# The Evolution of Taylor Rules and Its Simulation Analysis

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**Abstract.** Taylor rules are one of the most frequently applied monetary policy guidelines by the Federal Reserve, and also an important tool for the market to analyze and predict the trend of the Federal Reserve's policy interest rate. However, after 2000, especially after the subprime mortgage crisis, the explanatory and indicative function of Taylor rules for policy interest rates has significantly decreased. Against this background, Federal Reserve officials and economists have made a series of revisions to the variables and parameters used in Taylor rules, and several revised versions of the original Taylor rules have appeared one after another. empirical tests have been conducted on the fit between the theoretical interest rate and the federal funds rate on several of the main versions. At the same time, it was found that the Fed's policy interest rate adjustment actions generally lag behind the guidance of Taylor rules, and the width of the interest rate range under the guidance of Taylor rules is generally larger than the adjustment range of the Fed's policy interest rate.

**Keywords:** Tayor Rules, Bernanke Rules, Yellen Rules.

## 1 Introduction

Taylor rules were proposed by economist John Taylor in 1993 to provide a concise policy interest rate decision-making framework for central banks to set an appropriate federal funds rate level by considering the inflation rate and output gap in the economy. The core idea of the rules is that monetary policy should reflect the difference between the actual level of economic activity and its potential level, as well as the difference between the actual inflation rate and the target inflation rate.

However, since Taylor rules were proposed, the dynamic changes in the global economic environment and financial markets have required adaptive adjustments to the original rules. In particular, after the global financial crisis in 2008, the macroeconomic environment in the United States has changed significantly, such as the decline in labor force participation, the aging of the population, and the slowdown in technological innovation, which have jointly affected the potential economic growth rate and the level of the natural interest rate. In addition, economists and policymakers have re-examined and revised some basic parameters and variables in Taylor rules in an attempt to more accurately reflect current and expected economic conditions.


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This paper evaluates the performance of Taylor rules and its revisions in practical applications through literature review and empirical analysis, with a special focus on major revisions such as Bernanke rules, Evans rules, Yellen rules, and Bullard rules. The study analyzes the theoretical settings of these rules and their application in actual US monetary policy and explore the adaptability of each rule in different economic contexts and its effectiveness in guiding monetary policy. In section 2, the paper reviews previous papers discussing Taylor rules. In section 3, the study describes Taylor rules and analyze the applicability. In section 4, several revised versions of Taylor rules are introduced. In section 5, various Empirical tests are presented to evaluate the applicability of some revised versions. The conclusions follow in section 6.

## 2 Literature Review

In the field of modern monetary policy research, the global application and adaptability of Taylor rules and its revised version have always been a hot topic of academic discussion. The following review sorts out the main literature on Taylor rules from different perspectives and shows its practical effects in different economic systems and the evolution of its theory.

### 2.1 Global Application and Adaptability

Makram and Ma explore in detail its global application, re- revealing the ubiquity and flexibility of Taylor rules in different economic environments [1]. Besides, Michael Woodford examines the optimal application of Taylor rules from a theoretical perspective and explores how it affects economic stability in the monetary policy framework [2]. Additionally, the paper by Joseph Agyapong investigates the efficacy of the Taylor rules model in predicting exchange rates between OECD countries and the United States before and during the financial crisis, Guglielmo Maria Caporale, Mohamad Husam Helmi, Abdurrahman Nazif C, Faek Menla Ali, Akdeniz explores the application of Taylor rules in five emerging economies, including exchange rate factors and using nonlinear threshold models to more accurately describe monetary policy [3, 4].

### 2.2 Empirical Estimation and Methodological Issues

The parameter estimation of Taylor rules is crucial for policymakers. Robert Tchaidze analyzes the challenges of estimating Taylor rules parameters, especially emphasizing how to deal with the uncertainty of parameter estimation and the flexibility of the model in actual operations [5]. In Another paper, Carlos Carvalho, Fernanda Nechio and Tiago Tristao explore the feasibility of using ordinary least squares to estimate Taylor rules parameters and the endogeneity problems it faces, providing empirical insights into the estimation of US economic policy parameters [6]. Moreover, Chung Yan Sama, Robert McNownb, Soo Khoon Goha and Kim-Leng Goh discuss common methodological problems in typical Taylor rules studies [7]. The authors highlight

that numerous empirical analyses of the Taylor rules fail to adhere to essential econometric procedures, overlooking factors like unit roots, cointegration relationships, and serial correlation. The paper underscores that employing autoregressive distributed lag methods can address these issues and efficiently estimate the Taylor rules equation. In another paper, the implications of including asset prices in the Taylor rules specification are examined [8]. It explores how forward-looking Taylor rules, usually estimated via the Generalized Method of Moments (GMM), handle tests for overidentifying restrictions and the relevance of instruments, a process often overlooked in previous studies.

### 2.3 Modernization, Revision and Criticism

With the economic environment changes, Taylor rules also need to be constantly revised to adapt to new economic conditions. Ryan Mattson and Rex Jason Pjesk combine the Taylor rules with modern monetary theory and explore its application and adjustment in fiscal policy, thus expanding the theoretical framework of the Taylor rules [9]. Jess Benhabib, Stephanie Schmitt-Grohe and Martin Uribe criticize the risks and limitations that Taylor rules may bring in practical applications and emphasize the need for more flexibility and the ability to cope with complex economic dynamics in monetary policy formulation [10].

All the papers above focus on the properties and applications of the Taylor rules. However, Taylor rules have been developed by many economists in revised versions, which are few mentioned in the papers above. In this paper, some main revised versions will be introduced.

## 3 Introduction to Taylor Rules and Its Applicability

Since the 1990s, the Fed decided to use nominal interest rates as the main means of macroeconomic regulation, thereby changing the previous policy rules of using money supply regulation as an intermediate target. This was the background for the birth of the Taylor rules.

In 1993, John Taylor, based on data from 1987 to 1992, constructed a response function of the federal funds rate (Federal Reserve policy rate) to three variables: the natural interest rate (the long-term neutral real federal funds rate), the inflation gap (the difference between the inflation rates and the Fed's target inflation rates), and the output gap (the difference between the actual GDP growth rate and the potential GDP growth rate). He believed that the central bank should implement interest rate policies based on output and inflation.

Although the Fed does not advocate adhering to certain "mathematical rules" to set policy interest rates from the perspective of policy flexibility, interest rate rules help improve policy transparency and help the Fed explain the rationality of interest rate decisions to the market. Following the introduction of the Taylor rules, it developed into one of the simplest and most widely used monetary policy guidelines by the Fed,

becoming an essential tool for the market to analyze and predict the trajectory of the Fed's policy interest rates.

### 3.1 Introduction to Taylor Rules

The general form of Taylor's rules:

$$i_t = r^* + \pi_t + 0.5(\pi_t - \pi^*) + 0.5(y_t - y^*) \quad (1)$$

where $i_t$ is the federal fund interest rate (nominal policy interest rate) of the quarter t; $r^*$ is the natural interest rate, which is constant at 2%; $\pi_t$ is the inflation rate of the GDP flat reduction index in the past four quarters; $\pi^*$ is the Fed's target inflation rate; $y_t$ is the actual GDP growth rate; $y^*$ is the output target, which is constant at 2%. Therefore, the original version of Taylor rules can be simplified to:

$$i_t = 2\% + \pi_t + 0.5(\pi_t - 2\%) + 0.5(y_t - 2\%) \quad (2)$$

It can be seen that Taylor rules are well compatible with some key principles of the Fed's formulation of monetary policy: First of all, the Taylor rules make the long-term neutral actual federal fund interest rate, actual inflation rate and target inflation rate, actual GDP and its potential level known as under the circumstances, the policy interest rate has some predictability, and the process of using Taylor's rules for monetary policy communication, implementation and verification is relatively simple and transparent; secondly, according to the Taylor rules, the policy should be increased when inflation or total output increases. Interest rates should reduce policy interest rates when inflation or total output decreases, which is consistent with the dual goals that promote the maximum employment and stable prices of the Fed.

### 3.2 Analysis of Its Applicability

After Taylor rules were proposed for the subprime mortgage crisis, the US economy was in a period of ease and the economic activity and inflation situation was extremely stable, and the Philips curve was steep. In this context, the adjustment trajectory of the federal fund interest rate is basically in line with the trend of changes in the theoretical interest rate under the Taylor rules. However, after 2000, although the interest rate trend of the federal fund is basically converging with the theoretical interest rate under the Taylor rules, the interest rate level has been significantly lower than the theoretical value for a long time. Especially after the subprime loan crisis in 2008, the fit effect of the two declined significantly. The original interpretation of Taylor rules and predictive power of the actual policy interest rate decreased significantly, and a phased failure occurred. After the subprime mortgage crisis, the primitive Taylor rules had a significant decrease in the prospectiveness and indications of the policy interest rate trend, which was mainly due to the limitations of several aspects of its own settings:

Firstly, in the primitive Taylor rules, the inflation indicators used the GDP flat reduction index, which had a wide coverage, including government expenditure and the

price of capital goods. In addition, the factors of import prices were excluded. This setting obviously deviated from the inflation indicators that the Federal Reserve in the actual decision-making based on personal consumption expenditure as the statistical basis, that was, the core PCE with lower fluctuations.

Secondly, in the original Taylor rules, both the natural interest rates and potential economic growth were set at 2%. Clearly, this configuration failed to consider the shifts in potential economic growth and the presence of natural interest rates during significant changes in the economic environment.

Thirdly, the Primitive Taylor rules assumed that monetary policymakers understand the scale of the output gap. However, in fact, due to the difficulty of calculating the gap in the output, Federal Reserve officials usually had difficulty reaching an agreement on the output gap.

Fourthly, the output gap of the original Taylor rules was equal to the weight of the inflation gap, and the fixed unchanged was unable to reflect the adjustment of the Fed's policy in different periods.

## 4 The Evolution of Taylor Rules

After the subprime mortgage crisis, the US macroeconomic environment has changed significantly compared with the end of the last century: Due to factors such as the aging population, decreased labor participation rate and lack of technological innovation, US labor productivity growth is sluggish, The growth rate of potential economic growth in the medium and long term is constantly decreasing; Corresponding to the reduction of potential economic growth is the continuous decline of natural interest rates; The Natural interest rate estimated by the Federal Reserve decreased from about 2.25% in 2012 to about 0.5% in 2021. The median number of neutral nominal policy interest rates has also been significantly reduced, indicating that the Fed's monetary policy of the Federal Reserve estimated by the Federal Reserve is from 2012. At about 2.25% of the year to about 0.5% in 2021, the median number of neutral nominal policy interest rates has also been significantly reduced, indicating that the Fed's monetary policy space for negative impact has been significantly compressed.

The above changes explain the effect of why the original Taylor rules' instructions on policy interest rates will be greatly reduced, and it also prompts the Fed to think about new policy rules and become an important experience in the Fed's new currency policy framework in the later period. Based on this, in order to better portray and interpret the changes in the facts and the policy framework, the Federal Reserve officials and economists in the later period have revised the variables and parameters selected by the Taylor rules. The revised version, the more representative of which is Bernanke rules, Evans rules, Yellen rules and Bullard rules.

### 4.1 Bernanke Rules

In 2015, in response to Taylor's criticism of the Fed's long-term low interest rate, Bernanke made two points of correction of the original Taylor rules: Use the core

PCE to replace the GDP flat reduction index in the original Taylor rules as the actual inflation rate indicator; Lifting the reaction coefficient of the output gap from 0.5 to 1 to reflect that in actual decisions, the Fed is more inclined to accept a larger inflation variable in exchange for more stable output conditions.

Thus, Bernanke rules can be described as:

$$i_t = r^* + \pi_t + 0.5(\pi_t - \pi^*) + (y_t - y^*) \tag{3}$$

where $\pi_t$ is the average value of the core PCE inflation rate in the past four quarters. The simplified formula is:

$$i_t = 2\% + \pi_t + 0.5(\pi_t - 2\%) + (y_t - 2\%) \tag{4}$$

It can be seen that because Bernanke increased the weight of the output gap, Bernanke rules were more "pigeon faction" than the original Taylor rules -when the actual GDP was lower than the potential GDP, the theoretical interest rate under Bernanke rules the level will be lower.

### 4.2 Evans Rules

After the subprime mortgage crisis, by 2010, the U.S. inflation rate has risen to 1.9%, and the actual GDP growth rate has risen to 2.3%. According to the original Taylor rules, the federal fund interest rate should be close to 4%. However, the Fed believed that the recovery stage after the deep decline in the economy was the optimal decision to maintain ultra-low interest rates for a long time. As a result, the Federal Reserve revised Taylor rules in December 2012.

The revised rules were first proposed by the Chicago Federal Reserve Chairman Evans, which was also called Evans rules.

The revision of Evans rules for Taylor rules is mainly reflected in three points: Use the employment gap to replace the GDP output gap, which is reflected in the indicator, that is, the unemployment rate is used to replace the GDP growth rate. At the same time, the target unemployment rate is set to be an estimated average of 5.5% at that time, and gives a higher weight to the employment gap -set the coefficient of the employment gap to 2, which reflects the recovery phase after the subprime crisis, the Fed attaches importance to the labor market; consider the lagging defects of historical data of the original Taylor rules and Bernanke rules, the inflation rate indicators of Evans rules no longer adopt the historical data of inflation rate, but adjust to the expected data of the inflation rate in the next 1-2 years to improve The prospectiveness of interest rate decision-making; the critical value of the introduction of the indicator as the trigger condition for increasing zero interest rate-as long as the unemployment rate is > 6.5% or the inflation expectation value in the next 1-2 years is < 2.5%, the Fed will not increase the zero interest rate.

Thus, Evans rules can be described as:

$$i_t = r^* + \pi_{t+1} + 0.5(\pi_t - \pi^*) + 2(u_t - u^*) \tag{5}$$

where $\pi_{t+1}$ is the forecast inflation rate for the next 1-2 years; $u_t$ is the actual unemployment rate;$u^*$ is the target unemployment rate. The simplified formula is:

$$i_t = 2\% + \pi_{t+1} + 0.5(\pi_t - 2\%) + 2(u_t - 5.5\%) \tag{6}$$

### 4.3 Yellen Rules

Yellen has served as the chair of the Federal Reserve since 2014. The Yellen rules has made some parameter adjustments based on the Evans rules, especially in the estimation of the natural interest rate and natural unemployment rate, borrowing new research results to make it more ”time-varying”: firstly, the natural interest rate is measured by the Laubach-Williams model instead of a fixed value of 2%; secondly, the target inflation rate uses the long-term PCE forecast inflation rate; thirdly, the target unemployment rate is no longer fixed at 5.5%, but used as the natural unemployment rate regularly forecasted by the U.S. Congressional Forecast Office.

Thus, Yellen rules can be described as:

$$i_t = r^* + \pi_t + 0.5(\pi_t - \pi^*) + 2(u_t - u^*) \tag{7}$$

Since the target inflation rate and target unemployment rate adopted by the Yellen rules are both long-term targets, the rules mainly seek the optimal path of the policy interest rate in the next few years rather than in a single stage; at the same time, using dynamic forecasts of future inflation rate and unemployment rate as target values for these two indicators actually incorporates the feedback mechanism of policy effects into the framework of policy decision-making.

### 4.4 Bullard Rules

In 2018, St. Louis Fed President James Bullard further revised Taylor rules based on changes over the past 20 years, such as the weakening connection be- between unemployment and inflation, the aging of the U.S. population, and low inflation expectations, forming Bullard rules. Bullard’s further revision of Tay- lor rules is mainly reflected in: (1) The previous value of the policy interest rate it−1 is included with a certain smoothing coefficient, which is set to 0.85 to reflect the continuity of the policy and the important impact of the previous interest rate on the current period; (2) The natural interest rate is calculated as the HP filter trend term of the difference between the 1-year Treasury yield and the 12-month average Dallas Fed truncated average PCE inflation rate; (3) The inflation gap is equal to the market inflation expectation (5-year break-even inflation rate) minus the 2% inflation target, and the reaction coefficient of the inflation gap is increased to 1.5; (4) The employment gap is equal to the CBO’s predicted natural unemployment rate minus the current actual unemployment rate; (5) The reaction coefficient of the employment gap is reduced to 0.1 to reflect the flattening of the Phillips curve. Bullard rules can be described as:

$$i_t = \rho i_{t-1} + (1 - \rho)[r^* + \pi^* + \beta_1(\pi_t - \pi^*) + \beta_2(u_t - u^*)] \tag{8}$$

The simplified formula is:

$$i_t = 0.85 i_{t-1} + 0.15[r^* + 2\% + 1.5(\pi_t - 2\%) + 0.1(u_t - u^*)] \quad (9)$$

## 5 Simulation Test of Taylor Rules

### 5.1 Bernanke Rules

Compared with the original Taylor rules, the overall fit between the theoretical interest rate level and the policy interest rate level under Bernanke rules has been significantly improved. After 2000, although there is still a large deviation between the policy interest rate and the theoretical interest rate, the deviation is significantly smaller than that of the original Taylor rules, which shows that the Fed's interest rate decision after 2000 is still "abiding by the rules". More importantly, after the 2008 financial crisis, the time span for the theoretical interest rate under Bernanke rules to remain at a negative interest rate level has significantly increased (because the federal funds rate had fallen to a level close to 0 at the time, it was impossible to become negative with the theoretical interest rate), and the time for the theoretical interest rate to stabilize and turn positive was delayed to the fourth quarter of 2014, which is basically consistent with the time period when the Fed withdrew from the third round of QE at the end of October 2014. This is mainly because the US output gap was large after 2008, and the Bernanke rules significantly increased the weight of the output gap, so its theoretical interest rate level is significantly lower than the original Taylor rules (shown in Figure 1).

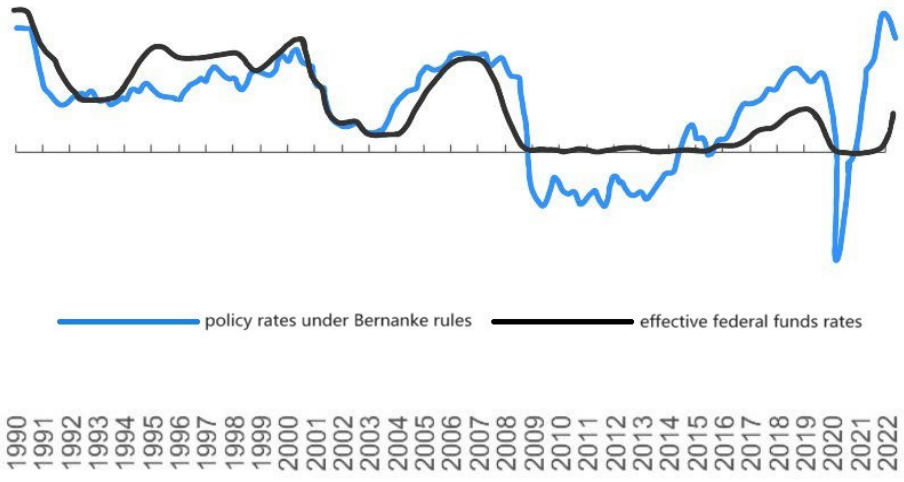


**Fig. 1.** Policy rates and effective federal funds rates under Bernanke rules (Data Sources: Congressional Budget Office, Federal Reserve Bank of Atlanta)

### 5.2 Yellen Rules

The test results show that from 1990 to 2008, the Yellen rules also fit the policy interest rate trend very well. After 2008, the theoretical interest rate under Yellen rules also deviated greatly from the policy interest rate, but similar to Bernanke rules, the theoretical interest rate was deeply negative for a long time, significantly lower than the zero-interest rate in the same period. The theoretical interest rate under Yellen rules turned positive in the fourth quarter of 2015, which was later than the theoretical interest rate under the Bernanke rules. This is also highly consistent with the time when the Federal Reserve actually started to raise interest rates (December 2015), further proving the effectiveness of Yellen rules (shown in Figure 2).

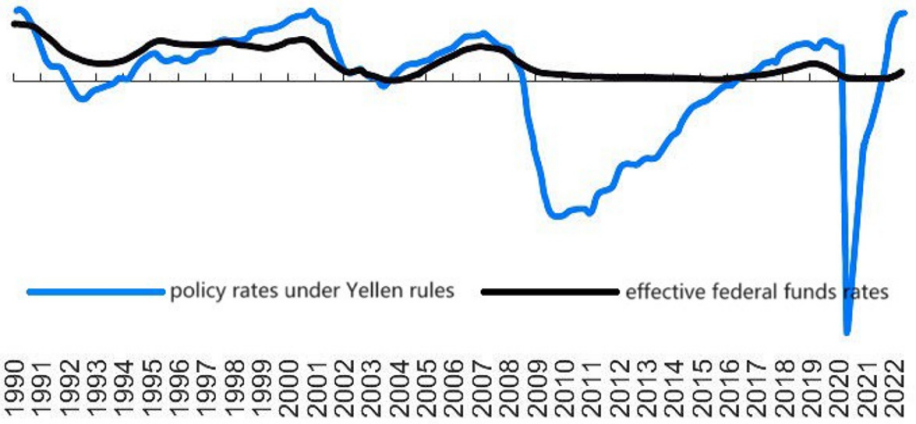


**Fig. 2.** Policy rates and effective federal funds rates under Yellen rules (Data sources: Congressional Budget Office, Federal Reserve Bank of Atlanta).

## 6 Conclusion

In terms of the timing of policy response, the Fed's policy interest rate adjustment actions generally lag behind the guidance of interest rate rules. Whether it is the rate cut in 2007, the rate hike at the end of 2015, the rate cut in 2019, or the current round of rate hikes starting in 2022, the changes in the federal funds rate tend to lag behind the policy rate adjustment timing indicated by the interest rate rules. This shows that even if the interest rate rules give theoretical guidance on rate cuts or rate hikes, in actual operations, the Federal Reserve may not respond immediately.

In terms of the adjustment range of the policy interest rate, the width of the interest rate adjustment range under the guidance of rules is generally wider than the Federal Reserve's policy interest rate adjustment range. In actual operation, the Fed's final policy interest rate peak in the interest rate hike cycle is generally lower than the theoretical interest rate peak level under the interest rate rules; accordingly, the Fed's policy interest rate low point in the interest rate cut cycle is also generally higher than the theoretical interest rate low point level under the interest rate rules. In other

words, the interest rate adjustment range under the rules' guidance is usually wider than the Fed's actual policy interest rate adjustment range.

The above two judgments also reflect such a rule: as a simple data model, the theoretical interest rate indicated by various versions of Taylor rules reacts more strongly and quickly to changes in variables; however, the Fed will consider more diverse factors in monetary policy decisions and will be more cautious in interest rate adjustments. In practice, it rarely makes large adjustments to interest rates based solely on fluctuations in inflation and output data.

Judging from the process of the birth of the Taylor rules, it is more of "rules of thumb" rather than an axiom obtained through rigorous deduction; similarly, any version of the Taylor rules only has a strong explanatory or guiding significance for the policy interest rate of this period within a specific monetary policy framework or a specific economic cycle - that is, there are no interest rate rules that always perfectly fit the actual interest rate trend.

Although the Taylor rules has always been one of the important references for the Federal Reserve to adjust interest rates, as a product of the "Great Moderation" period, it has been continuously revised in the later period, which also proves the fact that the biggest limitation of any single quantitative interest rate rules is that it is easy to oversimplify the facts and cannot fully reflect the complexity and systematic nature of the monetary policy decision-making process. In 2020, Federal Reserve Chairman Powell clearly pointed out that the Fed's decision is based on its long-term monetary policy objectives, its medium-term macroeconomic forecast, and a thorough evaluation of various risks, including systemic financial risks. This means that in actual decision-making, the Fed cannot make decisions based on a single interest rate rule. Therefore, the Taylor rules are by no means iron rules to guide the future policy interest rate trend. Mechanically applying the Taylor rules to predict the future policy interest rate has limited actual indicative significance.

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