Federal Reserve Act, establishing the Federal Reserve System. The Federal Reserve Act outlined the central bank's structure and articulated its monetary policy objectives. The Federal Reserve (the Fed) has a unique configuration among modern central banks. It includes both public and private organizations in a distributed monetary control system (Journal of Regulation, 2023).

This research will focus on the monetary policy objectives summarized in Section 2A of the Federal Reserve Act.

*The Board of Governors of the Federal Reserve System and the Federal Open Market Committee shall maintain long run growth of the monetary and credit aggregates commensurate with the economy's long run potential to increase production, so as to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates.*

(United States Congress, 1913)

These objectives have come to be interpreted as the Federal Reserve's dual mandate of price stability and full employment. Over the Federal Reserve’s 109-year history, the dual mandate has been the source of a healthy debate within academic, industrial, and political circles with differing opinions regarding the role of the central bank and how much emphasis it should place on its competing goals.

In 2012, the Federal Reserve reaffirmed its commitment to its statutory mandate from Congress and a balanced approach to monetary policy based on its dual mandate. The Federal Open Market Committee (FOMC) minutes include the following statement on Longer-Run Goals and Monetary Policy Strategy:

*Monetary policy is the primary determinant of inflation over the longrun it was determined that a long run target for inflation at 2 percent would be consistent with the long run objectives. The employment rate is however determined by the structure and dynamics of the labor markets hence establishing a long term unemployment rate is not appropriate.*

(Federal Open Market Committee, 2012)

In 1970, Arthur Okun succinctly captured the importance of this balancing act by the Federal Reserve in the concept of the Economic Discomfort Index (EDI). The EDI is an economic indicator that seeks to capture the economic health of the average citizen. The index is the sum of seasonally adjusted unemployment and the annual inflation rate. The EDI postulates that higher unemployment and higher inflation adversely affect the economic health of the average citizen. The EDI is often referred to as the Misery Index (Cohen, Ferretti, & McIntosh, 2014).

Adding to the complexity of the Fed’s balancing act is the uneven impacts of unemployment at the margins and price inflation on individual consumption profiles. Unemployment rates and the impact of monetary policy will differ by population segment, while individual consumers will experience inflation rates that can vary substantially from the Consumer Price Index (CPI). In balancing its dual mandate, the Federal Reserve directly impacts the well-being of individuals in the economy through the risk of unemployment or degradation of living standards caused by rising prices.

# Literature Review

The formula for the EDI and its historic values are explored in the article *“Economic Discomfort and Consumer Sentiment.”* (Lovell & Tien, 1999). The formula for the EDI is captured in the following figure 1:

p\* - annual rate change, CPI

U – unemployment rate

Figure 1: Economic Discomfort Index Formula

The graph below illustrates the EDI over time. It is noteworthy that the two components of the EDI are impacted differently by changes in the Federal Funds Rate. When the Federal Reserve wants to combat inflationary pressure, it will raise the Federal Funds Rate, slowing down economic growth, decreasing the inflationary pressures in the economy, and decreasing the demand for labor. When the Federal Reserve wants to reduce the unemployment rate, it will decrease the Federal Funds Rate, stimulating the economy and increasing the labor demand and increasing inflationary pressures in the economy (Board Of Governors Of The Federal Reserve System, 2020).

A graph showing the growth of the stock market

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Figure 2: Economic Discomfort Index (EDI)

From the perspective of the FOMC, a rule-based approach for balancing the competing priorities of inflation and unemployment when setting the short-term interest rates is illustrated in the Taylor Rule. The Taylor Rule is a widely used academic theory for research on monetary policy. The standard formulation (Figure 3) uses a combination of nominal interest rates, the Gross Domestic Product (GDP) gap, and the Inflation Target Gap to determine the federal funds rate (2019a; 2019b).

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- is the nominal federal funds rate

r\* - equilibrium real interest rate

π - current rate of inflation

y - real GPB

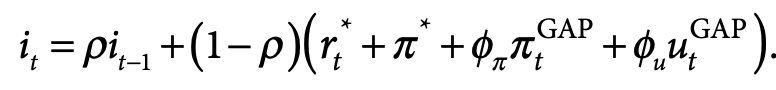
π \* - Fed’s inflation target

Figure 3: Taylor Rule Formula

(Kliesen, Is the Fed Following a ‘Modernized’ Version of the Taylor Rule? Part 1., 2019)

It should be noted that the GPD and Inflation Target Gap use different coefficients in the traditional formulation of the Taylor Rule.

Kliesen goes on to discuss a modernized version of the Taylor Rule that considers three major developments in monetary policy, First, the relatively low-interest rate regime that the economy is enjoying. Second, the achievement of stable low inflation rates. And finally, the flattening of the Phillips Curve. Kliesen’s analysis concludes that during the current expansion, the federal funds rate has been lower than what would be predicted by the Taylor Rule. Kliesen proposes that the Fed may be following a variation on the Taylor Rule to inform its decision-making on monetary policy. (Kliesen, Is the Fed Following a “Modernized” Version of the Taylor Rule? Part 2, 2019)



- nominal federal funds rate

𝘱 - one quarter lag term for the federal funds target rate with a fixed coefficient

- equilibrium real interest rate over time

π \* - Fed’s inflation target

- output inflation gap with a fixed coefficient

- unemployment gap with a fixed coefficient

Figure 2: Modified Taylor Rule

An interesting aspect of the modified Taylor Rule is the same coefficient is applied to the unemployment gap and the inflation gap, suggesting that inflation and unemployment have equal impacts on the federal funds rate.

The composition of the FOMC has changed overtime. Wilson (2019) analyzed the tenure of Federal Reserve Chairs from William McChesney to Janet L. Yellen. The researcher used the Unemployment Rate, the EDI, and the Taylor Rule to score the tenures of individual Federal Reserve Chairs in terms of the relative importance placed on each component of the dual mandate.

Wilson found that the approach to monetary policy has changed over time. Furthermore, he found the Yellen Fed to be the most dovish in history regarding short-term interest rates relative to inflation. Wilson was not able to conclude if behavioral changes are a function of changing macroeconomic dynamics or changes in how the decision-making members of the Fed view the role of the Federal Reserve as a whole (Wilson, 2019).

# Research Question

This analysis will not evaluate the relative merits of the dual mandate but will instead focus on how the Federal Reserve balances the dual mandate when setting monetary policy. I will endeavor to measure the relative importance of full employment and price stability in the Fed’s decision-making process. The analysis will use regression to evaluate the relative strength of the relationship between the federal funds rate, inflation, and unemployment.

Specifically, how much weight does the Federal Reserve put on inflation versus the pursuit of full employment in setting the target federal funds rate? Put another way, when faced with competing priorities or economic indicators, does the Federal Reserve favor one element of its dual mandates over the other?

To comprehensively analyze the Federal Reserve's decision-making process, I will explore the impacts of economic stress and the composition of the open market committee on its decision-making. Periods of economic stress include the stagflation era of the 1970s, the financial crisis of 2007, and the 2020 pandemic economy. During these times, the Federal Reserve took extraordinary measures to safeguard the economic system. To simplify the analysis, I will use the Federal Reserve Chair as a proxy for FOMC composition. In future studies, it would be interesting to analyze each member of FOMC, but that is beyond the scope of this paper.

# Hypothesis

Despite the Federal Reserve's stated mandate to take a balanced approach to monetary policy, there is a healthy debate regarding how measures of inflation and full employment impact decision-making by the FOMC. To explore this debate, I will focus on the inputs and outputs of the FOMC's monetary policy decision-making process. Specifically, I will focus on the economic indicators for inflation and unemployment as inputs to the FOMC decision. The output of the deliberations will be the Federal Funds Effective Rate.

Each decision by the FOMC is aligned with economic indicators that reflect one aspect of the dual mandate. Regression analysis will be used to quantify the relative impact of inflation and unemployment on the Federal Funds Effective Rate. Regression models will be built to predict the actions of the FOMC based on the level of inflation or the unemployment rate. The accuracy and performance of the individual models will reflect the weight that the FOMC assigns to the individual components of the dual mandate.

This research question is broken down into the following hypotheses:

* H0 - The Federal Reserve applies equal weights to inflation and employment targets when determining its monetary policy.
* H1 - The Federal Reserve emphasizes its inflation targets when determining monetary policy.
* H2 - The Federal Reserve emphasizes the employment rate when determining monetary policy.

# Methodology

## Dataset

The FOMC meets eight times a year. The output of the FOMC meetings includes meeting minutes and a target range for the Federal Funds Rate with an upper and lower bound. The Federal Reserve uses open market operation to influence the Federal Funds Rate to achieve the Target Range identified during the FOMC meeting. The analysis will use the monthly Federal Funds Effective Rate (FEDFUNDS) as the target variable for the regression models (Board of Governors of the Federal Reserve System (US), 2023).

There are numerous sources for Federal Reserve-related data. I will leverage time series data from the Federal Reserve Economic Data (FRED) project for this analysis. FRED is a project by the Economic Research Department of the Federal Reserve Bank of St Louis. It is a comprehensive collection of U.S. and international economic time series data. Figure 4 below, captures an example of the time series data available from FRED. The Federal Funds Effective Rate from the previous period (FEDFUNDS-1) will be captured as the time shifted value of the previous periods Federal Funds Effective Rate.

A graph showing the value of a federal fund

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Figure 4: Federal Funds Effective Rate Timeseries

The real interest rate

A graph showing the number of people in the same direction

Description automatically generated with medium confidence

Full employment can be characterized as the economy's unemployment rate aligning with the natural rate of unemployment, which is often estimated to be around 5%. The U-3 measure of labor underutilization as calculated by the U.S. Bureau of Labor Statistics (UNRATE) will be used as the measure of unemployment in this analysis. I will note that there are academics who take issue with this measure of unemployment because it undercounts the true rate of unemployment by omitting discouraged workers and workers who are underemployed (U.S. Bureau of Labor Statistics, 2023). The Modified Taylor Rule uses gap between the unemployment rate when the economy is at full employment and the observed unemployment rate. Figure 5 below, captures the federal unemployment rate time series.

A graph showing a line of a graph

Description automatically generated with medium confidence

Figure 5: Gap Unemployment Rate Timeseries

The Taylor Rule uses the GDP Gap as an indirect measure of full employment. The GDP Gap measures the current economic activity versus potential economic activity. The difference representing economic slack or excess capacity that can be applied to sustained economic growth.

GDPC1 - GDPPOT

A graph showing the growth of economic indicators

Description automatically generated

Figure 6: GDP Gap Timeseries

The change from 1 year ago of the Consumer Price Index for All Urban Consumers: All Items in U.S. City Average (CPIAUCSL) or (CPIAUCSL\_PC1) will be used to measure price stability.

A graph showing a line graph

Description automatically generated

Figure 7: Consumer Price Index (CPIAUCSL\_CH1) Timeseries

The timeseries datasets for this analysis will be constructed using a combination of FRED API calls and downloaded csv files from <https://fred.stlouisfed.org>.

The recession timeframes

A graph showing a line of a graph

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The composition of the FOMC

A graph showing the value of a stock market

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## Models

The relationship between inflation, unemployment, and the Federal Funds Effective Rate can be explored by comparing the performance of models based on the concepts behind the Taylor Rule. Regression models will be constructed to predict the Federal Funds Effective Rate as the response variable using the same predictor variable from the Taylor Rule and the Modified Taylor Rule. The performance of the models will be measured using Root Mean Squared Error (RMSE) and the adjusted R-squared evaluation metrics. The relative model performance and the analysis of the coefficients assigned to predictor variables will be an indicator of each economic measure's impact on the FOMC's decision-making process.

### Concept: Economic Discomfort Index

The EDI is one formulation of the trade-off between unemployment and inflation. Implicit in the formula is equal weighting of unemployment and inflation when calculating the EDI. The formulation of the EDI assumes a constant marginal rate of substitution between the pains of unemployment and the impacts of inflation. The research by Lovell et al. (1999) suggests that the EDI provides a measure of economic malaise as measured by the Survey Research Center’s Index of Consumer Sentiment. However, does this formulation also transfer to the FOMC deliberations? Figure 8 graphs the EDI against Federal Funds Effective Rate.

A graph of red and blue lines

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Figure 8: Economic Discomfort Index vs. Federal Funds Effective Rate

The EDI provides a simple trade-off function between inflation and unemployment. Regression analysis can be used to explore the linkages between this consumer trade-off and Federal Reserve’s decision-making process.

Include misery index by fed chair

### Concept: Taylor Rule and Modified Taylor Rule

The Taylor Rule is the best-known formula that prescribes how policy makers should adjust short term interest rates in response to economic variables (Policy Rules and How Policymakers Use Them, 2018). The Taylor Rule uses deviations from inflation targets and potential economic output to prescribe the federal funds rate that the Federal Reserve should target. As can be observed from the graph below the Modified Taylor Rule as a model has more predictive power than the Original Taylor Rule

Using the formula for the Taylor Rule

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- is the nominal federal funds rate or the effective federal funds rate. This will be the independent variable in the models.

r\* - is the equilibrium real interest rate. Taylor suggested that the equilibrium real interest rate should be invariant at 2.0% however overtime policy makes have adopted equilibrium real interest rate that varies overtime (Kliesen, Is the Fed Following a ‘Modernized’ Version of the Taylor Rule? Part 1., 2019). For this analysis I will use the equilibrium real interest rate calculated by the Federal Reserve Bank of New York (Federal Reserve Bank of New York, n.d.)

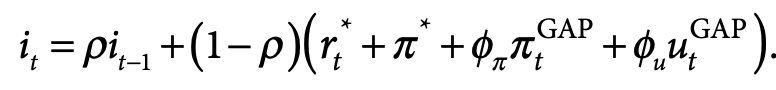
π – is the current rate of inflation. For this analysis I will use the CPIAUCSL\_PC1

y – is the real GDP. For this analysis I will use the

π \* - is Fed’s inflation target. This will be set to 2.0% (Ferguson & Lahiri, 2023)

Figure 3: Taylor Rule Formula

The Taylor Rule provides guidance for central banks as they adjust interest rates in response to economic conditions. It is a conceptual model that does not directly imply imperial support. This analysis will explore the formulation of the Taylor rule presented by Kliensen in his 2019 paper.



- nominal federal funds rate

𝘱 - one quarter lag term for the federal funds target rate with a fixed coefficient

- equilibrium real interest rate over time

π \* - Fed’s inflation target

- output inflation gap with a fixed coefficient

- unemployment gap with a fixed coefficient

Figure 2: Modified Taylor Rule

A graph showing the value of a stock market

Description automatically generated

Figure 9: Taylor Rule vs Federal Funds Effective Rate

The analysis reviews the effectiveness of the Taylor Rule in predicting the Federal Funds Effective Rate. The regression analysis will explore alternate coefficients for the Inflation Gap and the GDP Gap. The relative size of the coefficients will allow us to evaluate the implicit emphasis of the FOMC when making monetary policy decisions.

The Modified Taylor rule is based on the concept of the Taylor Rule however the GDP Gap is replaced by the Unemployment Gap.

Economist ague that this a better representation of the current Feds decision making.

From our dataset using the formulation of the Taylor Rule described in here and the Formulation of the Modified Taylor rule described her. The Adjusted R2 for the modified Taylor is significantly better than the negative adjusted r-squared for the original Taylor Rule.

A screenshot of a table

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The most significant change in the modified Taylor Rule is the existence of the Auto Regression term for the previous periods Effective Federal Funds Rate. When coupled with the Ø term at 0.85 this becomes the dominant component of the model.

It should be noted that both models fall short of the Naïve model when attempting to forecast the Effective Federal Funds Rate. The Naïve method uses the value in t-1 as the forecast for at t and is incredibly accurate with an adjusted r-squared of 0.9430.

### Concept: FOMC Composition

The FOMC composition focus on the fed chair but could extend this analysis to include the full membership list of the FOMC

A graph showing the growth of the stock market

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A screenshot of a graph

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If we apply Lasso regularization to the model that includes federal reserve chairs the Lasso model shrinks the one hot encoded coefficient associated with of each of the Fed Chairs to 0.

A graph with blue squares

Description automatically generated

The shape value impact for XGB Regression Model includes feature importance for Burns and Volker, have a positive feature importance. Slight impact from Burns, Volcker, Greenspan and Miller.

A graph with blue and red lines

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The analysis is interesting however inclusion of Federal Reserve Chair in the models would likely not work well since we do not see the same data in the training and the testing datasets.

### Regression Models

For the purposes of this analysis I selected two linear regression models ordinary least squares (OLS) model from statsmodels (https://www.statsmodels.org/dev/regression.html) and the Lasso regularization model from scikit learn (<https://scikit-learn.org/stable/modules/generated/sklearn.linear_model.Lasso.html#sklearn.linear_model.Lasso>).

I also select three Boosted decision tree models LGBM Regression model from LightGBM (<https://lightgbm.readthedocs.io/en/latest/index.html>), the XGBoost Regression model from dmlc XGBoost (<https://xgboost.readthedocs.io/en/stable/python/python_api.html>), and the AdaBoost Regression model form scikit learn (https://scikit-learn.org/stable/modules/generated/sklearn.ensemble.AdaBoostRegressor.html)

And finally since the dataset is a timeseries I explored the SARIMAX timeseries model SARIMAX from statsmodels (https://www.statsmodels.org/stable/examples/notebooks/generated/statespace\_sarimax\_stata.html)

The results where somewhat surprising I expected the boosted decision tree models to perform better however they seemed to perform well with the in sample dataset but adjusted r-squared for all three decision tree models dropped off significantly for the out of sample accuracy in all cases. The linear models performed well overall and the SARIMAX posted the highest adjusted r-squared for all final dataset.

### Feature Selection

The literature regarding the Federal Reserve dual mandate includes numerous options for predictors. We explored the Taylor rule in this paper however may others exist including

The following page includes several alternative to the taylor rule (<https://www.federalreserve.gov/monetarypolicy/policy-rules-and-how-policymakers-use-them.htm>) These rules uniformly include some concept of inflation, employment or gdp versus target.

As a starting point I selected

* Effective Federal Funds Rate from the previous period (FEDFUNDS-1)
* Inflation Gap (gap\_inf) – The Inflation Gap is calculated as the PCEPILFE\_CH1 – Target Inflation rate. For the purpose of this analysis I used a target rate of 2%
* GDP Gap (gap\_gdp) – The GDP Gap is calculated as percentage difference between GDP and Potential GDP (GDPC1 – GDPPOT) / GDPPOT.
* Unemployment Gap (gap\_ue) – The Unemployment Gap is calculated as the
* recession\_flag
* Real\_Interest\_Rate

The Lasso Model with regularized coefficients generates that following figure. The most important feature for predicting Effective Federal Funds Rate is the t-1 Effective Federal Funds Rate. The next most impactful feature is the recession flag followed by the Gap GDP. One interesting thing to note is that the Taylor Rule uses the GDP Gap and Inflation Gap while the Modified Taylor Rule uses that Inflation Gap and the Unemployment Gap.

A graph with blue squares

Description automatically generated

A screenshot of a computer

Description automatically generated

Using the regularization process decreases the Real-Interest Rate to near zero ().

In addition to the standard Taylor Model attributes I will test recession flag and the Auto Regressive Federal Funds Rate.

A graph of a graph

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A screenshot of a computer code

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### Model 1: Full Model

Model 1 is the full model that includes all features identified during the feature selection process. This includes all features with a non-zero coefficient after the regularization process of the Lasso model fit. The resulting model includes the following features:

* Effective Federal Funds Rate Previous Period
* GDP Gap
* Inflation Gap
* Unemployment Gap
* Recession Flag

With an Adj-R2 of 0.8863 for the test data the Lasso Regression model is the only model tested that outperforms the Naïve model on the testing dataset. The full diagram of model performance and exploration of model assumptions is covered in Appendix B.

Using an alpha of 0.0011 the coefficients for each feature are captured in the figure below. There are a few interesting outcomes to note from this model.

The coefficient associated with 1 lag effective federal funds rate is the largest in the model. This is consistent with the modified Taylor Rule that uses a 𝘱 = 0.85 as the coefficient for the t-1 Effective Federal Funds Rate. The terms associated with the Federal Reserve’s Dual Mandate, GPP gap, unemployment and inflation have relatively smaller coefficients in the model (less than 0.2)

A graph of a graph

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A screenshot of a computer code

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This model is consistent with the incremental approach that the federal reserve takes to interest rate adjustments. Ben Bernanke summed up this approach in 2004 speech on gradualism. “As a general rule, the Federal Reserve tends to adjust interest rates incrementally, in a series of small or moderate steps in the same direction.” (Bernanke, 2004).

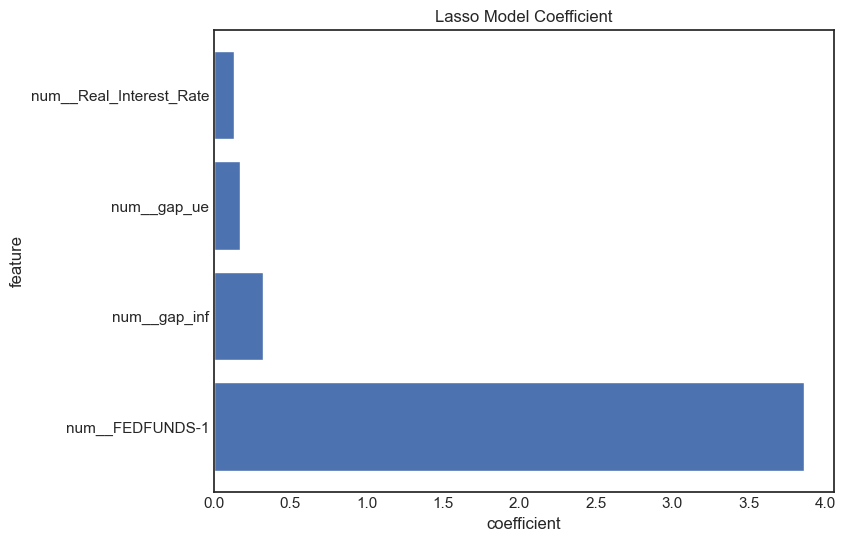
### Model 2: Modified Taylor Rule

The Taylor Rule provides guidance for central banks as they adjust interest rates in response to economic conditions. It is a conceptual model that does not directly imply imperial support. This analysis will explore the formulation of the Taylor rule presented by Kliensen in his 2019 paper.

* FEDFUNDS – is the effective federal funds rate in the () in Modified Taylor Rule
* FEDFUNDS-1 – is the effective federal funds rate from the previous period
* Real\_Interest\_Rate – is the equilibrium real interest rate over time ( in the Modified Taylor Rule
* gap\_inf – is the inflation gap in the the current period
* gap\_ue – is the unemployment gap in the current period ()
* Constants – The Fed’s inflation target is a constant so it is omitted from the predictor variables
* Coefficients – The model coefficients will provide estimates for 𝘱, and

The only model that outperformed the Naïve model was that OLS Linear Regression Model. The OLS model has a Adj-R2 0.9227 for the test data set which is well about the Adj-R2 for the Naïve model at 0.8830. However when reviewing the model summary for the linear model the intercept, the coefficient for the Unemployment Gap and the coefficient for the Real Interest rate were not statistically significant. A detailed review of the model summary is captured in Appendix B.

The Lasso Linear Regression model had a slightly lower Adj-R2 at 0.9226 was not quite as high as the OLS model however it was higher than the Naïve Model. The Effective Federal Funds Rate (t-1) has the highest coefficient by a factor of 10. It is interesting to note that the Inflation Gap has a coefficient roughly two times the size of the coefficient for the Unemployment Gap.



The shap summary plot below highlights the impact of each variable on the Effective Federal Funds Rate.

A graph with different colored dots

Description automatically generated

The Lasso Model based on the Modified Taylor Rule supports the theory that FOMC focus more on inflation component of the Federal Reserves Dual Mandate.

### Model 2: Modified Taylor Rule

### Model 1: Modified Taylor Rule (AR and Economic Cycle)

### Model 2: Modified Taylor Rule (AR)

### Model 1: OLS Regression Economic Discomfort Index

The model generated by the OLS regression analysis of the EDI demonstrates some explanatory power. The model’s adjusted R-squared of 0.585 suggest that inflation and unemployment could be used to predict almost 60% of the variation in the Federal Funds Effective Rate. Figure 10 depicts the summary statistics for the regression model.

A screenshot of a data sheet

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Figure 10: OLS Regression Economic Discomfort Index

Figure 11 below captures the Federal Funds Effective Rate versus the in-sample prediction and the out-of-sample forecast for the model.

A graph showing the value of a stock market

Description automatically generated

Figure 11: EDI OLS Regression vs Federal Funds Effective Rate

### Model 2: OLS Regression Taylor Rule

The model generated by the OLS regression analysis of the Taylor Rule demonstrates some explanatory power. The models adjusted R-squared of 0.529 indicates that the model can predict over 50% of the variation in the Federal Funds Effective Rate based on the inflation gap and the GDP gap.

A screenshot of a computer screen

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Figure 12: OLS Regression Taylor Rule

Figure 13 captures the Federal Funds Effective Rate versus the in-sample prediction and the out-of-sample forecast for the model.

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Figure 13: Taylor Rule OLS Regression vs Federal Funds Effective Rate

## Results

As expected, one of the challenges with modeling the FOMC’s decision making using historical data is the unprecedented nature of the Federal Reserve’s monitory policy over the past 16 years. The Federal Reserve pursued a zero-interest rate policy from end of 2008 through October 2014. However, all models analyzed here forecasted a federal funds rate greater than zero during these time periods.

This discrepancy between the actual Federal Funds Effective Rate and the forecasted federal funds rate adversely impacts the measure of model performance. The comparison of model performance using RMSE and adjusted R-squared against the training and testing data results in negative adjusted R-squared for all models tested.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Train | | Test | |
| Model | Root Mean Squared Error (RMSE) | Adjusted R-Squared | Root Mean Squared Error (RMSE) | Adjusted R-Squared |
| Taylor Rule | 2.7795 | 0.2962 | 2.8876 | -4.5997 |
| OLS EDI | 2.1716 | 0.5860 | 3.9915 | -8.7438 |
| OLS Taylor Rule | 2.3393 | 0.5316 | 4.0111 | -12.8461 |
|  |  |  |  |  |

Figure 14: Model Performance

The explorations of alternate forecast timeframes and modeling approaches has yielded some early results. Focusing on the timeframe prior to 2007 and using a SARIMAX model demonstrates better overall results. It should be noted that the resulting model includes an autoregressive term that contributes to the model accuracy.

A screenshot of a table

Description automatically generated

Figure 15: SARIMAX Taylor Rule

Figure 16 below captures the actual Federal Funds Effective Rate versus the in-sample prediction and the out-of-sample forecast for the model.

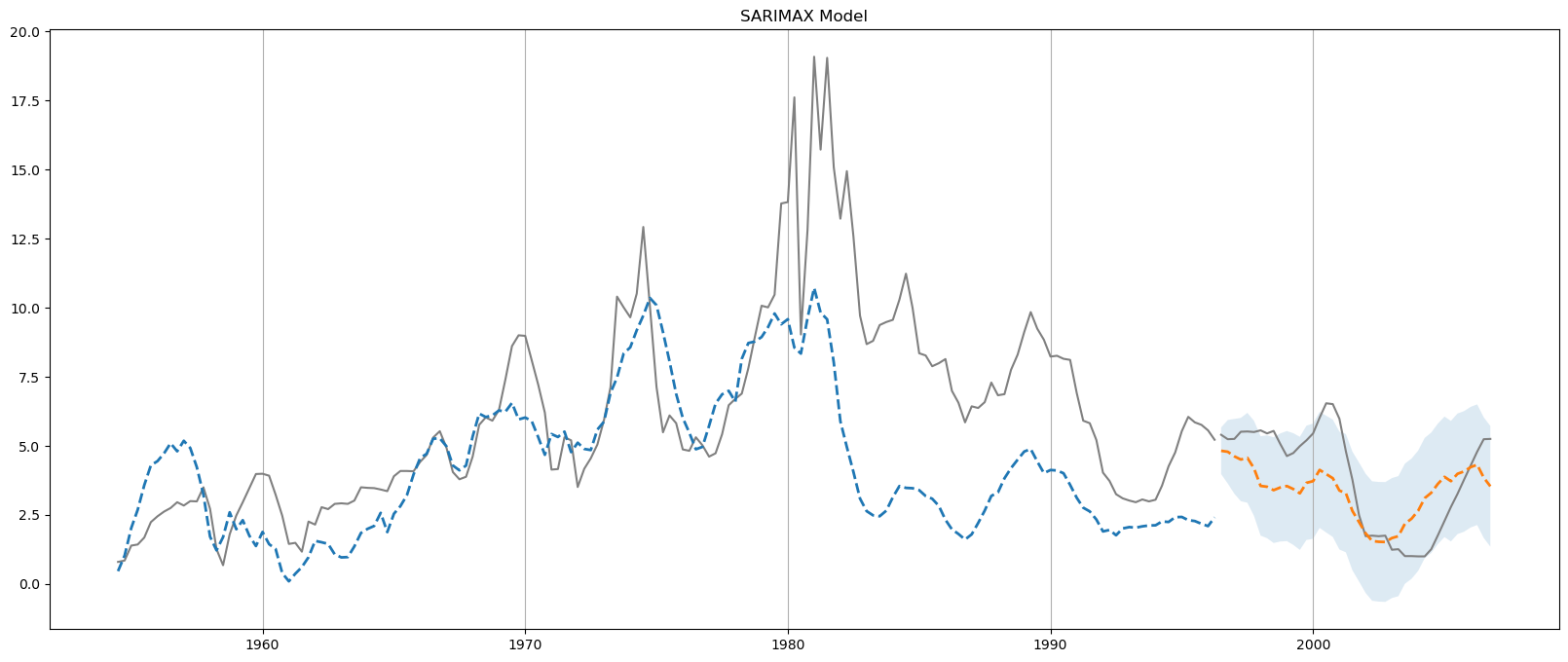


Figure 16: Taylor Rule SARIMAX vs Federal Funds Effective Rate

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Train | | Test | |
| Model | Root Mean Squared Error (RMSE) | Adjusted R-Squared | Root Mean Squared Error (RMSE) | Adjusted R-Squared |
| Taylor Rule | 5.1791 | -1.1213 | 4.463 | -4.9157 |
| SARIMAX | 3.3061 | 0.1421 | 1.4308 | 0.3920 |
|  |  |  |  |  |

Figure 17: Model Performance (1954 - 2006)

Interesting to note that the SARIMAX model has a higher adjusted R-squared for the testing data set. The low training adjusted R-squared of 0.1421 seems to be related to predictions around the 1980–1985 time periods. From the analysis completed to date it appears that economic cycles have an impact on the accuracy of the in-sample predictions and out-of-sample forecasting and should be factored into the analysis.

# Conclusion

The research question posed for this analysis focused on evaluating the relative emphasis that the Federal Reserve places on the individual components of its dual mandate. The initial exploration of the concepts behind the EDI and the Taylor Rule resulted in poorly fit models with negative adjusted R-squared.

Adjusting the forecasting window and changing the model type resulted in a model with a positive adjusted R-squared. Even though the Taylor Rule is the best-known formula prescribing how policy makers should adjust short-term interest rates, there are other models available. As part of the analysis, I will be reviewing the impact of economic cycles on the models, exploring alternate formulations of the Taylor Rule, and exploring other types of machine learning models.

This is based on a quarterly dataset. A more accurate view of the problem set would align the time periods to the FOMC meeting. This would add some complexity to the analysis due to the slight fluctuation in meeting scheduled.

# Appendix A: Feature Selection

# Appendix B: Model Performance

## Model 1: Full Model

The Full Model includes all features that had a non-zero coefficient when fit using the Lasso Regression Model. These features included:

* Effective Federal Funds Rate Previous Period
* GDP Gap
* Inflation Gap
* Unemployment Gap
* Recession Flag

The Lasso Linear Regression model was the only model that outperformed the Naïve model.

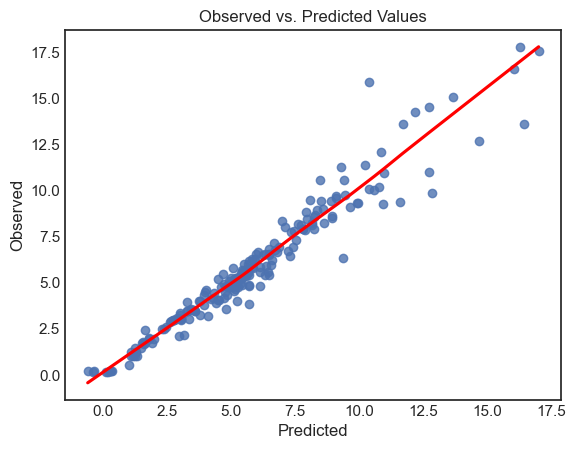
A screenshot of a table with numbers

Description automatically generated

### Lasso Regression Model

The following section explores the assumptions behind the Lasso Regression Model.

1. Linearity – For this model the linear relationship between the predictor variables and response variables holds. As can be seen in the graph below that plots predicted values vs target values, the values fall along a diagonal line indicating a linear relationship.



1. Homoscedasticity – The constant variance of residuals across the predicted values holds for this model. As can be observed in the scatterplot below there is only a slight pattern in the relationship between residuals and predicted values.

A graph with blue dots and a red line

Description automatically generated

1. Independence of Residuals – The Durbin-Watson Test statistic of 1.805 is close to the 2 indicates minimal autocorrelation in the model residuals. The Autocorrelation Function (ACF) chart indicates potential statistically significant autocorrelation lags.

A graph with blue dots and lines

Description automatically generated

1. Multicollinearity – The regularization process in the Lasso model addresses multicollinearity. As part of the feature selection process variables that exhibited multicollinearity were eliminated. Each of the features in the model has a positive coefficient.

A graph with blue squares

Description automatically generated

## Model 2: Modified Taylor Rule

The Model based on the concepts in the Modified Taylor Rule includes all four features used as variables in the Modified Taylor Rule.

* Effective Federal Funds Rate Previous Period
* Inflation Gap
* Unemployment Gap
* Real Interest Rate

The relative model performance for in sample and out of sample data is presented in the table below. The OLS Linear Regression model and the Lasso Linear Regression was the only models that outperformed the Naïve model.

A table of numbers and letters

Description automatically generated

### OLS Regression Model

The model summary shows a Adj-R2 of 0.928 however the coefficients associated with the Unemployment Gap and the Real Interest Rate predictor variables are not statistically significant. The coefficient p-values for the Unemployment Gap and the Real Interest Rate are above the 0.05 significance level.

A screenshot of a computer

Description automatically generated

### Lasso Regression Model

The following section explores the assumptions behind the Lasso Regression Model.

1. Linearity – For this model the linear relationship between the predictor variables and response variables holds. As can be seen in the graph below that plots predicted values vs target values, the values fall along a diagonal line indicating a linear relationship.

A graph of a red line with blue dots

Description automatically generated

1. Homoscedasticity – The constant variance of residuals across the predicted values does not holds for this model. As can be observed in the scatterplot below there is a slight pattern increasing trend in the relationship between residuals and predicted values.

A graph with blue dots and a red line

Description automatically generated

1. Independence of Residuals – The Durbin-Watson Test statistic of 1.525 is close to 2 but indicates some autocorrelation in the model residuals. The Autocorrelation Function (ACF) chart confirms the results of the Durbin-Watson Test.

A graph with blue dots and lines

Description automatically generated

1. Multicollinearity – The regularization process in the Lasso model addresses multicollinearity. The coefficients for the Real Interest Rate and the Unemployment Gap while not 0 are lower than the coefficients for Effective Federal Funds Rate (t-1) and the Inflation Gap.A graph with blue squares

   Description automatically generated

## Model 3: Recession Model

The Recession Model starts with the concepts of the Modified Taylor Rule then adds a Recession Flag. This model includes all four features used as variables in the Modified Taylor Rule and adds a boolean variable for an economic downturn or recession.

* Effective Federal Funds Rate Previous Period
* Inflation Gap
* Unemployment Gap
* Real Interest Rate
* Recession Flag

The relative model performance for in sample and out of sample data is presented in the table below. The OLS Linear Regression model and the Lasso Linear Regression was the only models that outperformed the Naïve model.

A table of numbers and letters

Description automatically generated

### OLS Regression Model

The model summary shows a Adj-R2 of 0.935 however the coefficients associated with the Real Interest Rate predictor variables is not statistically significant. The coefficient p-values for the Real Interest Rate is above the 0.05 significance level.

A screenshot of a data

Description automatically generated

By dropping the Real Interest Rate predictor variable from the OLS Linear Model. The fitted model will include all statistically significant coefficients however the Adj-R2 will drop below the threshold set by the Naïve model.

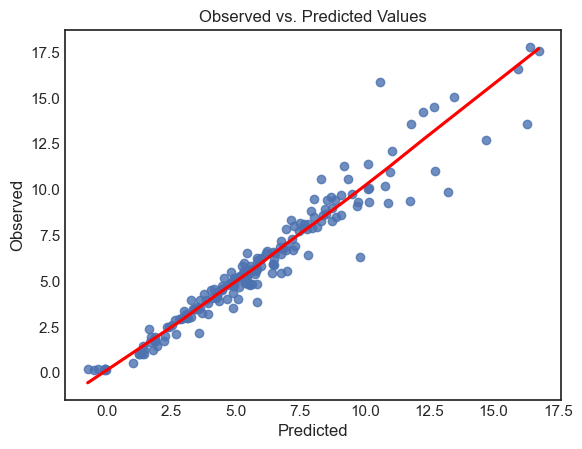
A screenshot of a computer

Description automatically generated

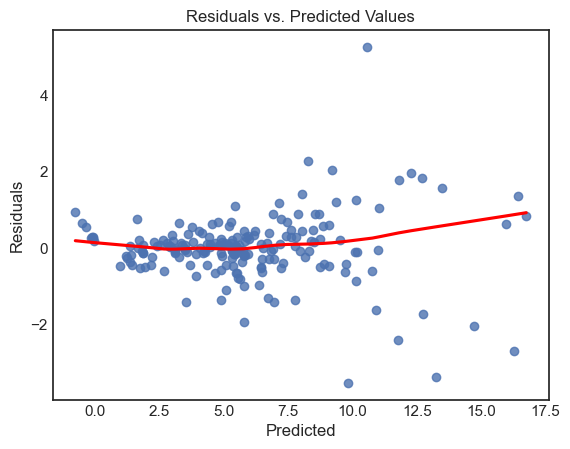
### Lasso Regression Model

The following section explores the assumptions behind the Lasso Regression Model.

1. Linearity – For this model the linear relationship between the predictor variables and response variables holds. As can be seen in the graph below that plots predicted values vs target values, the values fall along a diagonal line indicating a linear relationship.



1. Homoscedasticity – The constant variance of residuals across the predicted values does not holds for this model. As can be observed in the scatterplot below there is a slight pattern increasing trend in the relationship between residuals and predicted values.



1. Independence of Residuals – The Durbin-Watson Test statistic of 1.7268 is close to 2 indicating minimal autocorrelation in the model residuals. The Autocorrelation Function (ACF) chart indicates potential statistically significant autocorrelation lags.

A graph with blue dots and lines

Description automatically generated

1. Multicollinearity – The regularization process in the Lasso model addresses multicollinearity. The coefficients for the Real Interest Rate and the Unemployment Gap while not 0 are lower than the coefficients for Effective Federal Funds Rate (t-1) and the Inflation Gap.A graph with blue squares

   Description automatically generated

## Model 3: Simplified Model

The Model is a simplified model that includes the minimal features needed to create an effective model while limiting the VIF. The minimal features for this model include:

* Effective Federal Funds Rate Previous Period
* Inflation Gap
* Unemployment Gap

### OLS Regression Model

The statistic metrics from the model summary

1. Linearity - For this model the linear relationship between the predictor variables and response variables holds. As can be seen in the graph below predicted values vs actual values, fall along a diagonal line indicating a linear relationship.

A graph with a red line and a line with blue dots

Description automatically generated

1. Independence of Errors - The Durbin-Watson Test statistic of 1.726 is close to the 2 indicates minimal autocorrelation in the model residuals. The Autocorrelation Function (ACF) chart indicates potential statistically significant autocorrelation lags.

A graph with blue dots and lines

Description automatically generated

1. Homoscedasticity (Constant Variance of Residuals) – The smoothed curve of the residuals through the scatter plot does not indicates the presence of a strong pattern.

A graph with blue dots and a red line

Description automatically generated

1. Normality of Errors – The Shapiro-Wilk Test has a p-value that is less that 0.05 we can reject the null hypothesis in favor of the alternate hypothesis. The residuals deviate from normal distribution.
2. No Perfect Multicollinearity – For this model the Real Interest Rate and the FEDFUNDS-1 predictor variable exhibit a high degree correlations. The VIFs values for Real Interest Rate and the FEDFUNDS-1 predictor are 4.62 and 9.69 respectively

### Lasso Regression Model

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