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INTEREST RATES, THE TAYLOR RULE, THE QUANTITY EQUATION, AND THE PHILLIPS CURVE

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Abstract

This article combines the Taylor rule, the Friedman's Quantity Equation, and the Phillips curve to explore how deviations in the inflation rate, real GDP, money supply, money velocity, and the unemployment rate interact with the interest rate. The motivation is to understand which factors impact the interest rate and how. Applying monthly United States data from 1 January 1959 to 31 March 2022, the contribution and findings show that the deviation in the inflation rate, the deviation in the real GDP, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate are positively correlated with the interest rate. Regression analysis shows that the deviation in the inflation rate and the deviation in the real GDP are statistically positive and interact with the interest rate, consistently with Taylor. The interest rate increases with the money supply and the money velocity. Multicollinearity exists between the deviation in the real GDP and the deviation in the unemployment rate. The interest rate increases with the deviation in the unemployment rate, consistently with the Phillips curve. The deviation in the inflation rate, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate are good interest rate indicators. The combination explains the interest rate more realistically than the Taylor rule.

Keywords: Interest Rate, Taylor Rule, Quantity Equation, Phillips Curve, Money Supply, Money Velocity, Unemployment, Regression Analysis

JEL Classifications: C5, E24, E4, E5

1. Introduction

Central banks have multiple roles, with goals pertaining to economic growth, optimal employment or low unemployment rate, low inflation rate, exchange stability, financial stability, etc. The widely known Taylor (1993) rule is a tool for central banks to determine interest rates. It predicts and suggests the interest rate with four variables, i.e., the inflation rate, the equilibrium real interest rate, the gap in the inflation rate, and the gap in real GDP (gross domestic product). The Taylor

(1993) rule does not include the money supply, commonly accepted to impact the interest rate. The Quantity Equation (Friedman, 1970) connects the money supply, money velocity, price level (inflation rate), and real GDP. For the money supply, first, based on the law of supply and demand (Gale, 1955), the interest rate is the price of the money supply. Thus, the money supply increase causes the interest rate to decrease. Second, central banks tend to increase the interest rate to prevent massive withdrawals when the money supply increases. In addition, the increase in the money supply may cause inflation. If the inflation rate is high, central banks may be forced to increase the interest rate to stabilize the economy. Money velocity is related to the interest rate. As Taylor (1999) points out, velocity depends on the interest rate and real output or income. Money velocity is the average number of times that a unit of currency is circulated within a time period. Under a certain real output level, the increase of money velocity decreases the money supply. According to the Keynesian money demand theory (Keynes *et al.* 1971), when the money supply decreases, the money velocity has to increase to maintain the balance of the monetary market. Thus, the money velocity has an opposite impact on the interest rate compared with the money supply. Phillips (1958) connects the inflation rate and the unemployment rate in the short run, expressed in the so-called Phillips (1958) curve[1]. It suggests a negative relationship between inflation and unemployment rates in the short run. Taylor (1993) suggests that the inflation rate increases the interest rate. Hence, an inverse relationship is assumed between unemployment and interest rates (Prag, 1994). Therefore, it is reasonable to link the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. To our best knowledge, such combinations remain poorly explored. Thus, against this background, this article combines the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. This research identifies five variables involved in these three equations and explores their interaction with the interest rate.

This article chooses the following five independent variables which may statistically impact the interest rate, i.e., the deviation in the inflation rate, the deviation in the real GDP, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate. This article innovatively explores the combinations of the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. We employ the monthly data from 1 January 1959 to 31 March 2022 to explore the impact of these five variables on the interest rate in the United States. The research generalizes the Taylor (1993) rule by introducing money supply and money velocity captured in the Quantity Equation (Friedman, 1970) and the unemployment rate presented in the Phillips (1958) curve. Exploring the combinations of these three equations helps better understand the interactions of these five variables with the interest rate.

Although the money supply is not included in the Taylor (1993) rule, it has received substantial attention. The literature compares the Taylor (1993) rule with other rules, including the money supply rule (Minford *et al.* 2003), the Friedman rule (Srinivasan, 2000), and the solvency rule (Brancaccio and Fontana, 2013). Various studies analyze the Taylor (1993) rule and monetary policy (Asso *et al.* 2010; Auray and Fève, 2003; Castro, 2011; Kliesen, 2019)) or apply the Taylor (1993) rule to analyze central bank digital currencies (Wang and Hausken, 2022). The growth form of the Quantity Equation (Friedman, 1970) indicates the relationship between the inflation rate and changes in the money supply, money velocity, and GDP. Kang (1983) points out that the relationship between the money supply and the interest rate is robust since the money supply has a negative short-term liquidity effect on the interest rate and a positive long-term income effect. Qureshi (2021) investigates the role of money in Federal Reserve policy. The findings indicate that money is a relevant indicator for explaining the monetary policy.[2] The well-known Phillips (1958) curve explores the unemployment rate and suggests an inverse relationship

[1] The modern Phillips curves include a short-run Phillips curve and a long-run Phillips curve (Granger and Jeon, 2011). In the short run, it is commonly accepted that inflation and unemployment rates are inversely related. In the long run, that relationship breaks down (Russell and Banerjee, 2008). The economy maintains the natural unemployment rate regardless of the inflation rate. Thus, there is no tradeoff between inflation and interest rates in the long run. This article uses monthly data. Thus, it is reasonable to assume an inverse relationship between the inflation rate and the unemployment rate, as in a short-run Phillips curve.

[2] For monetary policy in a Central Bank Digital Currency System, see Wijngaard and Van Hee (2021).

between inflation rate and unemployment rate in the short run. It omits the interest rate term. Rocheteau and Rodriguez-Lopez (2014) explore the linkage between the money supply, liquidity (the interplay between the supply and demand for money), unemployment, and interest rates. They find that increased public liquidity (assets serving as media of exchange) causes the real interest rate and unemployment to increase.

The article shows a positive correlation between the interest rate on the one hand and the deviation in the inflation rate, the deviation in the real GDP, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate positively on the other hand. Regression analysis shows that the deviation in the inflation rate and the deviation in the real GDP are statistically positive and interact with the interest rate. The interest rate increases with the money supply and the money velocity. Multicollinearity exists between the deviation in the real GDP and the deviation in the unemployment rate, causing the removal of the deviation in the real GDP. The interest rate increases with the deviation in the unemployment rate. The deviation in the inflation rate, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate are goods interest rate indicators.

The remainder of the article is as follows. Section 2 illustrates the conceptual framework of dependent and independent variables and the analytic approaches. Section 3 presents the empirical data. Section 4 investigates the Pearson correlation between six variables, presents exploratory regression analysis, and contains a discussion. Section 5 summarizes the study giving conclusions.

2. Conceptual framework and the analytic procedures

2.1. Choosing the dependent and independent variables

The nomenclature is shown in Table A1 in the Appendix. This article investigates the variables that impact interest rates by incorporating the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. Interest rate is the dependent variable. We use five independent variables according to the incorporated approaches described as follows:

1. The deviation $(\pi - \pi^*)$ in the inflation rate is present in the Taylor (1993) rule as in Equation (1),

$$i = \pi + r^* + a_\pi(\pi - \pi^*) + a_y Log\left(\frac{y}{\bar{y}}\right), \tag{1}$$

where $i \in \mathbb{R}$ is the interest rate, $\pi \in \mathbb{R}$ is the inflation rate, $\pi^* \in \mathbb{R}$ is the target inflation rate, $r^* \in \mathbb{R}$ is the equilibrium real interest rate, whereas $a_\pi = a_y = 0.5$ are constants, $y \geq 0$ is the real GDP, and $\bar{y} \geq 0$ is the potential real GDP that can be sustained over the long term. The latter is a theoretical estimation of GDP when labor and capital are at their maximum sustainable amounts. Log denotes the logarithm with base ten.

2. The deviation $Log(y/\bar{y})$ in the real GDP is in Equation (1).
3. The deviation $Log(m/m_\tau)$ in the money supply, where $m > 0$ is the money supply that is present in the Quantity Equation (Friedman, 1970) as in Equation (2),

$$m * v = \pi * t, \tag{2}$$

where t is the volume of transactions and $m_\tau \geq 0$ is the money supply at some earlier point τ in time $(\tau \geq 0)$.

4. The money velocity v $(v \geq 0)$ is also present in the Quantity Equation in (2).
5. The deviation $\bar{u} - u$ between the natural unemployment rate $\bar{u}$ $(\bar{u} \geq 0)$ and the unemployment rate u $(u \geq 0)$. Both $\bar{u}$ and u are present in the Phillips (1958) curve in Equation (3),

$$gW = gW^T + f(\bar{u} - u), \tag{3}$$

where gW is the growth rate of money wages, gW^T is the growth trend rate of money wages, and $f(\cdot)$ is a function. Analogously to the Taylor (1993) rule in Equation (1), with the deviation $Log(y/\bar{y})$ in the real GDP and the deviation $\pi - \pi^*$ in the inflation rate, this article introduces the deviation $\bar{u} - u$ in the unemployment rate in Equation (3). Phillips (1958) assumes a negative relationship between the inflation rate π and the unemployment rate u, i.e. a positive relationship between the inflation rate π and the deviation $\bar{u} - u$ in the unemployment rate. Taylor (1993) assumes a positive relationship between the interest rate i and the inflation rate π. Combining assumptions of Phillips (1958) and Taylor (1993) implies a positive relationship between the interest rate i and the deviation $\bar{u} - u$ in the unemployment rate. This implication is consistent with Prag's (1994) finding of an inverse relationship between the interest rate i and unemployment rate u.

2.2. The analytic procedures

The article first shows the Pearson correlation coefficients between six variables. After that, the regression analysis is presented with an interest rate i as a dependent variable and the other five variables as independent variables. The regression analysis is updated and refined by removing insignificant independent variables. Consequently, independent variables which pass the significant test are selected. This approach is exploratory. The total amount of possible combinations with five independent variables is given by $\sum_{x=1}^{5}\binom{5}{x} = 31$, where $\binom{5}{x}$ denotes the binomial coefficient. Furthermore, the regression findings are presented and discussed. The analysis seeks to combine the three equations mentioned above in economics to enhance the understanding of the impact of these five variables on the interest rate i.

3. Empirics for the United States

This article collects and adopts monthly United States data from 1 January 1959 to 31 March 2022 from the following resources. The historical interest rate i is derived from the Board of Governors of the Federal Reserve System (US) (2022a). The inflation rate π data is obtained from the U.S. Bureau of Labor Statistics (2022a). The target inflation rate $\pi^* = 1.5\%$ is estimated from a previous study by Shapiro and Wilson (2019) from 1 January 2000 to 30 December 2007. For the remaining period from 1 January 1959 to 31 March 2022, we adopt the common $\pi^* = 2\%$, which Taylor (1993) also uses from 1 January 1984 to 30 September 1992. The real GDP y is estimated by the U.S. Bureau of Economic Analysis (2022). The real potential GDP $\bar{y}$ is derived from the U.S. Congressional Budget Office (2022b). The M2 money supply m is estimated from the Board of Governors of the Federal Reserve System (2022b). Inspired by previous studies (Batini, 2006; Batini and Nelson, 2001; Friedman and Schwartz, 1982), this study uses the money supply m_τ with a two-year lag. This approach suggests more than a one-year time lag from money printing to inflation. The unemployment rate u is evaluated by the U.S. Bureau of Labor Statistics (2022b). The natural unemployment rate $\bar{u}$ is estimated from the U.S. Congressional Budget Office (2022a).[3] This is the same natural rate of unemployment used in the Phillips (1958) curve. The money velocity v is estimated from the Federal Reserve Bank of St. Louis (2022). For the real GDP y, the real potential GDP $\bar{y}$, the natural unemployment rate $\bar{u}$, and the money velocity v, the quadratic interpolation method is adopted to convert the quarterly data to monthly data. Table 1 illustrates the descriptive statistics for the six variables.

According to Table 1, the sample size is $N = 735$. For the interest rate i, the minimum and maximum are 0.05% in April and May 2020 and 19.10% in July 1981, respectively, with an average of 4.85% and a standard deviation of 3.73%.

[3] The natural unemployment rate is the rate of unemployment arising from all sources except fluctuations in aggregate demand. Starting with the July 2021 report: "An Update to the Budget and Economic Outlook: 2021 to 2031", this series was renamed from "Natural Rate of Unemployment (Long-Term)" to "Noncyclical Rate of Unemployment".

Table 1. Descriptive statistics of six variables

Variable	N	Mean	S.D.	Min.	Median	Max.
(1) i	735	0.0485	0.0373	0.0005	0.0476	0.1910
(2) $\pi - \pi^*$	735	0.0182	0.0281	-0.0396	0.0112	0.1259
(3) $Log\left(\frac{y}{\bar{y}}\right)$	735	-0.0042	0.0105	-0.0523	-0.0041	0.0246
(4) $Log\left(\frac{m}{m_\tau}\right)$	735	0.0595	0.0237	0.0076	0.0577	0.1489
(5) v	735	1.7813	0.2215	1.0711	1.7664	2.1928
(6) $\bar{u} - u$	735	-0.0053	0.0169	-0.1019	-0.0016	0.0245

Notes: In Table 1, Column 1 presents the variable name. Column 2 is the sample size. Column 3 shows the mean of the six variables, whereas Column 4 is the standard deviation. Columns 5, 6, and 7 are the variables' minimum, median, and maximum values, respectively.

4. Correlation and regression analysis

4.1. Correlation

Table 2 shows the Pearson correlation between the interest rate i, the deviation $\pi - \pi^*$ in the inflation rate, the deviation $Log(y/\bar{y})$ in the real GDP, the deviation $Log(m/m_\tau)$ in the money supply, the money velocity v, and the deviation $\bar{u} - u$ in the unemployment rate. Notably, the variables are all positively related to the interest rate i. As shown in the second column of Table 2, the interest rate i has the highest correlation coefficient (0.7267) with the deviation $\pi - \pi^*$ in the inflation rate. This high number indicates that the deviation $\pi - \pi^*$ in the inflation rate is explanatory for the interest rate i. Thereafter follows the money velocity v at 0.3686, which suggests that the money velocity v is also essential for the interest rate i. This relationship has hardly been explored in the existing literature. The deviation $\bar{u} - u$ in the unemployment rate is 0.2201. This lower correlation coefficient expresses weak relation with the interest rate i. That sounds plausible since the unemployment rate u is usually not assumed to impact the interest rate i directly.

Table 2. Correlation matrix

Variables	i	$\pi - \pi^*$	$Log\left(\frac{y}{\bar{y}}\right)$	$Log\left(\frac{m}{m_\tau}\right)$	v	$\bar{u} - u$
i	1.0000					
$\pi - \pi^*$	0.7267	1.0000				
$Log\left(\frac{y}{\bar{y}}\right)$	0.1473	0.0552	1.0000			
$Log\left(\frac{m}{m_\tau}\right)$	0.0875	0.2170	-0.0443	1.0000		
v	0.3686	0.1157	0.2097	-0.5221	1.0000	
$\bar{u} - u$	0.2201	0.1189	0.8847	-0.0916	0.1878	1.0000

Note: Table 2 reports the correlation between the dependent variable interest rate i and five independent variables.

An even lower correlation coefficient exists for the deviation $Log(y/\bar{y})$ in the real GDP at 0.1473. This low correlation suggests that the deviation $Log(y/\bar{y})$ in the real GDP has a weak relationship with the interest rate i. Thereafter follows the deviation $Log(m/m_\tau)$ in the money supply with an even lower correlation coefficient at 0.0875. In that regard, Conrad (2021) argues that the interest rate i decreases in the money supply m. This low correlation coefficient may be explained by the net effect of the money supply m. First, the money supply rule implies a positive relationship between the money supply m and the interest rate i, as Ascari and Ropele (2013) suggest. Second, and in contrast, the interest rate i is the price of the money supply m from the supply and demand perspective. Hence when the money supply m increases, the interest rate i decreases (Carr and Smith, 1972). Therefore, the net effect of the money supply m on the interest rate i may be moderate. Noticeably, the deviation $Log(y/\bar{y})$ in the real GDP has a high correlation coefficient with the deviation $\bar{u}-u$ in the unemployment rate at 0.8847.

4.2. Analysis

This analysis investigates the statistical linear relationship between the dependent variable interest rate i and five independent variables as in Equation (4),

$$i = \beta_0 + \beta_1(\pi - \pi^*) + \beta_2 Log\left(\frac{y}{\bar{y}}\right) + \beta_3 Log\left(\frac{m}{m_\tau}\right) + \beta_4 v + \beta_5(\bar{u} - u), \quad (4)$$

where β_0 is the constant intercept term, $\pi - \pi^*$ is the deviation in the inflation rate, $Log(y/\bar{y})$ is the deviation in the real GDP, $Log(m/m_\tau)$ is the deviation in the money supply, v is the money velocity, and $\bar{u}-u$ refers to the deviation in the unemployment rate. The article enriches the regression analysis by removing the most insignificant independent variables. The significance level 1% is applied. Table 3 shows the results. The null hypothesis is the regression coefficient $\beta_\mathrm{i} = 0$ for $i = 0,1,\dots 5$, which implies no significant statistical relationship between the dependent variable and the independent variables.

Table 3. Regression results for the interest rate

	(1)	(2)	(3)	(4)	(5)
$\pi - \pi^*$	0.9561*** (0.0414)	0.8690*** (0.0384)	0.9389*** (0.0421)	0.8362*** (0.0399)	0.8565*** (0.0391)
$Log\left(\frac{y}{\bar{y}}\right)$	0.3830*** (0.103)	0.1534 (0.0973)	-0.1969 (0.1900)	-0.6188*** (0.1870)	
$Log\left(\frac{m}{m_\tau}\right)$		0.2065*** (0.0467)		0.2486*** (0.0504)	0.2170*** (0.0455)
v		0.0594*** (0.0042)		0.0621*** (0.0044)	0.0588*** (0.0040)
$\bar{u} - u$			0.4081*** (0.1070)	0.5389*** (0.1040)	0.1997*** (0.0572)
Intercept	0.0327*** (0.0009)	-0.0847*** (0.0088)	0.0328*** (0.0009)	-0.0919*** (0.0092)	-0.0837*** (0.0081)
N	735	735	735	735	735
Adj. R-squared	0.5383	0.6217	0.5450	0.6334	0.6277

Notes: The numbers are the regression coefficients. Standard errors are in parentheses. *, **, and *** denote significance levels at 10%, 5%, and 1%, respectively. The dependent variable is the interest rate i in regressions (1)-(5). Adj. R-squared expresses the adjusted R-squared, which shows the percentage of variation explained by the independent variables that affect the dependent variable.

Regression (1) represents the result when the interest rate i is the dependent variable, and $\pi - \pi^*$ and $Log(y/\bar{y})$ are two independent variables. This regression resembles the Taylor (1993) rule. Notably, the regression coefficients for $\pi - \pi^*$ and $Log(y/\bar{y})$ are positive and statistically significant at the 1% significance level.

Regression (2) represents the result when the interest rate i is the dependent variable, and $\pi - \pi^*$, $Log(y/\bar{y})$, $Log(m/m_\tau)$ and v are four independent variables. Since the deviation

$Log(m/m_\tau)$ in the money supply and the money velocity v are added to the Taylor (1993) rule, Regression (2) represents the combination of the Taylor (1993) rule and the Quantity Equation (Friedman, 1970). Again, the regression coefficients for the four independent variables are positive, where $\pi - \pi^*$, $Log(m/m_\tau)$ and v are significant at the 1% significance level. $Log(y/\bar{y})$ is nevertheless insignificant.

Regression (3) represents the result when the interest rate i is the dependent variable, and $\pi - \pi^*$, $Log(y/\bar{y})$, and $\bar{u} - u$ are three independent variables. Since the deviation $\bar{u} - u$ in the unemployment rate is added to the Taylor (1993) rule, Regression (3) represents the combination of the Taylor (1993) rule and the Phillips (1958) curve. As in regression (2), $Log(y/\bar{y})$ is insignificant with a p-value above 10%. The coefficient sign in Regression (3) is negative for $Log(y/\bar{y})$, in contrast to positive coefficients in Regressions (1) and (2). The other two independent variables, $\pi - \pi^*$ and $\bar{u} - u$, are positive and significant at the 1% level.

Regression (4) represents the result when the interest rate i is the dependent variable, and $\pi - \pi^*$, $Log(y/\bar{y})$, $Log(m/m_\tau)$, v, and $\bar{u} - u$ are five independent variables. Regression (2) incorporates the deviation $Log(m/m_\tau)$ in the money supply, the money velocity v, and the deviation $\bar{u} - u$ in the unemployment rate. It represents the combination of the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. All five independent variables are statistically significant at the 1% significance level. The coefficient for $Log(y/\bar{y})$ is significant and negative at the 1% significance level.

We further test the potential problem of multicollinearity among the variables in Regression (4). The estimation of the VIF (variance inflation factor) for $Log(y/\bar{y})$, $\bar{u} - u$, $Log(m/m_\tau)$, v, and $\pi - \pi^*$ gives 4.91, 4.89, 1.61, 1.58, and 1.19, respectively, with an average of 2.83. The VIFs for Regression (3) with respect to $\bar{u} - u$, $Log(y/\bar{y})$, and $\pi - \pi^*$ are 4.71, 4.65, and 1.03, respectively. The VIF estimates the severity of the multicollinearity problem in a regression analysis with the ordinary least squares estimation method. Generally, a VIF above 10 expresses a high degree of multicollinearity. A more conservative opinion is that a VIF above 2.5 indicates multicollinearity. According to Table 2, a high correlation coefficient of 0.8847 exists between $Log(y/\bar{y})$ and $\bar{u} - u$. The coefficient sign for $Log(y/\bar{y})$ changes from positive to negative from Regression (2), which contains $Log(y/\bar{y})$ but not $\bar{u} - u$, to Regressions (3) and (4), which contain both $Log(y/\bar{y})$ and $\bar{u} - u$. This suggests a multicollinearity issue in Regressions (3) and (4). Therefore, among $Log(y/\bar{y})$ and $\bar{u} - u$, we remove the independent variable with the highest VIF ($Log(y/\bar{y})$) in Regression (4) and run the regression again. The result is Regression (5), where the VIFs for $Log(m/m_\tau)$, $v, \pi - \pi^*$, and $\bar{u} - u$ are 1.54, 1.51, 1.15, and 1.05, respectively, with an average of 1.31. Findings suggest no multicollinearity concern in Regression (5).

4.3. Discussion and limitations

The regression analysis results in Table 3 suggest a positive impact of $\pi - \pi^*$, $Log(y/\bar{y})$, $Log(m/m_\tau)$, v and $\bar{u} - u$ on the interest rate i. In this article, we begin with the regression analysis illustrating the Taylor (1993) rule, then combine the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve. The multicollinearity issue is tested and addressed. Finally, Regression (5) presents a statistically significant result. Based on Regression (5), the coefficient for $\pi - \pi^*$ is statistically significant and positive at 0.8565, which indicates that the deviation $\pi - \pi^*$ in the inflation rate is essential for the interest rate i. The coefficient for $Log(y/\bar{y})$ is also found to be significant and positive at 0.3830 in Regression (1). However, $Log(y/\bar{y})$ is removed in Regression (5) due to multicollinearity, in contrast with Regressions (3) and (4). The result supports the Taylor (1993) rule, which confines attention to $\pi - \pi^*$ and $Log(y/\bar{y})$. The combination of the Taylor (1993) rule and the Quantity Equation (Friedman, 1970) explains interest rate i better, since the adjusted R-squared increases from 0.5383 in Regression (1) to 0.6217 in Regression (2). The second highest coefficient in Regression (5) is $Log(m/m_\tau)$ at 0.2170. This finding suggests that the deviation $Log(m/m_\tau)$ in the money supply is an important indicator for the interest rate i. The coefficients for $\bar{u} - u$ and v in Regression (5) are positively significant under the 1% level at 0.1997 and 0.05878, respectively. Hence the best combination of the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve is reported in Regression (5), which explains the interest rate i in a superior manner with the adjusted R-squared at 0.6277.

During the study period, the Federal Reserve adopts different operating procedures with respect to the federal funds rate, for example, free-reserves targeting, federal-funds-rate targeting, and non-borrowed reserves targeting, which implies different distributions for the federal funds rate. More recently, between late 2008 and late 2018 and again after March 2020, the Federal Reserve paid interest on both required and excess reserves at a rate at the top of its target range for the federal funds rate. The consequence is the virtual elimination of lending in the federal funds market by private banks (Afonso and Jalles, 2013; Bech and Klee, 2011) and a gradual drying up of that market (Dutkowsky and VanHoose, 2017) except for some borrowing of excess reserves from government-sponsored institutions like the Federal Home Loan Banks, the Federal National Mortgage Association, and the Federal Home Loan Mortgage Corporation by private banks that then held the funds on reserve at the Fed at the higher interest rate on reserves. One limitation is that the article mainly applies the central bank interest rate and does not account for what the central bank actually does. This article investigates the interest rate by extending the Taylor (1993) rule. The prediction is a recommendation or a reference for the central bank. This article finds an interest rule that explains the empirical interest rates better than the Taylor (1993) rule.

Another limitation is that the analysis has not explored the underlying mechanisms and the interactions between the five independent variables. Other potential limitations are the linear relationship assumption implicit in regression analysis and whether the independent variables are independent of each other.

5. Discussion

This article combines the Taylor (1993) rule, the Quantity Equation (Friedman, 1970), and the Phillips (1958) curve to explore the variables which may influence the interest rate. Correlation and regression analyses are adopted to show how these variables interact with the interest rate. The article uses empirical data for the United States. The Pearson correlation coefficients suggest that the deviation in the inflation rate, the deviation in the real GDP, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate are positively correlated with the interest rate. The highest Pearson correlation with the interest rate occurs for the deviation in the inflation rate, followed by the money velocity, the deviation in the unemployment rate, the deviation in the real GDP, and the deviation in the money supply. This ranking from high to low of the correlation coefficients between the interest rate and the five independent variables illustrates the focus variables that interact with the interest rate.

Regression analysis specifies that the deviation in the inflation rate and the deviation in the real GDP are statistically positive and interact with the interest rate. This finding is consistent with the Taylor (1993) rule. Second, the interest rate increases with the money supply and the money velocity. This connection is illustrated by combing the Taylor (1993) rule and the Quantity Equation (Friedman, 1970). Third, multicollinearity is present between the deviation in the real GDP and the deviation in the unemployment rate. Thus, the deviation in the real GDP is removed. Fourth, the interest rate also increases with the deviation in the unemployment rate, which is in line with the Phillips (1958) curve. Final regression suggests that the deviation in the inflation rate, the deviation in the money supply, the money velocity, and the deviation in the unemployment rate are good interest rate indicators. The Pearson correlation and regression analysis contribute to understanding how the five independent variables impact the interest rate. The findings are relevant to how central banks choose interest rate policies.

Future research may explore more comprehensibly potential indirect impact paths for how the five independent variables impact each other and the interest rate and include more variables. Some variables may be operationalized differently, e.g., the potential real GDP, the real equilibrium interest rate, and the natural unemployment rate. Variation and uncertainty in the variables may be accounted for, while a systematic comparison of the data for more countries and different periods is another future research direction.

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Appendix

Table A1. Nomenclature

i	Interest rate, $i \in \mathbb{R}$
π	Inflation rate, $\pi \in \mathbb{R}$
π^*	Target inflation rate, $\pi^* \in \mathbb{R}$
r^*	Equilibrium real interest rate, $r^* \in \mathbb{R}$
a_π	Constant
a_y	Constant
Log	The logarithm with base ten
y	Real GDP (Gross Domestic Product), $y \geq 0$
$\bar{y}$	Real potential GDP, $\bar{y} \geq 0$
m	Money supply, $m > 0$
m_τ	Money supply at some earlier point in time, $m_\tau > 0$
v	Money velocity, $v \geq 0$
$t \geq 0$	Volume of transactions
u	Unemployment rate, $u \geq 0$
$\bar{u}$	Natural unemployment rate, $\bar{u} \geq 0$
gW	Growth rate of money wages, $gW \geq 0$
gW^T	Growth trend rate of money wages, $gW^T \geq 0$