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Reassessing Non-linearity in the Monetary Policy of Pakistan: Using Smooth Transition Regression Model

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Dr Hasan Shahzad, Umar Shahzad and Dr Abdul Saboor[*]

ABSTRACT

This study examines whether monetary policy in Pakistan responds in the same way under different economic conditions or changes when the economy moves between weak and stronger activity. Quarterly data from 1995 to 2020 are analysed through an extended Taylor Rule and a Smooth Transition Regression framework. The results show two policy regimes. When the output gap is below the estimated threshold, inflation receives greater attention from the monetary authority. When the output gap is above the threshold, the response to output conditions becomes stronger. The findings indicate that the State Bank of Pakistan's policy response is not fully symmetric and varies with the state of the economy.

Keywords: Non-linear Monetary Policy, Smooth Transition Regression Model, STR, Taylor Rule, Monetary Policy of Pakistan

JEL Classification Codes: E52, E58, C22

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1. INTRODUCTION

Monetary policy rules and their allied issues are crucial for developing economies, including how a central bank conducts its monetary policy, how it responds to deviations of inflation, whether it is concerned only about economic growth or also about other economic indicators, and whether monetary authorities consider only the standard Taylor rule or other indicators as well. The aforementioned ideas are important to take into account while talking about the monetary policy rules especially for developing economies. This discussion has always been important but gained much larger interest after the financial crises of 2008–2009. Another important motivation for a deeper understanding of monetary policy rule is to evaluate its transmission to the macroeconomic indicators. This phenomenon is important for all economies but is more important for developing economies because developing economies are associated with greater uncertainty component about the business cycles. Moreover, uncertainty regarding arrangement of macroeconomic variables is also higher in the case of developing economies. In fact, developing economies are characterised by twin problems, i.e. excess productive capacity and high inflation. Due to the greater number of indicators that affect it, the monetary policy rule is more important in developing economies (Ali et al., 2025).

Another issue in developing economies, which was known earlier but experienced during the financial crisis, is that the monetary policies of the developing economies largely depend on the developed economies. Considering these facts and past experiences it is evident that especially in developing countries, one must take into account a larger set of macroeconomic variables in order to better understand the monetary policy rule. Moreover, central banks of developing economies are dependent upon the economic situation that leads to the nonlinearity in the monetary policy (Babu and Nair 2026). In order to investigate and find the potential nonlinearity or/and asymmetry in the monetary policy rule, this study has applied smooth transition regression model (STR) to the extended Taylor rule in the case of Pakistan. Mainly, literature available in the case of Pakistan is of linear monetary policy rule/ standard Taylor rule with inflation and output gap. In the recent past, extensions of Taylor rule are being widely used in order to better capture the relationships of interest rate with other macroeconomic variables (Ma et al., 2025). Many researchers have provided evidence of nonlinear Phillips Curve. Granger et al. (1993) have provided a framework in order to capture the non-linearity in the monetary policy function i.e. Smooth Transition Regression Model. Following Jawadi et al. (2014) and Baaziz and Labidi (2016) this study has empirically assessed both linear and nonlinear type Taylor functions using different variables and has found that lagged interest rate plays an important role in the transmission mechanism of monetary policy of Pakistan.

This study is an attempt to investigate the existence or non-existence of asymmetry / non-linearity in the monetary policy function. To obtain the required results, this study has employed Smooth Transition Regression model (STR) among other prerequisite and diagnostic tests. Quarterly data of Pakistan spanning from 1995 to 2020 has been used. The

common sample ends in 2020 because the quarterly series used for the variables in the extended Taylor Rule were compiled on a consistent basis for this period.

2. LITERATURE REVIEW

Monetary policy reaction functions are commonly examined through Taylor-type rules linking the policy interest rate with inflation and the output gap. The linear form assumes a symmetric response, while the nonlinear literature allows the response of monetary authority to vary across inflationary conditions, business-cycle phases and other macroeconomic states. Earlier work has also shown that nonlinearity may arise from asymmetric policy preferences and nonlinear aggregate supply or Phillips-curve behaviour (Nobay and Peel 2000; Dolado et al., 2005; Surico 2007).

Evidence from emerging economies supports the use of nonlinear reaction functions. Jawadi et al. (2014), using quarterly data for Brazil and China, found strong evidence of non-linearity and asymmetry and showed that the variables driving monetary policy adjustment differed across the two economies. Baaziz and Labidi (2016) similarly used LSTR specifications for Tunisia and Egypt and reported that monetary policy behaviour changes with macroeconomic conditions and unexpected events. Caporale et al. (2018) also found that an augmented nonlinear Taylor rule captured monetary authority reactions across high- and low-inflation regimes more accurately than a single linear specification.

A related group of studies focuses on regime-dependent policy responses. Shen et al. (2016) found asymmetric monetary policy reactions across price regimes in China, while Ma (2016) reported that a nonlinear Taylor rule was better suited to macroeconomic stabilisation. De Medeiros et al. (2016, 2017) found nonlinearities in the reaction function of the Central Bank of Brazil, particularly when output, inflation and exchange-rate shocks were large. Tawadros (2016) also found that the Reserve Bank of Australia reacted asymmetrically to inflation and output gaps in part of the sample. Together, these studies suggest that a constant policy response may conceal changes that become visible only when regimes are allowed to differ.

The transmission literature further indicates that interest-rate effects depend on financial and external conditions. Arwatchanakarn (2017) found important roles for monetary aggregates and interest rates in Thailand, with an exchange-rate channel that remained significant. Kamber and Mohanty (2018) showed that contractionary monetary policy surprises in China raise interest rates and reduce economic activity and inflation. Aikman et al. (2016) and Argimon et al. (2019) further showed that financial vulnerabilities and institutional balance-sheet characteristics can alter the strength of monetary transmission. These findings support the inclusion of broader economic conditions when assessing the policy rule of a developing economy.

Recent evidence for Pakistan adds two issues directly relevant to the present specification. Hussain et al. (2025), using a structural VAR for Pakistan, found that inflation reflects

several shocks, with important contributions from global commodity prices, money supply, fiscal stance, exchange-rate movements and inflation expectations. This implies that the policy-rate response to inflation may differ according to the source and state of inflationary pressure. Rehman et al. (2025) showed that measurement of Pakistan's output gap is sensitive to structural change and that a production-function approach provides an alternative estimate of potential output. Their evidence reinforces the importance of treating the output gap carefully when it is used as a policy-state variable. More recently, Yousaf (2026) examined the State Bank of Pakistan's reaction function using monetary policy communications from 2015 to March 2026, extending the empirical discussion toward the information set and balance of risks considered in policy decisions.

The literature therefore provides three broad conclusions. First, monetary policy reaction functions in emerging economies are frequently nonlinear. Second, inflation and the output gap remain central variables, but their importance can change across regimes and in the presence of supply, exchange-rate and financial shocks. Third, the Pakistan literature has mainly examined linear rules, threshold specifications or alternative measures of inflation and output. There remains scope to evaluate whether the response of the State Bank of Pakistan changes smoothly between regimes within an extended Taylor Rule. This study addresses that gap by applying the STR framework and allowing the output gap to determine the transition between policy regimes.

3. MATERIALS AND METHOD

3.1. Model Specification and Non-linearity

Whenever monetary policy or its application is discussed, Taylor rule is employed to explain/assess the behaviour of monetary policy, which links the rate given by the central bank with the inflation and output gap, as mentioned below:

$$i_t^* = \bar{r} + \pi^* + \beta(\pi^t - \pi^*) + \gamma\,(y^t - y^*)$$

Under this rule, nominal short-term interest rate is considered as the monetary policy instrument. If we observe the relationships in the equation, then we can conclude that interest rate would rise if inflation is above its targeted value and it would also rise if output increased more than its trend value. β and γ shows the sensitivity of nominal short-term interest rate to the deviations from the targeted inflation and output, respectively.

The above-mentioned model has a built-in assumption that reaction of monetary authority is symmetric towards both variables i.e. inflation and output. This might not be a realistic restriction. The monetary authority might behave differently towards both variables and the deviations from their targets. If there are chances that monetary authority might behave differently to the two aggregates, then the above-mentioned rule is not a suitable model, and a non-linear type Taylor rule might outperform the standard Taylor rule. This phenomenon is important for all the economies, but it is a crucial discussion for the developing economies like Pakistan, where various factors can cause a change in the

direction of monetary authority's decisions. A smooth Transition Regression (STR) model can explain the non-linearity in the behaviour of the aggregates. An STR model can consider change in regression coefficients from one regime to another (smoothly). This model has an advantage of a better structural theoretical account explaining the reactions of monetary authority which changes with the change in the state of economy.

Extending the theoretical work done by Granger et al. (1993) and Teräsvirta (1994), a two-regime smooth transition regression model considering a non-linear Taylor rule can be written as:

$$i_t = \vartheta' y_t + \tau' y_t F(n, c, s_t) + \varepsilon_t \qquad t = 1,\ldots\ldots,T$$

In this equation y_t indicates a vector of the independent variables, which are (1, $i_{t-1},\ldots\ldots,i_{t-n}$; $\pi_{t-1},\ldots\ldots,\pi_{t-n}$; $\tilde{z}_{t-1},\ldots\ldots,\tilde{z}_{t-n}$)′. The vector ϑ indicates the linear part of the model and τ' explains the non-linear part of the model.

This transition function can further take many forms like; one order logistic smooth transition function (LSTR1), two order logistic smooth transition function (LSTR2) or exponential smooth transition regression function (ESTR).

One order logistic smooth transition regression model may be explained as follows:

$$F(n, c, s_t) = [1 + \exp\{-n(s_t - c)\}]^{-1} \; ; n > 0$$

The above-mentioned equation is monotonically increasing in s_t, where *n* gives the slope of the parameter, indicating the speed of transition between the regimes and the parameter c denotes the location parameter, that determines the threshold.

In the same manner, following Teräsvirta, logistic smooth transition function of second order is given as:

$$F(n, c, s_t) = [1 + \exp\{-n(s_t - c_1)(s_t - c_2)\}]^{-1} \qquad ; n > 0$$

where, $c=\{c_1,c_2\}$ and $c_1 < c_2$.

This model depicts that the monetary authority may not generally select a strict inflation target but it might consider a target range / band.

Third form of the non-linear model is exponential smooth transition regression model which may be explained as:

$$F(n, c, s_t) = [1 - \exp\{-n(s_t - c)^2\}] \quad ; n > 0$$

Examination of the above given equation will conclude that exponential smooth transition regression model is a special case of two order logistic smooth transition regression where $c_1 = c_2$.

Now, going towards the testing of null hypothesis of linearity against its alternate hypothesis of non-linearity, a serious and troubling issue of identification can be expected.

This identification problem can be solved by approximating the transition function using a third-order Taylor series expansion. Teräsvirta has suggested following auxiliary regression to tackle the problem of identification:

$$i_t = \beta_0' y_t + \beta_1' y_t s_t + \beta_2' y_t s_t^2 + \beta_3' y_t s_t^3 + \varepsilon_t^* \quad ; t = 1,\ldots..,T$$

where, $\varepsilon_t^*=\varepsilon_t + \omega' z_t F(n, c, s_t)$, y_t gives a vector following k*1 order of the independent variables, $\beta_j = \gamma\widetilde{\beta_j}$ and β_j isdefined in terms ofω and c. The null hypothesis is given as H_0: $\beta_1 = \beta_2 = \beta_3 = 0$ against H_1: $\beta_i \neq 0, i = 1,2,3$.

The above-mentioned hypothesis will then be tested through LM -test, having null hypothesis as given below:

$$H_0: \varepsilon_t^* = \varepsilon_t$$

Once linearity is rejected and a suitable transition variable has been selected, the last question that arises is the selection of the appropriate transition function. Following Granger et al. (1993), the decision of selecting between LSTR1 or LSTR2 model would be made by running the following auxiliary equations:

$$H_{03}: \beta_3 = 0$$

$$H_{02}: \beta_2 = 0 | \beta_3 = 0$$

$$H_{01}: \beta_1 = 0 | \beta_3 = \beta_2 = 0$$

As per the methodology developed by Granger et al. (1993) LSTR2 model will be selected if the *p*-value is the minimum value among all, otherwise LSTR1 model will be selected as an appropriate one.

3.2. Unit Root Test

Stationarity is checked before estimation because non-stationary series can produce misleading results. A series is stationary when its mean and auto-covariances do not depend on time. The study therefore applies Dickey-Fuller (Dickey and Fuller 1979) and Augmented Dickey-Fuller (Dickey and Fuller 1981) unit root tests. The ADF form is used when higher-order lags are required.

$$Y_t = Y_{t-1} + \varepsilon_t$$

$$Y_t - Y_{t-1} = (1 - L)Y_t = \varepsilon_t$$

If a series becomes stationary after first differencing, it is integrated of order one, I(1). The standard unit-root null is tested against the alternative of stationarity, as represented in the equations below.

For an AR(1) process the Dickey-Fuller form is used; for a higher-order AR(p) process the augmented form is applied.

$$Y_t = \rho Y_{t-1} + X_t \delta + \varepsilon_t$$

The parameters are estimated with the disturbance term treated as white noise.

The unit-root case implies non-stationarity, while the alternative corresponds to stationarity around the specified deterministic component.

The hypotheses and transformed regression are shown below.

$$H_0: \rho = 1$$

$$H_1: \rho < 1$$

The Dickey-Fuller test is conducted by subtracting lagged value from both sides of the AR equation, let us continue with our above-mentioned example of AR(1) series:

$$\Delta Y_t = \alpha Y_{t-1} + X_t\delta + \varepsilon_t$$

Where $\alpha = \rho - 1$, hence the hypothesis will be as:

$$H_0: \alpha = 0$$

$$H_1: \alpha < 0$$

And will be treated with the standard t-ratio test:

$$t_\alpha = \hat{\alpha} \,/\, (se(\hat{\alpha}))$$

The standard DF can be used only if series is integrated of order one i.e. AR(1), otherwise ADF is used for any higher order, like depicted below an AR(p) series:

$$\Delta Y_t = \alpha Y_{t-1} + X_t\delta + B_1\Delta Y_{t-1} + B_2\Delta Y_{t-2} + \ldots\ldots\ldots + B_p\Delta Y_{t-p} + v_t$$

3.3. BDS Test

The BDS test was presented by Brock, Dechert, Scheinkman and LeBaron (Brock et al., 1996) to check for time dependence in a series. It can also be used to check whether the error terms are independently and identically distributed (IID). For instance, this test can be applied to an Auto-regressive Moving Average series to check any non-linear dependence in its residual's series. The first step is to select a distance (k), then a pair of points are considered. If the components of the series are found to be IID, then the probability of the distance among the points will be constant, denoted by $P_1(k)$. Generally, the pairs in each set are formed from consecutive observations.

Say for a series Y containing two observations *e* and *t,* construction of set of pairs will be like:

$$\{\{X_e, X_t\}, \{X_{e+1}, X_{t+1}\}, \quad \{X_{e+2}, X_{t+2}\}, \ldots\ldots, \{X_{e+p-1}, X_{t+p-1}\}$$

Where p denotes the number of points (consecutive) in the given set and the joint probability of all pairs present in the set is shown by $P_p(\varepsilon)$.

If we follow assumption of independence, then we can conclude that this joint probability would be equal to the product of individual probabilities (of pairs). So, by assuming that observations of the set are independent then:

$$P_p(\varepsilon) = P_1{}^p(\varepsilon)$$

It implies that for a series of n observations, the probability can be given as:

$$P_{p,n}(\varepsilon) = \frac{2}{(n-m+1)(nm)} \sum_{e=1}^{n-m+1} \sum_{t=e+1}^{n-m+1} \prod_{j=0}^{m-1} I_\varepsilon \left(X_{e+j}, X_{t+j}\right)$$

Here in this above-mentioned equation, I is a function:

$$I_\varepsilon(x,y) = \begin{cases} 1 & if\ |x-y| \le \varepsilon \\ 0 & other\ wise \end{cases}$$

$$b_{m,n}(\varepsilon) = P_{m,n}(\varepsilon) - P_{1,n-m+1}(\varepsilon)^m$$

$$\left(\sqrt{n-m+1}\right)\frac{b_{m,n}(\varepsilon)}{\sigma_{m,n}(\varepsilon)} \to N(0,1)$$

$$\sigma^2_{m,n}(\varepsilon) = 4\left(k^m + 2\sum_{j=1}^{m-1} k^{m-j} P_1^{2j} + (m-1)^2 P_1^{2m} - m^2 k P_1^{2m-2} \right)$$

$$k_n(\varepsilon) = \frac{2}{n(n-1)(n-2)} \sum_{t=1}^{n} \sum_{e=t+1}^{n} \sum_{r=e+1}^{n}$$

3.4. Keenan's Test

Keenan's test (Keenan 1985) provides an additional test of linearity by approximating a stationary time series through a second-order Volterra expansion. It modifies the Ramsey RESET procedure and evaluates whether the nonlinear component is statistically different from zero.

$$X_t = \mu + \sum_{u=-\infty}^{\infty} \sum_{v=-\infty}^{\infty} \theta_u a_{t-u} + \sum_{u=-\infty}^{\infty} \sum_{v=-\infty}^{\infty} \theta_{uv} a_{t-u} a_{t-v}$$

If the nonlinear term is zero, the approximation is linear. After selecting the lag length using an information criterion, the required auxiliary regressions are estimated and the F-type statistic shown below is used to test the null of linearity.

$$\widehat{\delta_t} = \frac{\sum_{t=p+1}^{n} \widehat{a_t} \widehat{\varphi}_t}{\sum_{t=p+1}^{n} \widehat{\varphi}_t}$$

$$\hat{F} = \frac{(n-2p-2)\widehat{n^2}}{(SSR - \widehat{n^2})}$$

$$H_0 : \sum_{u=-\infty}^{\infty} \sum_{v=-\infty}^{\infty} \theta_{uv} a_{t-u} a_{t-v} = 0$$

4. RESULTS AND DISCUSSION

Quarterly data of Pakistan is used from 1995 to 2020. The main sources of data are State Bank of Pakistan (SBP), World Development Indicators (WDI), International Financial Statistics (IFS), Pakistan Stock Exchange (PSE) and Economic Survey of Pakistan. The Real Gross Domestic Product represents the economic conditions including business trends of the economy. Quarterly rates of inflation are used. The nominal policy rate of Pakistan is the instrument used by the monetary authority to achieve its objectives. Raw materials are used as a proxy for changes in global demand and to control the price puzzle. Stock Price Index is used as equity price. All variables used in this study are expressed in log form, except the central bank rate.

Table 1 shows that the policy rate averaged 11.08%, with values ranging from 5.75 to 20% and a standard deviation of 3.76. The wide range relative to the mean indicates substantial variation in the policy stance over the sample. Positive skewness shows that relatively high-rate episodes occur in the upper tail, while kurtosis below three indicates a flatter distribution than the normal distribution. The Jarque-Bera p-value of 0.080 does not reject normality at the 5% level. These features are consistent with a policy rate that moved considerably across different macroeconomic conditions, providing a useful basis for testing whether the reaction function is regime dependent.

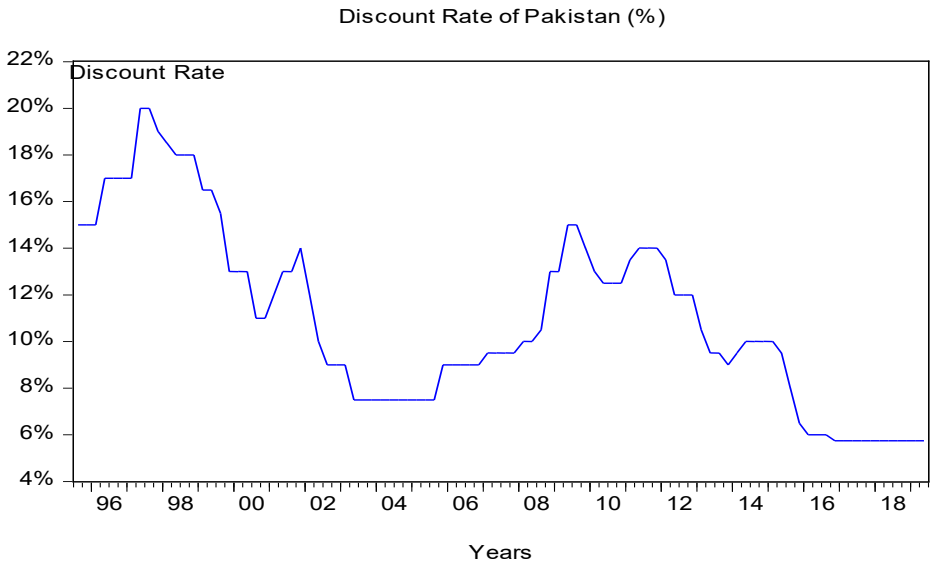
Table 1: Descriptive Statistics

Statistics	DR
Mean	11.0807
Median	10.000
Maximum	20.000
Minimum	5.7500
S.D.	3.7645
Skewness	0.4932
Kurtosis	2.4614
Jarque Bera (p-value)	5.0527 (0.080)

Source: Authors' own.

Figure 1 confirms sizeable changes in the policy rate over time rather than a stable path. These movements are consistent with shifts in inflationary and output conditions and motivate the subsequent tests of dependence and non-linearity.

Figure 1: Discount Rate Dynamics over Time



Source: Authors' own.

4.1. BDS Test

The dependence structure of the policy instrument is examined through the BDS test. The null hypothesis is IID against dependence. Because the sample is limited, bootstrap probabilities based on 10,000 and 100,000 iterations are also reported. Table 2 shows that the null is rejected across the reported dimensions, indicating statistically significant dependence in the policy-rate series.

Table 2: BDS Test Statistic Results

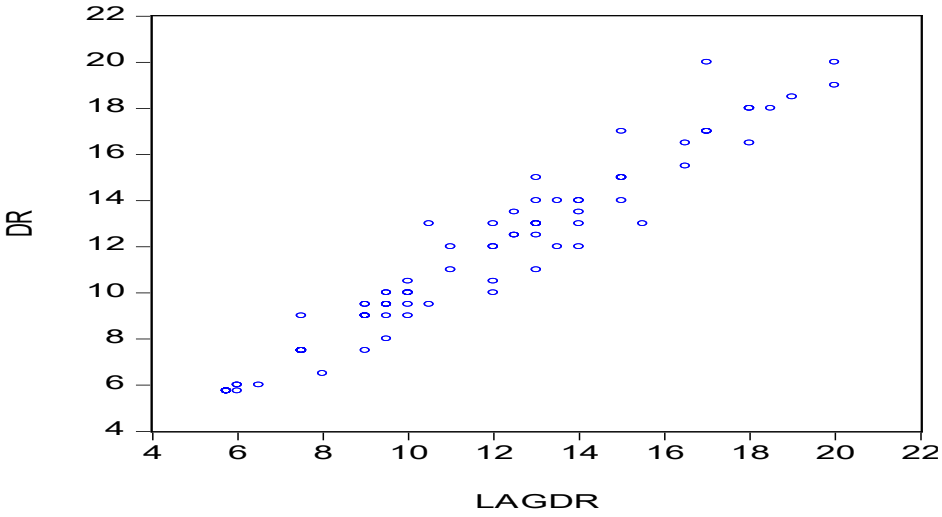
Dimensions	BDS Test Statistic	Standard Error	Z-Stat	Normal Probability	Bootstrap Probability (10000 iterations)	Bootstrap Probability (100000 iterations)
2	0.1680	0.0060	27.6935	0.0000	0.0000	0.0000
3	0.2848	0.0097	29.1549	0.0000	0.0000	0.0000
4	0.3609	0.0117	30.6298	0.0000	0.0000	0.0000
5	0.4053	0.0124	32.5786	0.0000	0.0000	0.0000
6	0.4284	0.0121	35.2663	0.0000	0.0000	0.0000

Source: Authors' own.

The BDS result establishes dependence but does not by itself identify whether that dependence is linear or non-linear. The bivariate marginal distribution is therefore used as an additional diagnostic. Figure 2 plots the central bank rate against its lag. The observations do not form a single ellipsoidal distribution, which provides graphical

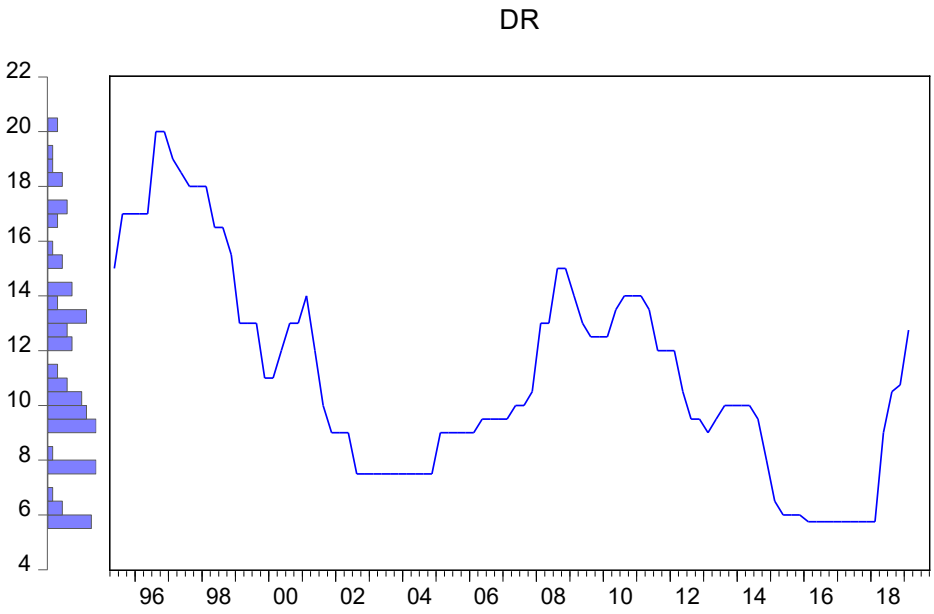
evidence consistent with non-linearity. Taken together, the BDS test and bivariate distribution support further examination of a nonlinear policy reaction function.

Figure 2: Bivariate marginal Distribution of Central Bank Rate



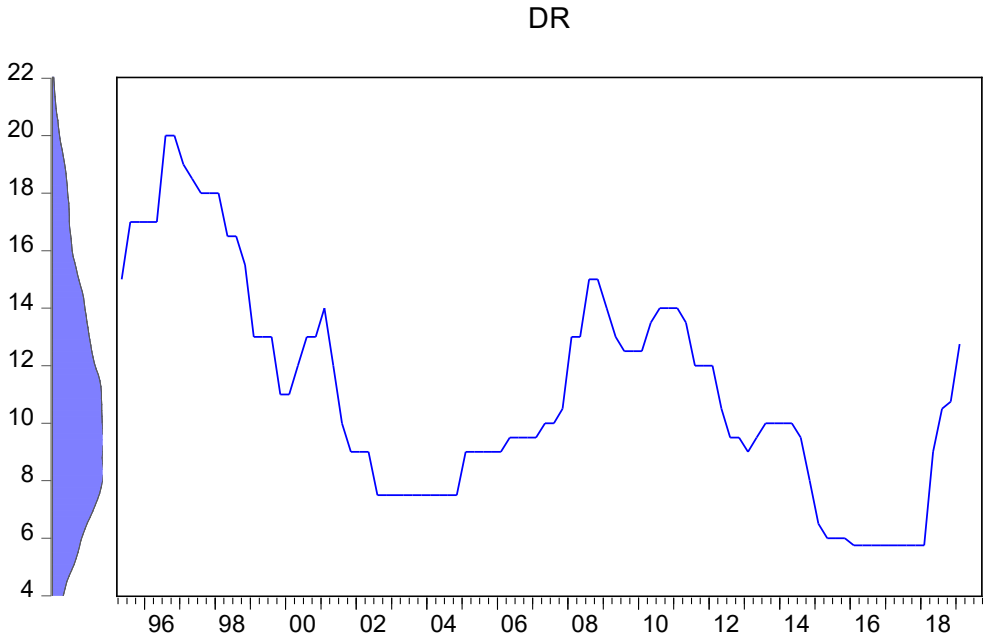
Source: Authors' own.

Figure 3: Graph with Histogram



Source: Authors' own.

Figure 4: Graph with Kernel Density



Source: Authors' own.

Additionally, linearity is checked using a general linearity test; the results are displayed in Table 3.

Table 3: Keenan's Test Statistic Results

Test Statistic	Results
Keenan's Test Statistic	4.16334
(P-value)	(0.044)

Source: Authors' own.

Keenan's test also rejects the null hypothesis of linearity at the 5% level (p = 0.044).

4.2. Unit Root Tests

Unit root tests reveal that all variables are I(1). Results of individual unit root tests are reported in Table 4. All variables were found to be non-stationary at levels, even when trends were considered. Stationarity was observed at first difference, so all variables used in the estimations are integrated of order one i.e. I(1).

Table 4: Unit Root Test Results

Variables	In Level		In First Difference	
	T-stat	P-value	T-stat	P-value
DR	-2.0725	0.2562	-7.2173	0.0000
LDCP	-1.2888	0.6321	-8.3087	0.0000
LDCPI	-2.3429	0.1610	-4.1724	0.0012
LDR	-2.0309	0.2734	-6.8094	0.0000
LDREER	0.1867	0.9704	-2.5886	0.0990
LDRGDP	-1.5787	0.4893	-3.4650	0.0112
LDRM	-1.5194	0.5196	-8.5501	0.0000
LDSE	-0.9396	0.7715	-9.1443	0.0000
OG	-1.4243	0.5673	-8.0920	0.0000

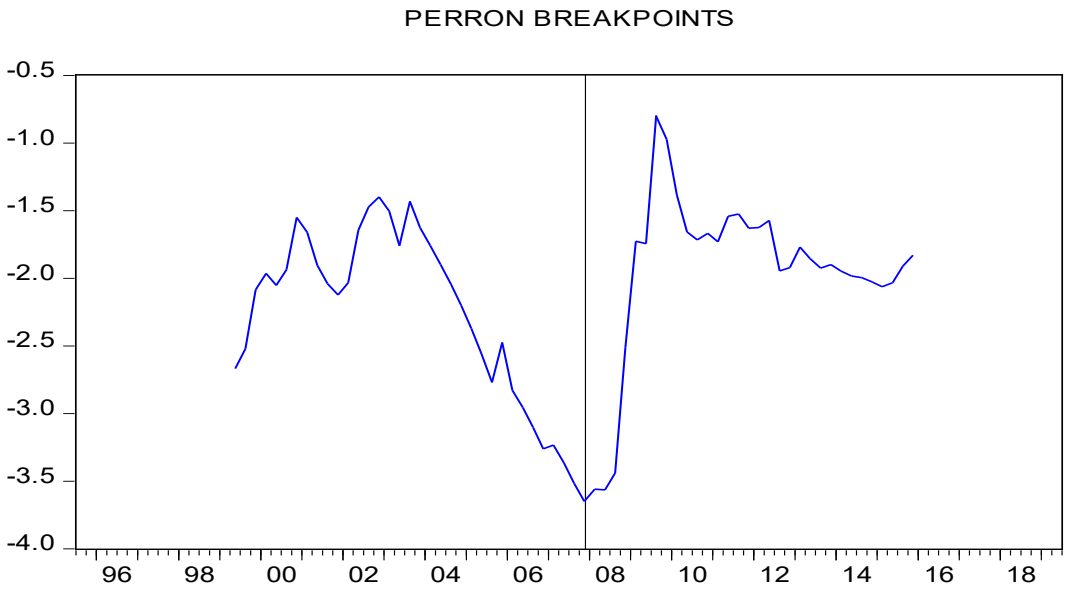
Source: Authors' own.

4.3. Structural Break Test

Before proceeding to the smooth transition regression model, Perron structural break test is applied to check the structural break(s) in the data, if any.

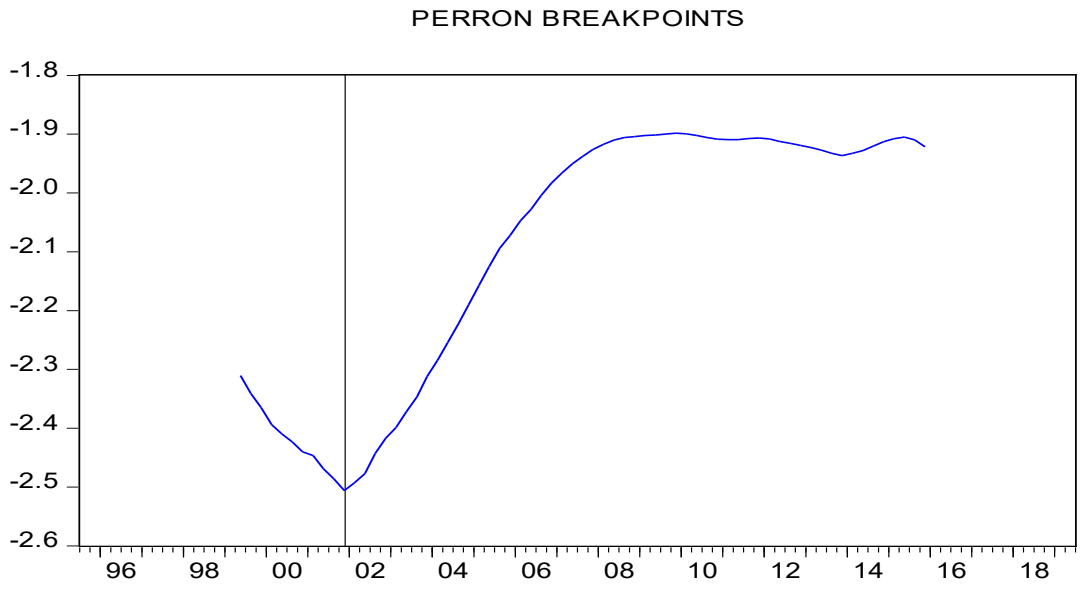
The Perron (1989) unit root test for structural break is used to check three types of structural breaks:

Figure 5: Structural Break in Intercept



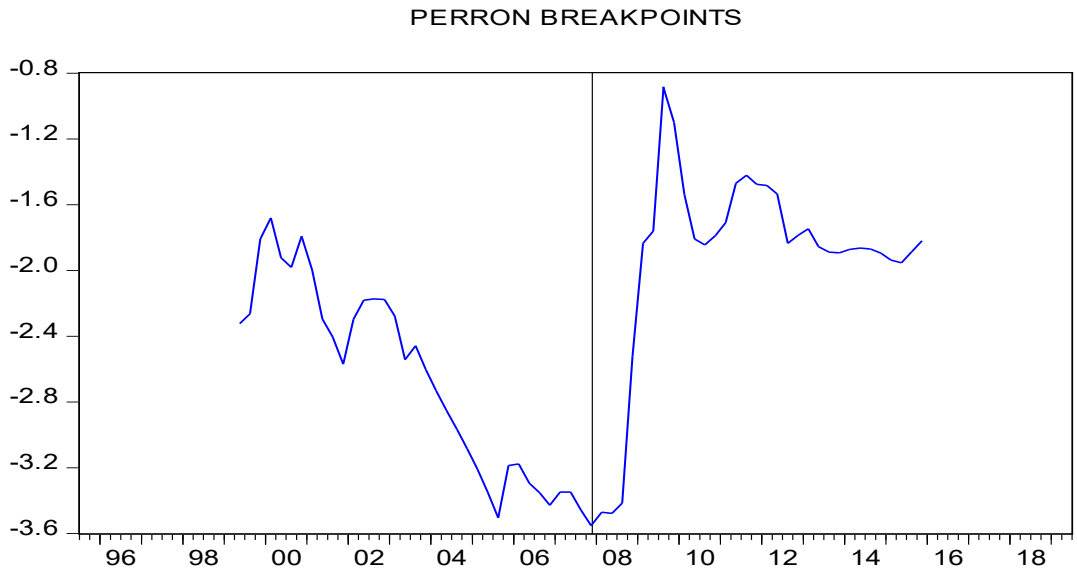
Source: Authors' own.

Figure 6: Structural Break in Trend



Source: Authors' own.

Figure 7: Structural Break in both Trend and Intercept



Source: Authors' own.

Table 5: Perron Structural Break Test

	In the Intercept	In the Trend	In both
Perron unit root value	-3.649	-2.506	-3.552
Chosen Lag Length	1	1	1
1% critical value	-5.92	-5.45	-6.32
5% critical value	-5.23	-4.83	-5.59
10% critical value	-4.92	-4.48	-5.29

Source: Authors' own.

Finally, for further investigation of the type of non-linearity in the data, linearity test is applied. All variables are deflated using the GDP deflator and taken in first differences because the STR model requires stationarity. To decide on the transition variable for Pakistan, the study applied STR tests using different variables and concluded that the output gap is a significant transition variable, as inflation and the other candidates showed insignificant results. The study therefore proceeds with the nonlinear framework considering the output gap as the transition variable; the results are shown in the table below:

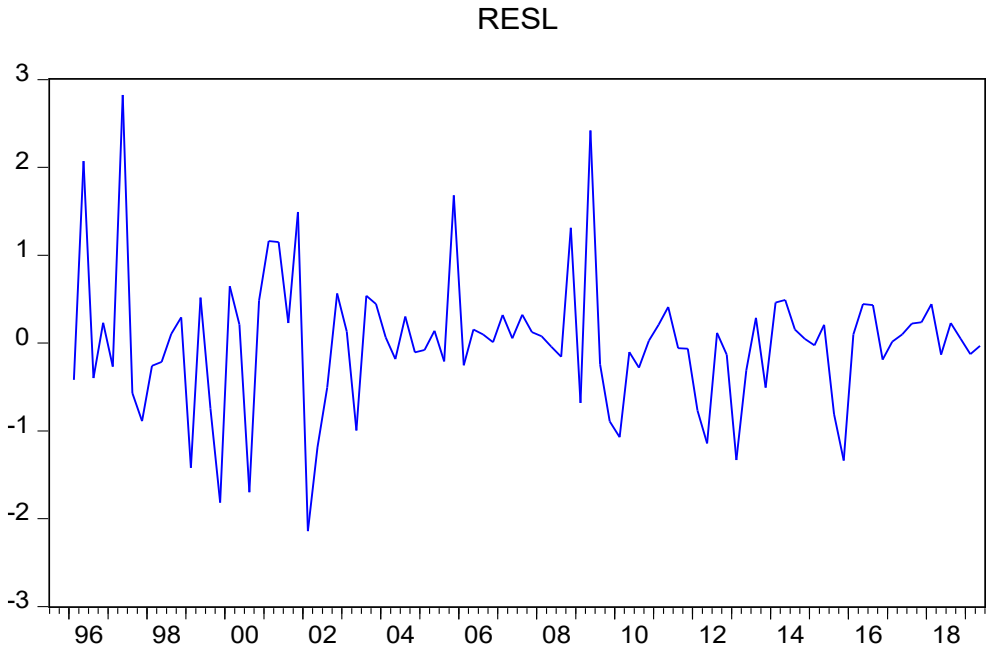
Table 6: Linear Model Estimates

	Variable	T-Statistic	P-Value
Lag-i	0.180**	2.111	0.037
INF	0.197***	3.073	0.002
OG	0.049	0.245	0.806
C	-0.452***	-2.994	0.003
Adj R^2	0.160	--	--
Log-Likelihood	-111.046	--	--

Source: Authors' own.

The linear estimates show that lagged interest rate and inflation are significant at 5% and 1%, respectively, while output gap is insignificant. The inflation coefficient is positive (0.197), which maps a rise in inflation to a higher policy interest rate in the linear specification. Lagged interest rate is also positive (0.180), indicating some policy persistence. However, adjusted R-squared is only 0.160 and the subsequent diagnostic tests show serial correlation and heteroskedasticity. These results suggest that a single linear response does not adequately capture changes in the monetary policy rule, providing the basis for the nonlinear specification.

Figure 8: Residual Series of the Linear Model



Source: Authors' own.

Table 7: Linear Model Unit Root Test

	T-Statistic	**P-Value**	**Critical values**
ADF	-10.330	0.000	1% :-3.503 5% :-2.893 10% :-2.583

Source: Authors' own.

Table 8: Breusch-Godfrey Serial Correlation LM Test of Linear Model

F-Stat	3.499	**Prob F**	0.034
Obs R squared	6.924	**Prob Chi-Sq**	0.031

Source: Authors' own.

Table 9: Breusch-Pagan-Godfrey Heteroskedasticity Test of Linear Model

F-Stat	6.083	**Prob F**	0.000
Obs R squared	15.848	**Prob Chi-Sq**	0.001

Source: Authors' own.

The Breusch-Godfrey and Breusch-Pagan-Godfrey tests reject the respective null hypotheses, indicating serial correlation and heteroskedasticity in the linear-model residuals. This further weakens the adequacy of the linear specification.

The residuals also show periods in which the linear Taylor-type rule would imply a policy rate different from the observed rate. This is consistent with the argument that the monetary authority's response can change with economic conditions rather than remain constant across the sample (Baaziz and Labidi 2016).

Accordingly, the linear model provides a broad average relationship but does not adequately explain the direction and intensity of policy responses in all periods.

Theoretically, the linear policy rule stems from the assumption of a linear aggregate supply or linear Phillips curve, which are themselves unrealistic assumptions, as monetary authorities might have asymmetric preferences (Surico 2007). In fact, there is a possibility of a nonlinear aggregate supply schedule which eventually results in a non-linear monetary policy rule (Dolado et al., 2005).

Therefore, a non-linear Taylor rule might be a better choice for explaining the dynamics of economic developments and the monetary authority's behaviour.

4.4. Choice of Transition Model

Linearity tests against STR non-linear tests were conducted allowing for different variables including inflation, output gap and lagged interest rate. Among all variables, the output gap was identified as the transition variable. This means that the output gap is responsible for the nonlinear behaviour of the central bank of Pakistan (the State Bank of Pakistan, SBP). The selection of the output gap as a transition variable was also observed by Baaziz and Labidi (2016) in the case of Egypt. Detailed results are shown in Table 10:

Table 10: Linearity Tests

Null Hypothesis	F-Statistics	P-value
H04 : b1=b2=b3=b4=0	2.434	0.020
H03 : b1=b2=b3=0	2.274	0.043
H02 : b1=b2=0	1.761	0.143
H01 : b1=0	3.446	0.036

Source: Authors' own.

Table 11: Teräsvirta Sequential Tests

Null Hypothesis	F-Statistics	P-value
H3 : b3=0	3.129	0.048
H2 : b2=0 | b3=0	0.141	0.868
H1 : b1=0 | b2=b3=0	3.446	0.036

Source: Authors' own.

Recommended Model: First order Logistic

Table 12: Escribano–Jordá Test

Null Hypothesis	F-Statistics	P-value
H0L : b2=b4=0	2.510	0.047
H0E : b1=b3=0	2.913	0.026

Source: Authors' own.

4.5. Recommended Model: First order Logistic

Since Prob(H0L) > Prob(H0E) and Prob(H0L) < 0.05, the Escribano–Jordá test selects the first-order logistic model (LSTR1) (Escribano and Jordá 1999). The tests select output gap as the transition variable, implying that changes in economic activity are associated with changes in the policy reaction function. This result is consistent with Baaziz and Labidi (2016), where output gap also served as a transition variable for Egypt. It is also relevant to recent evidence for Pakistan: Rehman et al. (2025) show that output-gap measurement is sensitive to structural conditions, which reinforces its importance as a state variable rather than a purely mechanical control. The selection of LSTR1 indicates two regimes and allows the coefficients to change smoothly as the output gap moves across the estimated threshold.

Furthermore, selection of LSTR1 model is an indication of two dissimilar regimes. One regime is linear and the other non-linear. The LSTR1 model gives the results of both regimes separately, as shown in Table 13.

The next step is to run the LSTR1 model in order to assess the monetary policy rule dynamics. Following model will be run to get the estimates of LSTR1 model:

$$i_t = \alpha_1 + \beta_1 i_{t-1} + b_{\pi 1}\pi_t + b_{y1}y_t + b_{r1}r_t + (\alpha_2 + \beta_2 i_{t-1} + b_{\pi 2} i_{t-1} + b_{\pi 2}\pi_t + b_{y2}y_t + b_{r2}r_t)G(\gamma, c, y_t)$$

The results are reported in Table 13.

Table 13: LSTR1 Model Estimates

	Linear Regime		
Variables	**Variable**	**T-Statistic**	**P-Value**
C	-0.120	-0.530	0.597
Lag-i	-0.032	-0.129	0.897
INF	0.481***	3.478	0.000
OG	-0.390	-1.541	0.127
	Non-Linear Regime		
C	-0.154	-0.628	0.531
Lag-i	0.265	0.998	0.321
INF	-0.385***	-2.857	0.005
OG	0.681**	2.583	0.011
γ	31.990	0.837	0.404
c	-1.074***	-30.309	0.000
Adj R^2	0.724	--	--
Log-Likelihood	-58.459	--	--

Source: Authors' own.

The results indicate that there are two regimes, as suspected. The first regime (linear regime) is similar to the specification of the augmented linear Taylor rule, the results of which are shown in Table 6. The second regime is one in which the output gap was higher (it can be called the expansion regime), and in this regime the monetary authority behaved differently, which motivated this study. This indicates a distinct regime in the sample period, with different economic developments, in which the central bank of Pakistan conducted monetary policy differently.

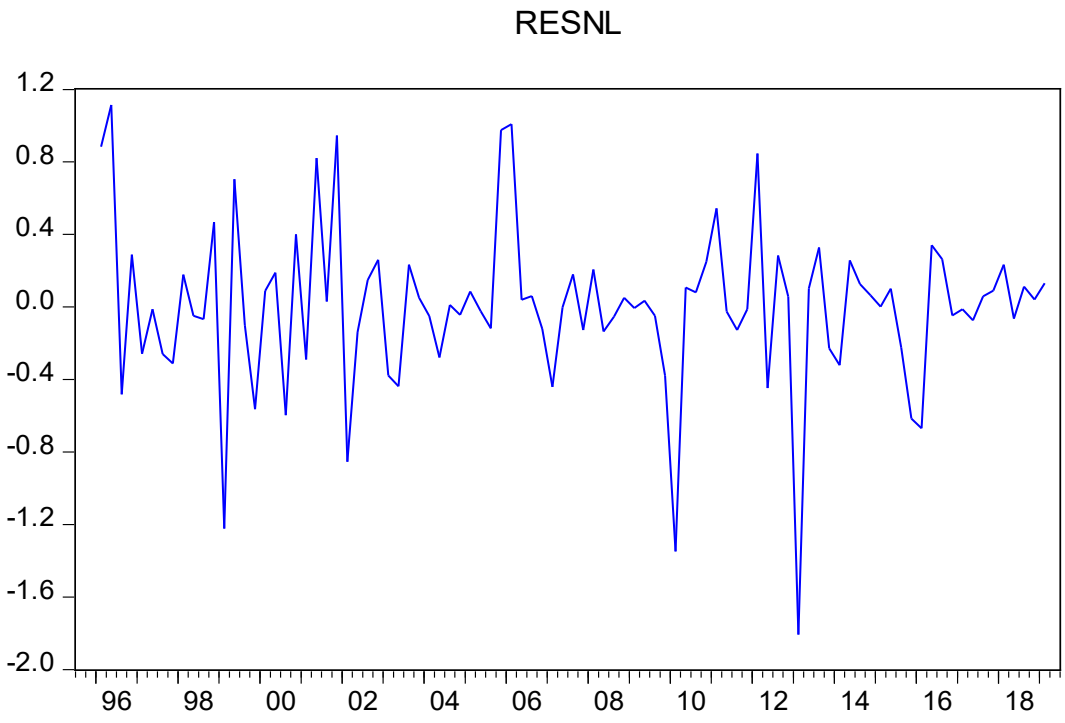
Table 13 shows that the response of monetary authority varies with the output-gap threshold of -1.074. The relationship between inflation and the policy interest rate is therefore regime dependent. In the linear regime (output gap below the threshold), the inflation coefficient is positive and significant (0.481), indicating a higher policy rate as inflation rises. The nonlinear-regime coefficients in Table 13 are additions to the linear-regime coefficients, so the inflation response above the threshold is their sum, $0.481 - 0.385 = 0.096$. It remains positive but is much smaller, so the significant negative adjustment term (−0.385) shows that the inflation response weakens as the economy moves across the threshold, rather than changing sign. The output-gap coefficient is insignificant in the linear regime (−0.390), but the significant adjustment term (0.681) raises the combined response above the threshold to 0.291. Thus, inflation remains an important policy variable, while the response to output becomes stronger when the output gap is above the threshold. Standard errors for the combined coefficients are not reported, so their significance cannot be assessed here. This state-dependent behaviour is consistent with recent Pakistan evidence that inflation is

driven by different shocks over time, including commodity prices, money supply, fiscal stance, exchange-rate changes and inflation expectations (Hussain et al., 2025).

The lagged interest-rate coefficient is insignificant in both reported regimes. The transition parameter is 31.99 and is statistically insignificant, while the threshold parameter of -1.074 is significant at 1%. The adjusted R-squared rises to 0.724, substantially above the linear model, indicating a better fit once regime-dependent responses are allowed.

The residual series of the non-linear model was estimated, and a pictorial view is given below:

Figure 9: Residual series of non-linear model



Source: Authors' own.

The nonlinear-model residuals still contain some large shocks, but the residual unit-root test shows stationarity at the 1% level. The remaining diagnostic tests indicate that the nonlinear specification resolves the serial-correlation and heteroskedasticity problems observed in the linear model.

Table 14: Non-Linear Model Unit Root Test

	T-Statistic	P-Value	Critical values
ADF	-10.521	0.000	1% :-3.506 5% :-2.894 10% :-2.584

Source: Authors' own.

The ADF statistics confirm that the nonlinear-model residuals are stationary at the 1% level.

Table 15: Breusch-Godfrey Serial Correlation LM Test of LSTR1 Model

F-Stat	0.588	**Prob F**	0.558
Obs R squared	1.389	**Prob Chi-Sq**	0.499

Source: Authors' own.

To test for serial correlation, the Breusch-Godfrey LM test was applied, and no serial correlation was found in the model.

Table 16: Breusch-Pagan-Godfrey Heteroskedasticity Test of LSTR1 Model

F-Stat	0.346	**Prob F**	0.9103
Obs R squared	2.196	**Prob Chi-Sq**	0.900

Source: Authors' own.

To check for heteroskedasticity, the Breusch-Pagan-Godfrey test was applied, and no heteroskedasticity was found in the model.

5. CONCLUSION

This study has used the STR model to evaluate the standing of a non-linear monetary policy rule in Pakistan using quarterly data from 1995 to 2020. The BDS and Keenan tests support the presence of non-linearity, while the transition tests select output gap as the transition variable and recommend the first-order logistic specification. The LSTR1 estimates indicate two regimes and show that the monetary policy response changes when the output gap crosses the estimated threshold. Inflation is significant in the linear regime and its combined response above the threshold is smaller (0.096 against 0.481), while the output-gap response becomes positive and larger above the threshold (0.291 against −0.390). The nonlinear model also provides a substantially better fit and passes the reported residual diagnostic tests. The results therefore support a state-dependent interpretation of Pakistan's monetary policy reaction function rather than a single symmetric response over the full sample.

6. POLICY RECOMMENDATIONS

The results suggest that the State Bank of Pakistan (SBP) should incorporate the state of the output gap explicitly when assessing the appropriate policy response instead of relying on a uniform response across expansionary and weak-growth conditions. Since inflation remains an important variable in both regimes, the SBP should continue to place price stability at the centre of policy decisions while distinguishing persistent inflationary pressure from temporary supply-side shocks. Regular estimates of the output gap, inflation expectations and the sources of inflation should therefore be incorporated into the Monetary Policy Committee's information set. The SBP may also strengthen communication by explaining how changes in inflation and the output gap affect the policy-rate decision under different economic conditions. For other relevant authorities, particularly fiscal and statistical institutions, timely and consistent quarterly macroeconomic data should be maintained and shared so that estimates of potential output, the output gap and inflation pressures can be updated reliably. Coordination should support price stability without compromising the operational independence of monetary policy.

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