

**Analyzing the United States Federal Reserve’s Dual Mandate**

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

David Simbandumwe

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Table of Contents

[Abstract 4](#_Toc152522129)

[Introduction 4](#_Toc152522130)

[Literature Review 6](#_Toc152522131)

[Economic Discomfort Index 6](#_Toc152522132)

[Taylor Rule 7](#_Toc152522133)

[Composition of the Federal Open Market Committee 8](#_Toc152522134)

[Research Question 9](#_Toc152522135)

[Hypothesis 9](#_Toc152522136)

[Methodology 10](#_Toc152522137)

[Dataset 10](#_Toc152522138)

[Models 15](#_Toc152522139)

[Results and Discussion 16](#_Toc152522140)

[Concept 1: Full Model 16](#_Toc152522141)

[Concept 2: Modified Taylor Rule 19](#_Toc152522142)

[Concept 3: Real Federal Funds Effective Rate 22](#_Toc152522143)

[Concept 4: Pre-2007 Timeframe 26](#_Toc152522144)

[Concept 5: Regression Model 27](#_Toc152522145)

[The Composition of the Federal Open Market Committee 29](#_Toc152522146)

[Other Concepts 31](#_Toc152522147)

[Conclusion 31](#_Toc152522148)

[Appendix A: Stationarity 35](#_Toc152522149)

[Appendix B: Model Performance 36](#_Toc152522150)

[Concept 1: Full Model 36](#_Toc152522151)

[Concept 2: Modified Taylor Rule 40](#_Toc152522152)

[Concept 3: Real Federal Funds Effective Rate 42](#_Toc152522153)

[Concept 4: Pre-2007 Timeframe 45](#_Toc152522154)

[Concept 5: Regression Model 49](#_Toc152522155)

[Concept 6: Simple Model 52](#_Toc152522156)

[Concept 7: Recession Model 55](#_Toc152522157)

[References 57](#_Toc152522158)

[Figures 61](#_Toc152522159)

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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 it conducts monetary policy. This paper provides insight into the Federal Reserve's deliberation process when setting the target range for the Federal Funds Rate by exploring models based on the concepts behind the Taylor Rule in order 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, outlining the central bank's structure, and articulating its monetary policy objectives. Section 2A of the Federal Reserve Act states the following:

*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.*[1]

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 these 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.* [2]

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, which is often referred to as the Misery Index, is an economic indicator that seeks to quantify 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 [3].

Adding to the complexity of the Federal Reserve’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 affects the well-being of individuals in the economy through the risk of unemployment or degradation of living standards caused by rising prices.

# Literature Review

## Economic Discomfort Index

The formula for the EDI and its historic values are explored in the article *“Economic Discomfort and Consumer Sentiment.”* [4]. The formula for the EDI is captured in Figure 1.

p\* - annual rate change, CPI

U – unemployment rate

Figure : Economic Discomfort Index Formula

Figure 2 illustrates the EDI over time. Notably, 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 economic growth, decreasing inflationary pressures, and decreasing labor demand. 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 inflationary pressures [5].

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Figure : Economic Discomfort Index (EDI)

## Taylor Rule

In a two-part research paper titled ***Is the Fed Following a “Modernized” Version of the Taylor Rule? (Part 1 / Part 2)*** Kliesen explores the Fed’s decision-making process in the context of the Taylor Rule [6]. 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 [6].

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- is the nominal federal funds rate

r\* - equilibrium real interest rate

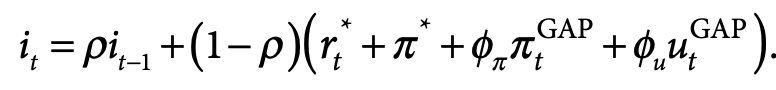
π - current rate of inflation

y - real GPB

π \* - Fed’s inflation target

Figure 3: Taylor Rule Formula

Kliesen goes on to discuss a modernized version of the Taylor Rule that considers three major developments in monetary policy: (1) the relatively low-interest rate regime that the economy is enjoying; (2) the achievement of stable low inflation rates; and (3) the flattening of the Phillips Curve. Kliesen’s analysis concludes that during the current expansion, the Federal Funds Effective 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 (Figure 4) to inform its decision-making on monetary policy. [7]



- 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

- inflation gap with a fixed coefficient

- unemployment gap with a fixed coefficient

Figure 4: Modified Taylor Rule

At the time of Kliesen’s publication in 2019, the economy was experiencing historically low interest rates and low levels of inflation. Since early 2021, there has been a reversal as the inflation rate increased and interest rates began to rise. In light of the economic conditions since 2021, it will be interesting to revisit the shape of the Philips Curve and the alignment of the Taylor Rule with the prevailing Federal Funds Effective Rate.

## Composition of the Federal Open Market Committee

The composition of the FOMC has changed over time. Wilson (2019) analyzed the tenure of Federal Reserve Chairs from William McChesney to Janet L. Yellen using the Unemployment Rate, the EDI, and the Taylor Rule to score the tenures of individual 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-led Federal Reserve 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 view the role of the Federal Reserve as a whole.

# Research Question

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

To comprehensively analyze the Federal Reserve's decision-making process, I explore the impacts of economic stress and the composition of the open market committee on its decision-making. The 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 used 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

The analysis focus on the inputs and outputs of the FOMC's monetary policy decision-making process. Specifically, on the economic indicators for inflation and unemployment as inputs to the FOMC decision. The output of the deliberations is 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 quantifies the relative impact of inflation and unemployment on the Federal Funds Effective Rate. Regression models 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 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 Effective 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. This analysis is based on the quarterly Federal Funds Effective Rate (FEDFUNDS) as the target variable for the regression models [8].

There are numerous sources for Federal Reserve-related data. I leveraged the 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 5 captures an example of the time series data available from FRED. The Federal Funds Effective Rate from the previous period (FEDFUNDS-1) is calculated as the time-shifted value of the previous periods Federal Funds Effective Rate.

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Figure : Federal Funds Effective Rate Timeseries

The Federal Funds Effective Rate is a nominal interest rate and includes an inflation component. I also reviewed the impact of using the real Federal Funds Effective Rate as the response variable. Figure 6 below depicts the real Federal Funds Effective Rate timeseries.

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Figure : Real Federal Funds Effective Rate

The real interest rate or R\* is the interest rate that is expected to prevail when the economic output is at its full sustainable level. For this analysis, I selected the Holston, Laubach, and Williams estimate (Measuring the Natural Rate of Interest, 2017). The real interest rate time series is presented in Figure 7.

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Figure : Real Rate of Interest

Full employment is 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), is used as the measure of unemployment in this analysis. I will note that some academics take issue with this measure of unemployment because it undercounts the true unemployment rate by omitting discouraged workers and underemployed workers [9]. The Modified Taylor Rule uses the gap between the unemployment rate when the economy is at full employment and the observed unemployment rate. Figure 8 below captures the federal unemployment rate and the unemployment rate gap as a time series.

A graph showing a line of employment

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Figure : Gap Unemployment Rate Timeseries

The Inflation Gap is the difference between the current rate of inflation and the Federal Reserve’s long term target inflation rate. Taylor Rule uses the GDP Gap to measure full employment indirectly. Figure 9 below depicts the Inflation Gap.

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Figure : Inflation Gap Timeseries

The original formulation of the Taylor Rule uses the GDP Gap to measure full employment indirectly. The GDP Gap measures current economic activity versus potential economic activity—the difference representing economic slack or excess capacity that can be applied to sustained economic growth. Figure 10 below depicts the GDP Deflator and the calculated GDP Gap.

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Figure : GDP Gap Timeseries

The measure of price stability used in this analysis is based on 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). Figure 11 illustrates the CPI timeseries.

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Figure : Consumer Price Index (CPIAUCSL\_CH1) Timeseries

The recession timeframes (Figure 12) use the business cycle turning points determined by the National Bureau of Economic Research (NBER). The business cycle time series is available on FRED for download.

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Figure : Recession Time Series

For this analysis, I use the Fed Chair as a proxy for the FOMC composition (Figure 13). In future papers, it might be worthwhile to explore the individual members of FOMC and how their composition has changed over time [10].

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Figure : Fed Chair Overtime

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

## Models

I explore the relationship between inflation, unemployment, and the Federal Funds Effective Rate by comparing the performance of models based on the concepts behind the Taylor Rule. I constructed ARIMA models to predict the change in the Federal Funds Effective Rate as the response variable using the same predictor variable from the Taylor and Modified Taylor Rules. The performance of the models was measured using the Root Mean Square Error (RMSE) as the evaluation metric. The relative model performance and the analysis of the coefficients assigned to predictor variables indicate each economic measure’s impact on the FOMC’s decision-making process.

The following list of timeseries models are used in this analysis:

* Seasonal Autoregressive Integrated Moving Average (SARIMA) model form Pmdarima
* Seasonal Autoregressive Integrated Moving Average (SARIMA) model from Statsmodel
* Error, Trend, Seasonality (ETS) Model from Statsmodel. The ETS Model is fit with the response variable only and provides a minimal performance baseline.

The benefit of using time series models is that they can implicitly account for cyclical or seasonal trends across predictor and response variables. The relationship between observations in the timeseries is modeled by tuning the following parameters:

Timeseries order

* p: Autoregressive order
* d: Degree of differencing
* q: Moving average order

Timeseries seasonal components

* P: Seasonal autoregressive order
* D: Seasonal differencing
* Q: Seasonal moving average order
* s: Seasonal period (the length of the seasonal cycle)

# Results and Discussion

## Concept 1: Full Model

The literature regarding the Federal Reserve’s dual mandate includes numerous options for predictor variables. I explored the Taylor Rule and its derivations in this paper; however, many other models exist, including the Balanced-Approach Rule, the ELB-Adjusted Rule, and the First-Difference Rule. These rules uniformly include concepts of inflation, interest rates, employment, historic federal funds rate rates, and GDP levels.

As a starting point I, selected the following model features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Inflation Gap (gap\_inf) as the PCEPILFE\_CH1 – Target Inflation rate. (Target Inflation is 2% for the purpose of this analysis)
* GDP Gap (gap\_gdp) as percentage difference between GDP and Potential GDP (GDPC1 – GDPPOT) / GDPPOT.
* Unemployment Gap (gap\_ue) as the difference between full employment and current unemployment rate. (Full employment is 5% for the purpose for this analysis)
* Recession Flag (recession\_flag) – Indicator of recession during the period
* Real Interest Rate (Real\_Interest\_Rate)

The ARIMA model fit with the predictor variables identified above generates the coefficients in Figure 14. The coefficients in gray have a p-value greater than 0.05 and are considered not statistically significant. The remaining coefficients are used for the models developed in this paper.

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Figure : Feature Selection SARIMA Coefficients

The ARIMA Model built for this concept starts with the features identified in Figure 14 and eliminated the coefficients that are not considered statistically significant. The resulting model includes the following features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Inflation Gap (gap\_inf)
* GDP Gap (gap\_gdp)
* Recession Flag (recession\_flag)

With a RMSE of 0.3372 for the test data the ARIMA model outperforms the baseline ETS model. Figure 15 illustrates the predicted Federal Funds Effective vs the actual rate over time.

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Figure : ARIMA Model Prediction FFER Full Model

This ARIMA model does not meet all the underlying assumptions of the modeling framework. Specifically, the analysis of residuals shows evidence of heteroskedasticity. The complete summary of model performance and an exploration of model assumptions can be found in Appendix B.

This concept follows the original formulation of the Taylor Rule that represents unemployment with the GDP Gap. Figure 16 below highlights the relative size of the model coefficients. The most important feature in the model is the Federal Funds Effective Rate (t-1) from the previous period. The next most impactful feature is the recession flag, followed by the Inflation and GDP gaps.

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Figure : ARIMA Coefficients for the Full Model

The importance of historic rates in this model is consistent with the Federal Reserve’s incremental approach to interest rate adjustments. Ben Bernanke summed up this approach in a 2004 speech on gradualism, stating, “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” [11].

## Concept 2: Modified Taylor Rule

The Taylor Rule is the best-known formula that prescribes how policymakers should adjust short-term interest rates in response to economic variables [12]. The Taylor Rule uses deviations from inflation targets and potential economic output to prescribe the target Federal Funds Effective Rate. The most significant difference between the Taylor Rule and the modified Taylor Rule is the existence of the autoregression term for the previous periods. The Federal Funds Effective Rate (t-1) from the last period, when coupled with the þ coefficient of 0.85, significantly improves the Modified Taylor Rule’s predictive power.

As can be observed from Figure 17 the Modified Taylor Rule (ffef\_tr2) as a model has more predictive power than the Original Taylor Rule (ffef\_tr1). This finding aligns with the conclusions presented by Kliensen [7].

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Figure : Taylor Rule vs Federal Funds Effective Rate

Figure 18 summarizes the model performance of the Taylor Rule and the Modified Taylor Rule.

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Figure : Model Performance Taylor Rule, Modified Taylor Rule

Using the formula in Figure 19 as a starting point, I can generate a feature list for this concept.

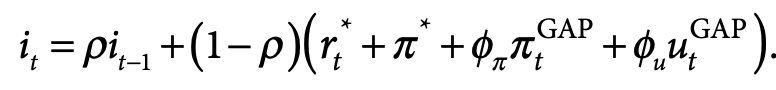


Figure 19: Modified Taylor Rule Formula

* – is the nominal federal funds rate or the Federal Funds Effective Rate. This is the response variable in the models.
* 𝘱 – is the one quarter lag term for the federal funds target rate with a fixed coefficient or the Federal Funds Effective Rate (t-1)
* - is the equilibrium real interest rate over time. 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 [6]. For this analysis I use the equilibrium real interest rate calculated by the Federal Reserve Bank of New York [13]
* π \* - Fed’s inflation target. This is set to 2.0% [14]
* – is the output inflation gap with a fixed coefficient. GDP Gap (gap\_gdp) is calculated as percentage difference between GDP and Potential GDP (GDPC1 – GDPPOT) / GDPPOT.
* - is the unemployment gap with a fixed coefficient. For this analysis I use the difference between full employment and current unemployment rate. (Full employment is set at 5% for the purpose for this analysis)

The timeseries analysis explores alternate coefficients for the Federal Funds Effective Rate (t-1), the Inflation Gap, and the Unemployment Gap. The relative size of these coefficients in the fitted models provide insight into the FOMC’s decision-making process. The ARIMA models include the following variables:

* FEDFUNDS – is the Federal Funds Effective Rate in the () in Modified Taylor Rule
* FEDFUNDS-1 – is the Federal Funds Effective 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 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 provide estimates for 𝘱, and

The ARIMA model for this concept did not outperform the baseline ETS model. The ARIMA model generates a RMSE of 4.5242 for the test data as compared to 1.3674 for the ETS model. In Figure 20, you can observe the 95% confidence interval surrounding the estimates. The width of the confidence interval indicates uncertainty about both the level of and changes in the expected longer-run real federal funds rate is large.

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Figure : Modified Taylor Rule Predictions of the FFER

Furthermore, when reviewing the model summary, the coefficient for the Federal Funds Effective Rate from the previous period (t-1) and the coefficient for the Real Interest rate were not statistically significant. The summary of the model coefficients are illustrated in Figure 20 and a detailed review of the model summary is captured in Appendix B.

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Figure : Modified Taylor Rule Model Coefficients

Although the ARIMA model based on the Modified Taylor Rule is interesting to explore the resulting model includes two coefficients that are not statistically significant limiting its usefulness for this analysis.

## Concept 3: Real Federal Funds Effective Rate

The Federal Funds Effective Rate is a nominal interest rate that includes inflation. This concept is based on real interest rates and uses the Real Federal Funds Effective Rate (FEDFUNDS\_CPIAUCNS\_PC1) as the response variable. The models for this concept include the following features:

* Inflation Gap
* Unemployment Gap

The impact of using a real interest rate on the relationship between inflation and unemployment is somewhat counterintuitive. The correlation between Federal Funds Effective Rate and inflation is positive, while the correlation between the real Federal Funds Effective Rate and inflation is negative. Figure 22 depicts the correlation plot of the dataset used for this analysis. It illustrates the relationship between nominal interest rates, real interest rates, and the economic indicators used in this analysis.

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Figure : Feature and Response Variable Coefficients

The relationship between the real Federal Funds Effective Rate and inflation is illustrated in Figure 23. The most recent interest rate cycle starting in 2020 demonstrates this negative relationship. During this period, the economy experienced an increasing inflation rate and a decreasing real Federal Funds Effective Rate. There was a negative relationship between inflation and the real Federal Funds Effective even though the FOMC was consistently raising its target funds rate.

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Figure : Real FFER vs CPI

The ARIMA timeseries model for this concept outperforms the baseline ETS model. The ARIMA model generated a RMSE of 2.2577 for the test data as compared to 3.0701 for the ETS model. In Figure 24, the shaded area around the predicted real Federal Funds Effective Rate represents the 95% confidence interval. The model is forecasting a significant amount of uncertainty or variance in the predicted values. The complete diagram of model performance and exploration of model assumptions can be found in Appendix B.

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Figure : ARIMA Model Forecast for Real FFER

The feature coefficients for this model are presented in Figure 25. The features with the largest impact on the predictions of the real Federal Funds Effective Rate are the Unemployment Gap and the Inflation Gap.

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Figure : ARIMA Model Coefficient – Real FFER Model

As noted earlier, using the real Federal Funds Effective Rate changes the relationship between the predictor and response variables. The coefficient values indicate a negative relationship between the real Federal Funds Effective Rate and unemployment gap and a negative relationship between the real Federal Funds Effective Rate and the Inflation Gap. Using the real interest rates as the response variable complicates that analysis and necessitated additional efforts to understand implications of the model.

## Concept 4: Pre-2007 Timeframe

This concept omits the data set for the 2007 Financial Crisis and instead focus on the pre-2007 timeframe. The models for this concept include the following features:

* Unemployment Gap (gap\_ue)
* Inflation Gap (gap\_inf)

The ARIMA generated a RMSE of 1.9937 for the test data as compared to 2.6388 for the ETS model. In Figure 26, the shaded area around the predicted real Federal Funds Effective Rate represents the 95% confidence interval. The model is forecasting a significant amount of uncertainty or variance in the predicted values. The large error variance for the confidence interval highlights a limitation in the underlying model and the fitted coefficients should be reviewed with this in mind. The complete diagram of model performance and exploration of model assumptions can be found in Appendix B.

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Figure : ARIMA Model Predictions Pre 2007 Timeframe

The feature coefficients for this model are presented in Figure 27. The features with the largest impact on real Federal Funds Effective Rate predications are the Unemployment Gap and the Inflation Gap. This model is consistent with the previous models explored here. The relative size of the Unemployment Gap coefficient is larger. Than the Inflation Gap coefficient.

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Figure : ARIMA Model Coefficients for Pre 2007 Timeframe

## Concept 5: Regression Model

The Regression concept is based on the features from the Modified Taylor Rule that have a non-zero coefficient after Lasso models regularization. The response variable for this model is the Federal Funds Effective Rate difference (FEDFUNDS\_diff). This model based on this concept includes the following features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Unemployment Gap (gap\_ue)
* GDP Gap (gap\_gdp)
* Real Interest Rate (Real\_Interest\_Rate)

The Lasso Regression Model generated a RMSE of 1.3836 for the test data set. The predictions values for the Federal Funds Effective Rate vs actual are depicted in Figure 28. The complete diagram of model performance and exploration of model assumptions can be found in Appendix B.

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Figure : Lasso Model Predicted FFER

The feature coefficients for this model are presented in Figure 29. The features with the largest impact on real Federal Funds Effective Rate predications are the Federal Funds Effective Rate (t-1) followed by the Unemployment Gap, the Inflation Gap, and finally the Real Interest Rate.

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Figure : Lasso Model Coefficients

## The Composition of the Federal Open Market Committee

The FOMC composition analysis focuses on the Fed Chair but could be extended to include another member of the FOMC in the future. Figure 30 depicts the Effective Federal Funds Rate, plotted against the Economic Discomfort Index, and aligned to the tenure of the Fed Chair.

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Figure : Economic Discomfort Index vs. Federal Funds Effective Rate

There is a stark contrast between the tenures of Volker, Miller, Powell, and Yellen. It is interesting to note the peaks in the EDI during the tenure of Burns and Powel. The unemployment rates between the tenure of Yellen (5.06), Greenspan (5.53), and Miller (5.89) are not too dissimilar; however, all three faced very different inflation rates and Effective Federal Funds Rates. Figure 31 summarizes the economic indicators by Federal Reserve Chair.

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Figure : Economic Indicators by Fed Chair

It is worth considering the EDI in the abstract. The formulation of the EDI is simplistic in nature and includes assumptions regarding the marginal rate of substitution between unemployment and the impacts of inflation. It assumes that individuals would be willing to trade off 1.0% point of inflation for 1.0% percentage point of unemployment.

The EDI provides a simple trade-off function between inflation and unemployment. However, does this formulation also transfer to the FOMC deliberations? The timeseries analysis in this paper explores the linkages between economic indicators and the Federal Reserve’s decision-making process.

Fitting the ARIMA model with the following features generates the coefficients depicted in Figure 32:

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

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Figure : Fed Chair – Lasso Model Coefficients Graph

From the analysis, it is unclear whether the Federal Reserve Chair significantly impacts FOMC’s decision-making. This analysis does not support Wilson’s (2019) conclusions [15]. Wilson’s paper is based on the Original Taylor Rule; further exploration of his conclusion using the Modified Taylor Rule would be beneficial.

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 [15].

## Other Concepts

For completeness of analysis, I reviewed several additional concepts. The associated models for these concepts included coefficients that were not statistically significant. A detailed review of the summary and the assessment of model assumptions for the two models detailed below is captured in Appendix B.

* Simple Model Concept – This was a two-feature model that only includes the Unemployment Gap and the Inflation Gap. While all coefficients of the simple ARIMA model are statistically significant, the model fails to outperform the baseline ETS model on the out-of-sample test data.
* Recession Model Concept – The models in this concept include three features the Unemployment Gap, the Inflation Gap, and a Boolean flag for recessions. The coefficient for the recession flag in this model is not statistically significant.

# Conclusion

This analysis includes a baseline ETS model that fits the response variable without any exogenous variable. The resulting RMSE for the ETS model is the performance baseline that I compare against all other models. Three models underperformed the baseline including the Modified Taylor Rule, the Simple Model, and the Recession Model. These results are somewhat surprising; I expected the Simple Model and the Model based on the Modified Taylor rule to perform better.

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 the end of 2008 through October 2014. So, while the economic indicators that underpin the various model forecasted a higher Federal Funds Effective Rate, the rate remained at zero for this time period. This dynamic impacted the accuracy of all the models. The Pre-2007 concept was an attempt to isolate this time period.

Figure 33 below highlights the performance of each model and the associated coefficients for the Inflation Gap and the Unemployment Gap. The coefficients are for normalized predictor variables with a mean of 0 and a standard deviation of 1, which have the same scale and thus can be compared directly.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Concept | Description | RMSE | Dual Mandate | Coefficient |
| Concept 1: Full Model | | | | |
| ARIMA | * FEDFUNDS-1 * gap\_inf * gap\_gdp * recession\_flag | 0.3372 | gap\_gdp | 0.2956 |
| gap\_inf | 0.3435 |
| Concept 3: Real Federal Funds Effective Rate | | | | |
| ARIMA | * gap\_ue * gap\_inf | 2.2577 | gap\_ue | -2.3736 |
| gap\_inf | - 1.9227 |
| Concept 4: Pre 2007 Timeframe | | | | |
| ARIMA | * gap\_ue * gap\_inf | 1.9937 | gap\_ue | - 2.3075 |
| gap\_inf | 0.9256 |
| Concept 5: Regression | | | | |
| Lasso | * gap\_ue * gap\_inf | 1.3836 | gap\_ue | - 0.1362 |
| gap\_inf | 0.1037 |
| Composition of the Federal Reserve | | | | |
| ARIMA | * gap\_ue * gap\_inf | 4.8604 | gap\_ue | - 0.6256 |
| gap\_inf | 0.3125 |
|  |  |  |  |  |

Figure 33: Model Performance

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. 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.

The results of the ARIMA models are consistent. All ARIMA models fit a coefficient for the Unemployment Gap that is larger than the coefficient for the Inflation Gap. On the surface this would indicate that the Federal Reserve more heavily focuses on the full employment component of the dual mandate. It would be worthwhile to evaluate the impact of the positive autoregressive (AR) and moving average (MA) coefficients on the overall model however that analysis is beyond the scope of this paper. More analysis is required to understand all the dynamics behind the ARIMA models. However, there is evidence that the Federal Reserve places a greater emphasis on full employment then it does on price stability when conducting monetary policy.

It should be noted that the Lasso Regression Model generated a supporting finding. In the Lasso regression model, the coefficient for the Unemployment Gap (-0.1362) is larger than the coefficient for the Inflation Gap (0.1037). Although the difference between the coefficients is relatively small, the finding is consistent with the outputs of the ARIMA Models.

Other opportunities for additional analysis and exploration include: First, the dataset used for this analysis is quarterly. The consistent duration of each time period simplifies that modeling however a more accurate analysis would take into account the FOMC meeting calendar. This adds complexity but better aligns the analysis with the decision-making timelines I am modeling. Second, the current analysis is based on historical data. It implicitly assumes that the relevant GDP, unemployment, and inflation data is available within the prediction timeframe. This implicit assumption must consider reporting lags and restatements/recalculations of the economic indicators.

# Appendix A: Stationarity

The Timeseries models used for this analysis require stationary data or data that can be made stationary after differencing. The ACF plot for the Federal Funds Effective Rate (FEDFUNDS) is not stationary.

A graph with blue lines and dots

Description automatically generated

This is confirmed by the Augmented Dickey-Fuller Test. The ADF test reports a test statistic of -1.9252 and a p-value of 0.3203. Given the p-value above 0.05 we fail to reject the null hypothesis at a 95% confidence level. The FEDFUNDS rate is a non-stationary dataset.

Running the same analysis on the first difference of the Federal Funds Effective Rate we see a few indicators of autocorrelation however a p-value 0.0 there is statistical evidence to reject the null hypothesis in favor of the alternate hypothesis. The first difference of the Federal Funds Effective Rate is Stationary.

A graph with blue dots and points

Description automatically generated

# Appendix B: Model Performance

## Concept 1: Full Model

This concept uses p-values to select all the statistically significant features from the available feature. I selected the coefficients with p-values less than 0.05 to indicate statistical significance at the 95% confidence level. The models for this concept include the following features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Inflation Gap (gap\_inf)
* GDP Gap (gap\_gdp)
* Recession Flag (recession\_flag)

With a RMSE of 0.3372 the ARIMA model performs better than the baseline ETS model on the testing dataset.

A table with numbers and letters

Description automatically generated

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 491.821 with all coefficient p-values less than 0.05.

A screenshot of a computer

Description automatically generated

A visual inspection of the model diagnostics identified a few areas of concern specifically the standardization of residuals and some divergence from the diagonal in the Q-Q plot.

A group of graphs showing different types of graphs

Description automatically generated with medium confidence

This next section explores the underlying assumptions of the ARIMA model.

1. Stationarity – The model fit using the differencing order term of 1 (d = 1) and the first difference of the FEDFUNDS is stationary
2. Residual Normality – As can be observed from the diagnostic plot above and the scatterplot below the residuals appear to be normally distributed. A graph showing a line and a line

   Description automatically generated with medium confidence
3. Residual Autocorrelation – The visual inspection of the residual ACF graph indicates potential autocorrelation in the time series at lag 7.

A graph with blue dots and numbers

Description automatically generated

The Ljung- Box test confirms these findings.

A screenshot of a cell phone

Description automatically generated

1. Heteroskedasticity – The results of the ARCH test heteroskedasticity generate a p-value of 0.0005 indicating evidence of heteroskedasticity in the model residuals.

The ARIMA model does not meet all the underlying assumptions of the modeling framework. Specifically, the analysis of residuals shows evidence of heteroskedasticity.

## Concept 2: Modified Taylor Rule

This concept is based on the Modified Taylor Rule and includes all four features used as variables in the Modified Taylor Rule. The models for this concept include the following features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Unemployment Gap (gap\_ue)
* Inflation Gap (gap\_inf)
* Real Interest Rate (Real\_Interest\_Rate)

The relative model performance for in sample and out of sample data is presented in the table below. The two ARIMA implementations failed to outperform the simple ETS time series model with no exogenous variable.

A table with numbers and letters

Description automatically generated

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 490.104; however, two coefficient and the intercept generate p-values greater than 0.05.

A screenshot of a document

Description automatically generated

This ARIMA model includes two feature coefficients and an intercept coefficient that are not statistically significant.

## Concept 3: Real Federal Funds Effective Rate

The Federal Funds Effective Rate is a nominal interest rate an inflation component. This concept fits uses the Real Federal Funds Effective Rate (FEDFUNDS\_CPIAUCNS\_PC1) as the response variable. The models for this concept include the following features:

* Unemployment Gap (gap\_ue)
* Inflation Gap (gap\_inf)

With a RMSE of 2.2577 the ARIMA model performs better than the baseline ETS model on the testing dataset.

A table with numbers and letters

Description automatically generated

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 473.238 with all feature coefficient p-values less than 0.05.

A screenshot of a data table

Description automatically generated

A visual inspection of the model diagnostics identified a few areas of concern specifically the standardization of residuals and some divergence from the diagonal in the Q-Q plot.

A collage of graphs

Description automatically generated

1. Stationarity – The model fit using the differencing order term of 1 (d = 1) and the first difference of the FEDFUNDS is stationary
2. Residual Normality – As can be observed from the diagnostic plot above and the scatterplot below the residuals appear to be normally distributed. A graph with blue dots and red line

   Description automatically generated
3. Residual Autocorrelation – The visual inspection of the residual ACF graph indicates no existence of autocorrelation in the time series.

A graph with blue dots and numbers

Description automatically generated

The Ljung- Box test confirms these findings over 10 lags.

A screenshot of a cell phone

Description automatically generated

1. Heteroskedasticity – The Ljung-Box test of the squared residuals indicates generated a p-value of 0.0026 indicating the presence of heteroskedasticity in the time series residuals.

## Concept 4: Pre-2007 Timeframe

This concept omits the data set beyond 2007 Financial Crisis and instead focus on the pre-2007 timeframe. The models for this concept include the following features:

* Unemployment Gap (gap\_ue)
* Inflation Gap (gap\_inf)

The SARIMAX model and the auto ARIMA models both perform better than the baseline ETS model on the testing dataset.

A table of numbers and letters

Description automatically generated

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 392.266 with all coefficient p-values less than 0.05.

A screenshot of a data sheet

Description automatically generated

A visual inspection of the model diagnostics identified a few areas of concern specifically the standardization of residuals, some divergence from the diagonal in the Q-Q plot and evidence of residual autocorrelation.

A collage of graphs and diagrams

Description automatically generated

1. Stationarity – The model fit using the differencing order term of 1 (d = 1) and the first difference of the FEDFUNDS is stationary
2. Residual Normality – As can be observed from the diagnostic plot above and the scatterplot below the residuals appear to be normally distributed. A graph with blue dots and red line

   Description automatically generated
3. Residual Autocorrelation – The visual inspection of the residual ACF graph indicates the existence of autocorrelation in the time series.

A graph with blue dots and lines

Description automatically generated

The Ljung- Box test confirms these findings over 10 lags.

A screenshot of a cell phone

Description automatically generated

1. Heteroskedasticity – The Ljung-Box test of the squared residuals indicates generated a p-value of 0.0318 indicating the presence of heteroskedasticity in the time series residuals.

## Concept 5: Regression Model

The Regression Concept is based on the features from the Modified Taylor Rule that have a non-zero coefficient after Lasso models regularization. The response variable for this model is the Federal Funds Effective Rate difference (FEDFUNDS\_diff). This model includes the following features:

* Federal Funds Effective Rate from the previous period (FEDFUNDS-1)
* Unemployment Gap (gap\_ue)
* GDP Gap (gap\_gdp)
* Real Interest Rate (Real\_Interest\_Rate)

The relative model performance for in sample and out of sample data is presented in the table below.

A screenshot of a graph

Description automatically generated

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, which plots predicted values vs target values, the values fall along a diagonal line indicating a linear relationship.

A graph showing a red line and blue dots

Description automatically generated

1. Homoscedasticity – The constant variance of residuals across the predicted values does not hold 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 1.579 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.

A graph with blue squares

Description automatically generated

## Concept 6: Simple Model

This concept uses p-values to select all the statistically significant features from the available feature. I selected the coefficients with p-values less than 0.05 to indicate statistical significance at the 95% confidence level. The models for this concept include the following features:

* Inflation Gap
* Unemployment Gap

A table with numbers and letters

Description automatically generated

The SARIMAX model and the auto ARIMA models both underperform the baseline ETS model on the testing dataset.

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 476.507 with all coefficient p-values less than 0.05. The summary reports 2 warnings about unstable standard errors that we will monitor as we continue the analysis.

A screenshot of a document

Description automatically generated

A visual inspection of the model diagnostics identified a few areas of concern—specifically the standardization of residuals and some divergence from the diagonal in the Q-Q plot.

A group of graphs showing different types of graphs

Description automatically generated with medium confidence

1. Stationarity – The model fit using the differencing order term of 1 (d = 1) and the first difference of the FEDFUNDS is stationary
2. Residual Normality – As can be observed from the diagnostic plot above and the scatterplot below, the residuals appear to be normally distributed.

A graph with dots and lines

Description automatically generated

1. Residual Autocorrelation – The visual inspection of the residual ACF graph indicates no existence of autocorrelation in the time series.

A graph with blue dots and numbers

Description automatically generated

The Ljung- Box test confirms these findings over 10 lags.

A screenshot of a cell phone

Description automatically generated

1. Heteroskedasticity – The Ljung-Box test of the squared residuals generated a p-value of 0.0037 indicating the presence of heteroskedasticity in the time series residuals.

## Concept 7: Recession Model

This concept uses p-values to select all the statistically significant features from the available feature. I selected the coefficients with p-values less than 0.05 to indicate statistical significance at the 95% confidence level. The models for this concept include the following features:

* Inflation Gap
* Unemployment Gap
* Recession Flag

The SARIMAX model and the auto ARIMA models both underperform the baseline ETS model on the testing dataset.

A table with numbers and letters

Description automatically generated

The following section explores the assumptions behind the Auto ARIMA Timeseries Model from the pmdarima project. The model summary shows an AIC of 476.507 with all coefficient p-values less than 0.05.

A screenshot of a computer

Description automatically generated

A visual inspection of the model diagnostics identified a few areas of concern specifically the standardization of residuals and some divergence from the diagonal in the Q-Q plot.

A collage of graphs

Description automatically generated

1. Stationarity – The model fit using the differencing order term of 1 (d = 1) and the first difference of the FEDFUNDS is stationary
2. Heteroskedasticity – The Ljung-Box test of the squared residuals indicates generated a p-value of 0.0037 indicating the presence of heteroskedasticity in the time series residuals.

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# Figures

[Figure 1: Economic Discomfort Index Formula 6](#_Toc152522096)

[Figure 2: Economic Discomfort Index (EDI) 6](#_Toc152522097)

[Figure 3: Taylor Rule Formula 7](#_Toc152522098)

[Figure 4: Modified Taylor Rule 8](#_Toc152522099)

[Figure 5: Federal Funds Effective Rate Timeseries 10](#_Toc152522100)

[Figure 6: Real Federal Funds Effective Rate 11](#_Toc152522101)

[Figure 7: Real Rate of Interest 11](#_Toc152522102)

[Figure 8: Gap Unemployment Rate Timeseries 12](#_Toc152522103)

[Figure 9: Inflation Gap Timeseries 12](#_Toc152522104)

[Figure 10: GDP Gap Timeseries 13](#_Toc152522105)

[Figure 11: Consumer Price Index (CPIAUCSL\_CH1) Timeseries 13](#_Toc152522106)

[Figure 12: Recession Time Series 14](#_Toc152522107)

[Figure 13: Fed Chair Overtime 14](#_Toc152522108)

[Figure 14: Feature Selection SARIMA Coefficients 17](#_Toc152522109)

[Figure 15: ARIMA Model Prediction FFER Full Model 18](#_Toc152522110)

[Figure 16: ARIMA Coefficients for the Full Model 18](#_Toc152522111)

[Figure 17: Taylor Rule vs Federal Funds Effective Rate 19](#_Toc152522112)

[Figure 18: Model Performance Taylor Rule, Modified Taylor Rule 20](#_Toc152522113)

[Figure 19: Modified Taylor Rule Formula 20](#_Toc152522114)

[Figure 20: Modified Taylor Rule Predictions of the FFER 21](#_Toc152522115)

[Figure 21: Modified Taylor Rule Model Coefficients 22](#_Toc152522116)

[Figure 22: Feature and Response Variable Coefficients 23](#_Toc152522117)

[Figure 23: Real FFER vs CPI 24](#_Toc152522118)

[Figure 24: ARIMA Model Forecast for Real FFER 24](#_Toc152522119)

[Figure 25: ARIMA Model Coefficient – Real FFER Model 25](#_Toc152522120)

[Figure 26: ARIMA Model Predictions Pre 2007 Timeframe 26](#_Toc152522121)

[Figure 27: ARIMA Model Coefficients for Pre 2007 Timeframe 27](#_Toc152522122)

[Figure 28: Lasso Model Predicted FFER 28](#_Toc152522123)

[Figure 29: Lasso Model Coefficients 28](#_Toc152522124)

[Figure 30: Economic Discomfort Index vs. Federal Funds Effective Rate 29](#_Toc152522125)

[Figure 31: Economic Indicators by Fed Chair 30](#_Toc152522126)

[Figure 32: Fed Chair – Lasso Model Coefficients Graph 30](#_Toc152522127)

[Figure 33: Model Performance 33](#_Toc152522128)