

Asymmetric Impacts of Inflation on the US Bond Rates and FED's Pre-Emptive Policy

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ABSTRACT: This study investigates the asymmetric impacts of changes in inflation rates on the US bond rates. This investigation is constructed on the Fisher Equation. To this end, the nonlinear ARDL model is applied. Empirical findings indicate that only the decreases (π_t^-) in inflation rates affect bond rates. This asymmetric impact therefore shapes the FED's monetary policy in terms of determining the bond rates at lower cost. When the inflation rate rises, the FED will know (in advance) that they do not need to increase the bond rates. This reminds us the FED's former *pre-emptive strike* policy against inflation.

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Keywords: Fisher Effect, Nonlinear and Linear ARDL Models, The FED, Pre-emptive Strike.

1 Introduction

For over 80 years, researchers have evaluated the link between interest rates and inflation. The empirical testing of this relationship dates back to Irving Fisher's study entitled *The Theory of Interest*¹. According to Fisher (1930), nominal interest rates incorporate the

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¹For the detailed information about the Fisher Effect, see *The Theory of Interest* (Fisher, 1930).

expected inflation rates, without affecting the real interest rates. Fisher (1930) came to this conclusion after his findings exhibited remarkably high coefficients of correlation between nominal interest rates and inflation rates between 1890 and 1927 (for the USA), and 1820 and 1924 (for the UK). Fisher (1930) postulates this relationship as a *one-to-one* long-run relationship running from expected inflation rates to interest rates, where interest rates closely follow price changes. This relationship, coined as the “Fisher effect”, has since become a special matter of interest to economists and monetary authorities, due to the fact that the absence or presence of this link is crucially important for macroeconomic decisions.

The aim of this study is to approach-examine the Fisher effect from a different methodological perspective based on nonlinear relationship between inflation and interest rates for the US. The rationale of the nonlinear (asymmetric) approach is that rising uncertainties in the economies and asymmetric information problem in financial markets can easily cause asymmetric (nonlinear) behaviors-decisions by the economic actors which are lenders, borrowers, and central banks. We believe that this nonlinear approach may make our study different from previous empirical studies. Moreover, with this approach, we hope to be able to analyze these asymmetric effects based on the Fisher effect. The expected empirical findings of this study will provide very useful information to the FED to manage its monetary policy proactively.

2 Literature Review

Since the publication of Fisher’s (1930) seminal findings, many scholars have empirically tested this relationship and have found inconclusive evidence of the validity of the Fisher effect. For instance, Peláez (1995) used cointegration analysis for the USA and found no evidence of the Fisher effect. Lee et al. (1998) and Chen (2015) applied Granger causality tests and found evidence of the Fisher effect for the US and China respectively. Ghazali and Ramlee (2003) tested the Fisher effect using Autoregressive Fractionally Integrated Moving Average (ARFIMA) model for G7 countries, including the USA. They found no evidence supporting this effect between interest rates and inflation rates. Edirisinghe et al. (2015) used the co-integration technique and error correction model (ECM) for Sri Lanka and found no evidence of the Fisher effect for this country. Clemente et al. (2017) tested the Fisher effect using Bai–Perron procedure for G-7 countries. They found weak evidence of the Fisher effect between nominal interest rates and inflation rates. Ito (2016) applied the co-integration technique for Sweden and identified the Fisher effect only for 2, 3, 4, 5- and 7-year bonds rates, and not for 10-year bonds.

These results, however, were challenged by those of other studies. For instance, Mishkin (1991), Mishkin and Simon (1995) and Incekara et al. (2012) used cointegration analyses and found the evidences of the Fisher effects for for the US, Australia and Turkey respectively. Crowder and Hoffman (1996) and Weidmann (1997) used vector er-

ror correction (VEC) and found the evidence of the Fisher effect for the US and Germany respectively. Malliaropoulos (2000) tested the Fisher effect using the VEC and Vector Autoregressive (VAR) models for the USA and found the evidence supporting Fisher effect between interest rates and inflation rates in the long run. Wong and Wu (2003) used ordinary least squares (OLS) and instrumental variables regression estimates for G7 countries. They obtained the evidence of the Fisher effect between long-horizon nominal stock returns and expected inflation rates. Berument and Jelassi (2002) investigated the Fisher effect for 26 both developed and developing countries by applying the instrumental variable method between Treasury bills rates and inflation rates. They discovered that the Fisher effect holds more for the developed countries than the developing ones. Million (2004) tested this relationship for the USA, using the Threshold Autoregressive (TAR) test and produced evidence supporting the Fisher effect between nominal interest rates and inflation rates. Toyoshima and Hamori (2011) tested the Fisher effect for the USA, the UK and Japan and found evidence of the Fisher effect between short and long-term nominal interest rates and inflation rates. Adegboyega et al. (2013) tested the Fisher effect with the autoregressive distributed lag (ARDL) model and found partial effect for Nigeria. Yaya (2015) used the co-integration technique for ten African countries and found the Fisher effect only for Kenya. Cai (2018), using the quantile cointegration technique, found the Fisher effect for the US.

There are, of course, many reasons, such as structural breaks in the time series, sample period, sample size, the methodology and appropriate (cointegration) tests, etc., which can cause such ambiguity in the verification of validity of the Fisher effect. One of them can stem from the assumption that the relationship between interest rate and inflation is linear (symmetric), which means that an increase in the inflation rate raises the nominal interest rate, while a decrease reduces it. This relationship, however, can potentially be nonlinear (asymmetric). What follows is that both increases and decreases in inflation rates may affect the nominal interest rate differently (asymmetrically). This study attempts to address the issue of the Fisher effect following this methodological approach, which may be beneficial to our understanding of how increases and decreases in inflation rates affect the nominal interest rates separately in terms of Fisher effect. In this study, the Fisher effect is tested for different maturity US interest rates. In addition, by applying this approach, we hope to be able to determine whether these increases and decreases in inflation rates have symmetric or asymmetric effects on nominal interest rates (see Empirical Methodology). Another potential output of adopting this approach is that it may provide us with mathematical values to describe and introduce a different version of partiality for the Fisher effect.

The rest of this study is divided into three sections. Section 3 explains the empirical methodology. Section 4 provides empirical results of the study. Section 5 presents concluding remarks as well as offers possible recommendations for further research. It also draws conclusions for FED's monetary policy.

3 Empirical Methodology

In order to test the Fisher effect, we use the most common form of the Fisher equation.

$$i_t = r_t^e + \pi_t^e + \varepsilon_t \quad (1)$$

where i_t is the nominal interest rate, r_t^e is the *ex-ante* real interest rate, π_t^e is the expected inflation rate and ε_t is the error term. Lenders during the life of a loan are expected to require nominal interest rates to avoid the eventual loss in their purchasing power caused by the expected inflation rate. Thus, with the absence of money illusion, the expected inflation rate should be fully transmitted to the nominal interest rate, so that r_t^e is approximately constant in the long run. Under the assumption of rational expectations, the Fisher equation can now be written in the following form since the expected inflation rate equals the current inflation rate ($\pi_t^e = \pi_t$):

$$i_t = \alpha + \beta\pi_t + \varepsilon_t \quad (2)$$

Here, in the common linear representation form of the Fisher equation, if $\beta=1$ it means that the nominal interest rate has a *one-to-one* relationship with the inflation rate, which implies a full Fisher effect in the long run. If β is greater² or less³ than 1, there is a partial Fisher effect. The positive sign of β means that an increase in the inflation rate raises the nominal interest rate, while a decrease reduces it, supporting a full or partial Fisher effect. The interest rates, used in our study, are Federal Funds rates, 3-month Treasury bill rates, 1-year, 5-year and 10-year treasury bonds rates. The sample period of the study ranges from 1985Q1 to 2019Q3, which is the most recent data set. What is more, we use quarterly data in order to reduce the volatility. The data of quarterly nominal interest rates were obtained from the database of the Federal Reserve Bank of St. Louis (FED). The rates of quarterly inflation were measured by GDP implicit price deflator (2010=100). The data of GDP deflator were obtained from IMF Data Planet. It should be noted that additional control variables in the models may provide more accurate empirical results. Our empirical model, however, was based on testing the *Fisher effect* specifically (see Eqn. 2). Therefore, we did not incorporate any control variables in our model.

The econometric methodology of this study differs from the previous studies which use

²Darby-Feldstein or tax-adjusted effect (Darby, 1975; Feldstein, 1976) implies that β is greater than 1. This is due to the fact that when the nominal interest rates are taxed, the changes in nominal interest rates adjust higher than the changes in expected inflation to maintain the constant ex-ante real interest rate.

³Mundell-Tobin effect (Mundell, 1963; Tobin, 1965) implies that β is less than 1 since lenders shift from nominal to real assets when there is an increase in expected inflation.

Note: Apart from Fisher effect, Wicksell price effect (Wicksell, 1907) implies that the sign of β is to be negative. This is due to the fact that if the interest rate is less than natural interest rate, inflation is likely to arise, and if the interest rate exceeds the natural rate, this should cause deflation. Contrary to Fisher effect, changes in inflation follow the changes in interest rates in Wicksell' (1965) price effect.

the form of Fisher equation in Eqn. 2. The nonlinear ARDL model, recently introduced by Shin et al. (2014), enables us to decompose inflation rates (π_t) as π_t^+ (increases in inflation rates) and π_t^- (decreases in inflation rates) as two new variables derived from π_t . Therefore, we are able to examine the Fisher effect both in π_t^+ and π_t^- separately. It should also be noted that both linear and nonlinear ARDL models provide advantage by tracing the evaluation/adjustment from the short-run impacts/deviations (following disturbances) to the long-run value, using the dynamic multiplier effects (as in Shin et al. (2014)). Decomposed π_t^+ and π_t^- are constructed with the concept of partial sum process in the following way:

$$\pi_t^+ = \sum_{j=1}^t \Delta\pi_j^+ = \sum_{j=1}^t \max(\Delta\pi_j, 0) \tag{3}$$

$$\pi_t^- = \sum_{j=1}^t \Delta\pi_j^- = \sum_{j=1}^t \min(\Delta\pi_j, 0) \tag{4}$$

where π_t^+ and π_t^- are the partial sum process of increases and decreases in π_t ⁴. After the decomposition process, we first present the model in Eqn. 2 in accordance with the linear ARDL model by Pesaran et al. (2001), since the nonlinear ARDL model asymmetrically extends this model under nonlinearity and asymmetry.

$$\Delta i_t = \alpha_0 + \sum_{j=1}^p \alpha_{1j} \Delta i_{t-j} + \sum_{j=0}^q \alpha_{2j} \Delta \pi_{t-j} + \alpha_3 i_{t-1} + \alpha_4 \pi_{t-1} + \varepsilon_t \tag{5}$$

In Eqn. 5, while the short-run effects of the changes in inflation rates on nominal interest rates are considered by the sign and significance of α_{2j} , the long-run effects are considered by the sign and significance of α_4 . The Fisher effect is supported both in the short and in the long run if α_{2j} and α_4 are significantly positive.

In the next step, we pursue the methodology by Shin et al. (2014) and transform the linear model in Eqn. 5 into the following nonlinear ARDL model (see Eqn. 6) with two new variables as π_t^+ and π_t^- derived from π_t . The nonlinear model adds the nonlinearity or asymmetry to the relationship between nominal interest rates and movements in inflation both in the short and in the long run by reserving all merits of the linear model.

$$\Delta i_t = \alpha_0 + \sum_{j=1}^p \alpha_{1j} \Delta i_{t-j} + \sum_{j=0}^q \alpha_{2j} \Delta \pi_{t-j}^+ + \sum_{j=0}^n \alpha_{3j} \Delta \pi_{t-j}^- + \alpha_4 i_{t-1} + \alpha_5 \pi_{t-1}^+ + \alpha_6 \pi_{t-1}^- + \varepsilon_t \tag{6}$$

In Eqn. 6, the short-run effects of increases (π_t^+) and decreases (π_t^-) in inflation rates on nominal interest rates are considered separately by the signs and significances of α_{2j} and α_{3j} respectively. On the other hand, long-run effects are considered by the signs and significances of α_5 and α_6 . While the short-run Fisher effect is supported if α_{2j} and α_{3j}

⁴ π_t^+ and π_t^- are the cumulative sum of positive (increases) and cumulative sum of negative (decreases) in π respectively.

are significantly positive, the long-run Fisher effect is supported if α_5 and α_6 significantly positive. Decisions of partial and full Fisher effects will be determined by comparing these two new variables' estimated coefficients with 1 (denoting a *one-to-one* relationship by Fisher (1930)). For instance, if $\alpha_5 = \alpha_6 = 1$, then full Fisher effect in the long run is supported. On the other hand, if α_5 and $\alpha_6 \neq 1$, it supports a partial Fisher effect in the long run. The positive signs of α_{2j} , α_{3j} , α_5 and α_6 signify the *same directional relationships* with i_t (nominal interest rate). For instance, if α_5 and α_6 are significantly positive, it means that, while an increase in inflation rate (π_t^+) raises the nominal interest rate (i_t), a decrease (π_t^-) reduces. It lends the validity of Fisher effect in the long run. This comparison is the same for the short-run Fisher effect between α_{2j} and α_{3j} .

In addition, the nonlinear ARDL model enables us also to understand whether increases (π_t^+) and decreases (π_t^-) in inflation rates have symmetric or asymmetric effects on nominal interest rates. In order to formally decide between symmetry or asymmetry, we apply Wald test for the short (W_{SR}) and for the long run (W_{LR}). The insignificant coefficient of long-run Wald test (W_{LR}) confirms that changes in inflation rates have symmetric effects on the bond rates in the long run since we cannot reject the null hypothesis of $\pi_t^+ = -\alpha_5/\alpha_4 \neq \pi_t^- = -\alpha_6/\alpha_4$. On the other hand, a significant coefficient of short-run Wald test (W_{SR}) confirms asymmetric effects since we can reject the null hypothesis of $\sum_{j=0}^q \alpha_{2j} \Delta \pi_t^+ \neq \sum_{j=0}^n \alpha_{3j} \Delta \pi_t^-$. Furthermore, the structure of the nonlinear ARDL model with its decomposed variables may also mathematically enable us to describe and introduce different version of the partial Fisher effects in the long run, if either $-\alpha_5/\alpha_4$ or $-\alpha_6/\alpha_4$ is significantly positive. For instance, significantly positive $-\alpha_5/\alpha_4$ will imply that an increase in inflation rate will lead to an increase in the nominal interest rate, supporting the validity of a partial Fisher effect in the long run unilaterally (partially) by π_t^+ . Similarly, if $-\alpha_6/\alpha_4$ is significantly positive, it will imply that a decrease in the inflation rate will lead to a decrease in the nominal interest rate also supporting the validity of a partial Fisher effect in the long run unilaterally (partially) by π_t^- . Here, the concept of partiality is considered-interpreted with unilateral-singular effects of π_t^+ and π_t^- separately on the nominal interest rates in an individual parametric manner. In this study, when analyzing decisions of partial and full Fisher effects, 1 is also used as a threshold parameter proposed by Fisher as a *one-to-one* relationship.

4 Empirical Results

This section of the current paper presents descriptive statistics relevant to the study (see Table 1).

Before running the model, in order to determine whether the series are stationary, Ng and Perron (2001) unit root test mitigating the *size distortion* problems of Phillips-Perron (PP) test is applied. The results are presented in Table 2.

The test results indicate that the series are stationary at different levels (see Table 2).

Table 1: Descriptive Statistics

	$i_{(1)}$	$i_{(2)}$	$i_{(3)}$	$i_{(4)}$	$i_{(5)}$	π	π^+	π^-
Mean	3.7	3.5	3.8	4.7	5.3	2.2	-7.1	5.8
Median	3.9	3.7	3.9	4.8	5.1	2.0	-6.7	4.9
Maximum	9.7	8.9	9.4	11.2	11.6	4.1	-0.4	12.9
Minimum	0.1	0.0	0.1	0.7	1.6	0.2	-14.0	0.0
Std. Dev.	2.8	2.7	2.7	2.6	2.4	0.8	4.1	3.7
Skewness	0.2	0.1	0.1	0.2	0.3	0.4	-0.2	0.3
Kurtosis	1.8	1.7	1.8	2.0	2.3	2.8	1.8	1.8
Jarque-Bera	8.9	9.1	8.7	5.9	5.2	3.0	9.2	9.7
Probability	0.0	0.0	0.0	0.1	0.1	0.2	0.0	0.0
Sum	487.4	459.1	500.6	628.7	699.8	292.0	-950.3	773.3
Sum Sq. Dev.	1062.8	943.1	995.8	879.8	730.7	87.8	2166.1	1770.5
Observations	144	144	144	144	144	144	144	144

Table 2: Ng-Perron Unit Root Test Results

Variable	Ng-Perron test statistics			
	MZ_a	MZ_t	MSB	MPT
$i_{(1)}$	-2.63	-1.02	0.38	8.81
$i_{(2)}$	-0.74	-0.44	0.60	21.14
$i_{(3)}$	-0.86	-0.50	0.58	19.66
$i_{(4)}$	0.15	0.14	0.90	48.95
$i_{(5)}$	0.63	0.85	1.34	111.64
π	-13.19**	-2.49**	0.18**	7.31
π^+	1.83	2.12	1.16	107.53
π^-	1.62	2.79	1.71	218.48
$\Delta i_{(1)}$	-16.36***	-2.81***	0.17***	1.67***
$\Delta i_{(2)}$	-20.41***	-3.19***	0.15***	4.46
$\Delta i_{(3)}$	-12.90**	-2.53**	0.19**	7.06
$\Delta i_{(4)}$	-17.48***	-2.94***	0.16***	5.25
$\Delta i_{(5)}$	-28.35***	-3.75***	0.13***	3.25*
$\Delta \pi^+$	-9.68**	-2.19**	0.22**	2.53**
$\Delta \pi^-$	-7.47*	-1.92*	0.25*	3.29*
	Critical Values			
1%	-13.80	-2.58	0.17	1.78
5%	-8.10	-1.98	0.23	3.17
10%	-5.70	-1.62	0.27	4.45

Note: ***, ** and * denote statistical significances at 1%, 5% and 10% levels respectively. The optimal lags were automatically selected by using the Modified Akaike Information Criterion. Δ denotes the first differences of the series. The numbers in parentheses are the codes of interest rates in different maturities: (1): Federal Funds rates, (2): 3-months treasury bill rates, (3): 1-year treasury bond rates, (4): 5-year treasury bond rates and (5): 10-year treasury bond rates.

Therefore, it is necessary to apply bounds testing to understand whether the series are cointegrated. The test results of bounds testing for the linear and nonlinear models are reported in Panel A and B in Table 3.

The critical values, tabulated by Pesaran et al. (2001), are shown in Table 3 for the linear and nonlinear models. Our calculated statistics exceed the upper bounds at 1%, 5%

or 10% significances in both linear and nonlinear models. Hence, the empirical results of the linear and nonlinear ARDL models indicate that series are cointegrated. The long-run and short-run estimates of linear ARDL model and diagnostic statistics are reported in Panels A and B in Table 4.

The test results of Panel A in Table 4 for the linear ARDL model support partial Fisher effects only for 5 and 10-year bonds rates in the long run since their estimated coefficients are significantly positive and lower or higher than 1. However, 5-year bond rates respond to the changes in inflation rates more than 10-year ones. Therefore, error correction mechanism of the models works since ECT is significant. On the other hand, the empirical results in Panel B support partial Fisher effects for all interest rates in the short run. The pattern of different size partial Fisher effects starting from the Federal Funds rates to the 10-years treasury bond rates resembles a letter of “U” in the short-run (for Δi_{t-1}). The nonlinear ARDL model and diagnostic statistics are reported in Table 5.

The test results in Table 5 for the nonlinear ARDL model support long-run partial Fisher effects for only Federal Funds rates (1) since its estimated coefficient is significantly positive and lower or higher than 1. However, the new version of partial Fisher effect, described and introduced in this study, also support partial Fisher effects for 3-month treasury bill rates (2), 1-year treasury bond rates (3), 5-year treasury bond rates (4) and 10-year treasury bond rates (5) in the long run. This is because the estimated coefficients of either π_t^+ or π_t^- are significantly positive. This technical determination may be considered a significant contribution to the literature of the partial Fisher effect. Moreover, while increases (π_t^+) in inflation rates do not affect these bond rates, decreases (π_t^-) do. 10-year treasury bond rates (5) respond to the changes in inflation the most (1.27). Consequently, comparative results of both models indicate that nonlinear ARDL model detects partial Fisher effects more than the linear ARDL model does in the long-run.

In addition, significant long-run (W_{LR}) Wald statistics in Table 5 confirm that increases (π_t^+) and decreases (π_t^-) in inflation rates have asymmetric effects on all bonds rates (except Federal funds rates (1)) since $\pi_t^+ = -\alpha_5/\alpha_4 \neq \pi_t^- = -\alpha_6/\alpha_4$. Furthermore, the significant short-run Wald test (W_{SR}) statistics confirm asymmetric effects since $\sum_{j=0}^q \alpha_{2j} \Delta \pi_t^+ \neq \sum_{j=0}^n \alpha_{3j} \Delta \pi_t^-$.

5 Conclusion

In this study, we applied the nonlinear ARDL model, developed by Shin et al. (2014). This model allowed us to decompose the changes in inflation rates as two new variables derived from the original inflation series. Therefore, it enabled us to analyze the Fisher effect both in terms of increases and decreases in inflation rates separately. This decomposition also helped us to understand whether increases and decreases in inflation rates had symmetric or asymmetric effects on the nominal interest rates in terms of the Fisher effect. In

addition, decomposed variables also made it possible for us to describe and introduce a different version of the partial Fisher effect based on each variable's unilateral-singular (denotes partial) effect on the nominal interest rates. Therefore, this study, through the use of the nonlinear ARDL model, addressed both the Fisher effect issue and the partiality concept from a different methodological perspective.

The empirical findings of this study indicate that the nonlinear model with the described version of partial Fisher effect discovers-detects potentially existing but concealed partial Fisher effects, which the linear model does not discover-detect. Moreover, the nonlinear model, indicates that increases (π_t^+) and decreases (π_t^-) in inflation rates have asymmetric (different) effects on the bond rates both in the long-run and short-run. It has been proved that while increases (π_t^+) in inflation rates do not affect the bond rates, decreases (π_t^-) do. What follows is that, that the US government has more power to control the bond rates when the inflation decreases. As for the FED's, these detected asymmetric and symmetric relations between the bond and inflation rates will shape the FED's monetary policy responses in terms of determining the bond rates at lower cost. When the inflation rate rises the FED will know (in advance) that they do not need to increase the bond rates. This is crucially important for the FED's pre-emptive strike against inflation.

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Table 3: Test Results of Bounds Testing

Panel A: Linear															
<i>F Bounds Test</i>															
<i>k</i>	<i>F</i> -stat.	Critical Values					<i>t</i> -stat.	<i>t Bounds Test</i>							
		I0 Bound		I1 Bound				I0 Bound		I1 Bound					
		10%	5%	1%	10%	5%	1%	10%	5%	1%	10%	5%	1%		
(1)	1	5.86	5.59	6.56	8.74	6.26	7.3	9.63	-3.43*	-3.13	-3.41	-3.96	-3.4	-3.69	-4.26
(2)	1	10.29***	5.59	6.56	8.74	6.26	7.3	9.63	-4.55***	-3.13	-3.41	-3.96	-3.4	-3.69	-4.26
(3)	1	8.44**	5.59	6.56	8.74	6.26	7.3	9.63	-4.12**	-3.13	-3.41	-3.96	-3.4	-3.69	-4.26
(4)	1	8.01**	5.59	6.56	8.74	6.26	7.3	9.63	-4.01**	-3.13	-3.41	-3.96	-3.4	-3.69	-4.26
(5)	1	16.03***	5.59	6.56	8.74	6.26	7.3	9.63	-5.68***	-3.13	-3.41	-3.96	-3.4	-3.69	-4.26

Panel B: Nonlinear															
<i>k</i>	<i>F</i> stat.	Critical Values					<i>t</i> -stat.	Critical Values							
		I0 Bound		I1 Bound				I0 Bound		I1 Bound					
		10%	5%	1%	10%	5%	1%	10%	5%	1%	10%	5%	1%		
(1)	2	5.09*	4.19	4.87	6.34	5.06	5.85	7.52	-3.94*	-3.13	-3.41	-3.96	-3.63	-3.95	-4.53
(2)	2	7.54***	4.19	4.87	6.34	5.06	5.85	7.52	-4.79***	-3.13	-3.41	-3.96	-3.63	-3.95	-4.53
(3)	2	6.37**	4.19	4.87	6.34	5.06	5.85	7.52	-4.40**	-3.13	-3.41	-3.96	-3.63	-3.95	-4.53
(4)	2	6.08**	4.19	4.87	6.34	5.06	5.85	7.52	-4.30**	-3.13	-3.41	-3.96	-3.63	-3.95	-4.53
(5)	2	9.01***	4.19	4.87	6.34	5.06	5.85	7.52	-5.24***	-3.13	-3.41	-3.96	-3.63	-3.95	-4.53

Note: *k* is the number of regressors. ***, ** and * denote cointegration at the 1%, 5% and 10% significance levels. The numbers in parentheses are the codes of interest rates in different maturities: (1): Federal Funds rates, (2): 3-months treasury bill rates, (3): 1-year treasury bond rates, (4): 5-year treasury bond rates and (5): 10-year treasury bond rates.

Table 4: The Estimates of Linear ARDL Model

Var.	(1)		(2)		(3)		(4)		(5)	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
π_t	0.55	0.35	-0.10	0.37	-0.11	0.77	0.47*	0.08	0.35**	0.00
Panel A: Long-Run										
$\Delta\theta_{t-1}$	0.64***	0.00	0.58***	0.00	0.51***	0.00	0.38***	0.00	0.45***	0.00
$\Delta\theta_{t-2}$	-	-	0.02	0.78	-0.07	0.42	-0.10	0.21	-0.04	0.63
$\Delta\theta_{t-3}$	-	-	0.22**	0.02	0.30***	0.00	0.23***	0.00	0.22***	0.00
$\Delta\theta_{t-4}$	-	-	-0.10	0.28	-0.14	0.13	-	-	-	-
$\Delta\theta_{t-5}$	-	-	0.04	0.67	0.18*	0.06	-	-	-	-
$\Delta\theta_{t-6}$	-	-	0.20**	0.02	0.13	0.13	-	-	-	-
$\Delta\pi_t$	0.28***	0.00	0.16	0.11	0.22*	0.07	0.33**	0.01	0.28**	0.01
$\Delta\pi_{t-1}$	-	-	-	-	-	-	-0.21	0.13	-	-
Constant	0.40***	0.00	0.95***	0.00	1.06***	0.00	1.42***	0.00	2.76***	0.00
ECT_{t-1}	-0.06***	0.00	-0.12***	0.00	-0.12***	0.00	-0.20***	0.00	-0.35***	0.00
Panel B: Short-Run										
R^2	0.98	-	0.98	-	0.98	-	0.97	-	0.97	-
Adj. R^2	0.98	-	0.98	-	0.98	-	0.97	-	0.97	-
DW	2.03	-	1.92	-	1.95	-	1.93	-	1.97	-
χ^2_{SC}	1.61	0.44	2.13	0.34	1.14	0.56	1.05	0.59	1.49	0.47
χ^2_{NOR}	43.79	0.00	12.86	0.00	0.46	0.79	0.55	0.75	1.56	0.45
χ^2_{HET}	27.19	0.12	82.13	0.07	86.63	0.03	47.27	0.34	46.53	0.36
EG_{MAX}	-11.76	0.00	-10.83	0.00	-10.97	0.00	-11.05	0.00	-11.21	0.00

Note: χ^2_{SC} is Breusch-Godfrey LM test for serial correlation, χ^2_{NOR} is the Jarque-Bera test for normality, χ^2_{HET} for White heteroscedasticity, EG_{MAX} is largest value of the Engle-Granger residual-based ADF test. All these additional diagnostic test results indicate that there are no evidences of serial correlation, misspecification of the optimum models and heterogeneity. The normally distributed series are cointegrated. ***, ** and * denote significance at the 1%, 5% and 10% levels. The numbers in parentheses are the codes of interest rates in different maturities: (1): Federal Funds rates, (2): 3-months treasury bill rates, (3): 1-year treasury bond rates and (5): 10-year treasury bond rates and (4): 5-year treasury bond rates.

Table 5: The Estimates of Nonlinear ARDL Model

Var.	⁽¹⁾		⁽²⁾		⁽³⁾		⁽⁴⁾		⁽⁵⁾	
	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.	Coeff.	Prob.
Constant	0.36***	0.02	1.03***	0.00	0.62**	0.01	2.32***	0.00	1.13*	0.08
i_{t-1}	-0.95***	0.00	-0.13***	0.00	-0.08***	0.00	-0.23***	0.00	-0.12*	0.09
π_{t-1}^+	0.06	0.14	0.003	0.93	0.027	0.62	0.09	0.27	0.11	0.11
π_{t-1}^-	0.07*	0.09	0.089**	0.04	0.057	0.27	0.21**	0.01	0.158	0.05
Δi_{t-1}	0.61***	0.00	0.73***	0.00	0.52***	0.00	0.34***	0.00	0.28**	0.01
Δi_{t-2}	-	-	-	-	-0.16*	0.09	-0.15*	0.09	-0.24**	0.03
Δi_{t-3}	0.21***	0.00	-0.20**	0.02	0.41***	0.00	-	-	0.04	0.73
Δi_{t-4}	-	-	-0.16*	0.06	-0.12	0.19	-	-	-0.08	0.42
Δi_{t-5}	-0.25***	0.00	-	-	0.11	0.22	-0.18**	0.03	-0.18*	0.07
Δi_{t-6}	-	-	0.52***	0.00	-	-	0.17*	0.05	0.02	0.78
Δi_{t-7}	-	-	-0.25**	0.01	-0.08	0.29	-0.25***	0.00	-0.17*	0.06
Δi_{t-8}	-	-	-	-	-	-	0.13	0.10	0.04	0.63
$\Delta \pi_t^+$	-	-	0.53**	0.01	-	-	1.03***	0.00	0.53*	0.05
$\Delta \pi_{t-1}^+$	-	-	-	-	-	-	-1.15***	0.00	-0.40	0.13
$\Delta \pi_{t-2}^+$	-	-	-	-	-	-	0.37	0.31	0.28	0.29
$\Delta \pi_{t-3}^+$	-0.34***	0.00	-	-	-	-	-0.25	0.48	0.03	0.90
$\Delta \pi_{t-4}^+$	-	-	-	-	-0.23	0.19	-	-	-0.20	0.42
$\Delta \pi_{t-5}^+$	-	-	-	-	-	-	-0.31	0.37	-0.27	0.29
$\Delta \pi_{t-6}^+$	-	-	-	-	-	-	-	-	0.14	0.58
$\Delta \pi_{t-7}^+$	-	-	-	-	-	-	0.24	0.49	-0.34	0.21
$\Delta \pi_{t-8}^+$	-	-	-	-	-0.22	0.23	-0.74*	0.05	-0.31	0.24
$\Delta \pi_t^-$	0.18	0.14	-	-	0.18	0.28	0.55*	0.08	0.41*	0.06
$\Delta \pi_{t-1}^-$	-	-	-0.34	0.10	-	-	-	-	-0.34	0.12
$\Delta \pi_{t-2}^-$	-	-	-	-	-	-	-	-	0.09	0.68
$\Delta \pi_{t-3}^-$	0.54***	0.00	-	-	-	-	-0.40	0.22	-0.33	0.15
$\Delta \pi_{t-4}^-$	-0.35***	0.00	-	-	-	-	0.89**	0.01	0.85***	0.00
$\Delta \pi_{t-5}^-$	0.40***	0.00	-	-	0.41***	0.00	0.54	0.10	-0.10	0.67
$\Delta \pi_{t-6}^-$	-	-	-	-	-	-	-0.28	0.37	0.10	0.67
$\Delta \pi_{t-7}^-$	-	-	-	-	-	-	0.56*	0.08	0.04	0.86
$\Delta \pi_{t-8}^-$	-	-	-	-	-	-	-	-	0.11	0.62
ECT_{t-1}	-0.07***	0.00	-0.11***	0.00	-0.10***	0.00	-0.15***	0.00	-0.27***	0.00

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Table 6: The Estimates of Nonlinear ARDL Model (Continued)

Var.	Normalized Long-Run Coefficients									
	(1)		(2)		(3)		(4)		(5)	
	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.	Coeff.	t-stat.
π_{t-1}^+	0.069*	1.45	0.02	0.08	0.33	0.47	0.39	1.10	0.93	1.23
π_{t-1}^-	0.76**	1.67	0.65***	2.36	0.71*	1.41	0.92***	3.08	1.27**	2.02
R^2	0.98	-	0.66	-	0.49	-	0.45	-	0.37	-
Adj. R^2	0.98	-	0.62	-	0.43	-	0.32	-	0.19	-
χ_{SC}^2	12.87	0.37§	9.72	0.64§	17.84	0.12§	12.71	0.39§	17.82	0.12§
χ_{FF}^2	0.49	0.48§	0.16	0.68§	4.40	0.03§	1.40	0.23§	0.006	0.93§
χ_{NOR}^2	42.13	0.00§	63.88	0.00§	4.69	0.09§	1.13	0.56§	3.48	0.17§
χ_{HET}^2	118.79	0.00§	115.26	0.00§	115.41	0.22§	48.53	0.00§	28.30	0.50§
W_{LR}	-0.006	-0.44#	0.63***	6.57#	0.37***	2.60#	0.53***	5.97#	0.34**	2.27#
W_{SR}	1.12***	3.63#	0.38**	2.02#	-1.05***	-2.89#	-4.03***	-3.26#	1.38*	1.41#
EG_{MAX}	-8.42***	0.00§	-7.07***	0.00§	-8.34***	0.00§	-3.38**	0.01§	-8.70***	0.00§

Note: χ_{SC}^2 is Breusch-Godfrey LM test for serial correlation χ_{NOR}^2 is the Jarque-Bera test for normality, χ_{FF}^2 is Ramsey test for functional form, χ_{HET}^2 for White heteroscedasticity, W_{LR} and W_{SR} are long and short-run Wald tests. Null hypothesis of this Wald test is symmetry. EG_{MAX} is largest value of the Engle-Granger residual-based ADF test. All these additional diagnostic test results indicate that there are no evidences of serial correlation, misspecification of the optimum models, heterogeneity. The normally distributed series are cointegrated. Normalized long-run coefficients are obtained with $\pi_t^+ = -\alpha_5/\alpha_4$, $\pi_t^- = -\alpha_6/\alpha_4$. When the normalized coefficients were calculated 6 digits were used after comma. However, the coefficients in this table are reported only in 2 digits since we have lack of space. Critical t-table values are 2.32, 1.64 and 1.28 for 1%, 5% and 10%. # denotes t-statistic. § denotes prob. value. ***, ** and * denote significance at the 1%, 5% and 10% levels. The numbers in parentheses are the codes of interest rates in different maturities: (1): Federal Funds rates, (2): 3-months treasury bill rates, (3): 1-year treasury bond rates, (4): 5-year treasury bond rates and (5): 10-year treasury bond rates.