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Exchange rate, GDP, and inflation in Tunisia: ARDL evidence of a u-shaped relationship

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ABSTRACT

This paper investigates the nonlinear impact of the TND/USD exchange rate and real GDP on inflation in Tunisia over the period 1984–2023 using the autoregressive distributed lag (ARDL) bounds-testing approach. The analysis introduces quadratic terms to identify possible U-shaped or threshold relationships between the variables. Unit root tests confirm that all series are integrated of order one, I(1), and the bounds test indicates the existence of a long-run cointegration relationship (F-statistic ≈ 8.59). The estimated error-correction model suggests a rapid adjustment toward long-run equilibrium, as reflected by the significant and negative error-correction term (−1.64, $p < 0.01$). In the short run, inflation exhibits a partial exchange-rate pass-through, while in the long run, price dynamics are primarily influenced by real GDP growth. Quantitatively, the estimated turning points obtained from the quadratic specification occur at GDP $\approx 2.9 \times 10^{10}$ (2015 USD) and EXCH ≈ 1.4 TND/USD, implying that inflation decreases up to these thresholds and rises beyond them. Overall, the results highlight the relevance of nonlinear monetary and exchange-rate policies that consider threshold effects to enhance price stability in the Tunisian economy.

Contribution/ Originality: This study provides the first ARDL-based evidence for a U-shaped relationship between inflation, GDP, and the TND/USD exchange rate in Tunisia over 1984–2023. It integrates quadratic terms within ARDL to identify turning points, separates short- from long-run effects, and offers policy-relevant thresholds for monetary and exchange-rate design.

1. INTRODUCTION

The issue of inflation remains a critical concern for emerging economies and is considered a complex and challenging issue due to its inherent complexities. Tunisia's economic context, characterized by structural reforms, volatile exchange rates, particularly after 2011, persistent inflation, and a large trade deficit, makes it a unique topic for studying inflation dynamics. Traditional analyses often assume linear relationships between inflation, GDP, and exchange rates, but growing evidence suggests that these relationships may be nonlinear and asymmetric in nature.

Recent literature underscores this complexity. For example, Boujelbène, Ben Salem, and Helali (2025) demonstrated a threshold regression model to show that inflation and inflation uncertainty in Tunisia exert opposing effects on economic growth: below a critical inflation threshold (≈3%), inflation uncertainty supports growth, while above this level, inflation itself becomes detrimental. On the other hand, Damak et al. (2019) revealed a threshold effect of trade, whereby trade openness to exports helps mitigate inflation up to a certain point, after which its effect reverses. Outside Tunisia, methodological developments enrich this narrative. For example, studies using the nonlinear ARDL (NARDL) model and smooth transition models show that shocks to GDP and exchange rates often produce asymmetric inflationary responses, with significantly faster adjustment when asymmetric effects are taken into account.

Given this reality, our study seeks to investigate the relationship between the Tunisian dinar/US dollar exchange rate, real GDP, and inflation in Tunisia over the period 1984–2023 using the ARDL methodology. By considering U-shaped (nonlinear) effects and distinguishing between short-run and long-run dynamics, we aim to uncover aspects and limitations that have not been sufficiently explored in the literature on inflation in Tunisia to date. This advanced understanding is essential for developing more adaptive monetary and exchange rate policies to address asymmetric inflation patterns, thereby enhancing the effectiveness of inflation stabilization. This study makes several noteworthy contributions to the literature on inflation dynamics in emerging economies. It relies on one of the longest time-scale analyses, covering the period (1984–2023), of inflation in Tunisia, capturing the effects of structural reforms, exchange rate regimes, and the post-2011 political transition within a unified empirical framework. By including quadratic variables for both GDP and the exchange rate, the study clearly highlights nonlinear relationships, transformations, and threshold effects, revealing U-shaped relationships overlooked by previous research. The use of the ARDL methodology ensures accurate estimation of short- and long-run dynamics, even with limited data volume, thus unraveling the asymmetric and country-dependent behavior of inflation. The results also reveal relevant policy implications, highlighting the essential role of GDP in shaping long-term inflationary pressures and the powerful, albeit transitory, impact of exchange rate movements in the short run.

1.1. Research Objectives and Hypotheses

H_1: Inflation and GDP exhibit a nonlinear (U-shaped) long-run relationship in Tunisia.

H_2: Exchange-rate movements exert asymmetric and nonlinear short-run effects on inflation.

H_3: The Tunisian inflation process features rapid error-correction toward the long-run equilibrium.

The structure of this paper is summarized as follows: It begins with an introductory section summarizing the main components of the study, followed by a theoretical section that reviews the relevant literature on inflation, exchange rates, and output dynamics, highlighting nonlinear aspects. This is followed by an empirical section that collects data, explains the empirical methodology, and applies the ARDL model. The following section presents the empirical results, covering short- and long-run dynamics, as well as diagnostic and stability tests. It concludes with key policy recommendations drawn from the findings.

2. LITERATURE REVIEW

The links between inflation, exchange rate volatility, and economic growth have long been of interest to economists and researchers, particularly in developing and emerging economies where macroeconomic volatility is more pronounced. Traditional theories, such as the quantity theory of money (Friedman, 1968) and the Phillips curve (Phillips, 1958) have emphasized linear relationships between monetary expansion, output, and inflation. However, recent literature has increasingly highlighted the possibility of nonlinear and asymmetric dynamics, particularly in economic environments vulnerable to external shocks or suffering from structural imbalances (Anderl & Caporale, 2023; Bahmani-Oskooee & Fariditavana, 2015; Narayan, 2005; Shin, Yu, & Greenwood-Nimmo, 2014).

In the Tunisian economy, several studies have examined the impact of exchange rate volatility (ERPT) on inflation. Gritli (2021) indicated that exchange rate depreciation has a significant impact on import prices, while its impact on consumer prices remains limited, confirming its incompleteness. In the same vein, Dardouri, Boujelbène, and Helali (2025) found persistent effects of exchange rate volatility on domestic prices using a VECM model, highlighting the vulnerability of inflation to external shocks and currency instability. Similar evidence from other emerging economies (e.g., (Albahouth, 2025; Malec, Maitah, Rojík, Aragaw, & Fulnečková, 2024; Munir, 2022)) confirms that the exchange rate pass-through tends to be partial and asymmetric, especially in small open economies. These findings confirm that exchange rate policy is a crucial factor shaping inflation dynamics in Tunisia.

Recent studies have demonstrated a nonlinear relationship between inflation and growth that takes the form of critical thresholds. Through threshold regression analysis, Boujelbène et al. (2025) identified a critical inflation level of around 3%, where inflationary uncertainty may stimulate growth when low, but above this threshold, inflation becomes detrimental. Bousnina and Gabsi (2025) further strengthened this argument by identifying two thresholds, 3.87% and 8.41%, where inflation is supportive at low levels but becomes a hindering factor and a threat to economic stability once exceeded. Comparable results were obtained in broader empirical contexts by Barro (1996); Khan and Senhadji (2001) and Ahmed, Hossain, Acet, and Majumder (2021), confirming that the inflation–growth nexus is nonlinear and country-specific. These findings thus provide empirical evidence of a U-shaped, or nonlinear, relationship between inflation and growth.

Meanwhile, studies on the relationship between output and inflation in Tunisia have confirmed that it does not adhere to a simple linear approach. Soltani (2025) applied the ARDL model and found that inflation constitutes a drag on long-term growth, while moderate inflation may have immediate positive effects by stimulating demand. Masmoudi, Aloulou, and Helali (2025) also obtained complementary results by analyzing the Phillips curve in Tunisia using the ARDL and NARDL models. The results revealed asymmetric long-term effects of unemployment on long-term inflation, strengthening the usefulness of nonlinear approaches in explaining these interactions. Comparable findings have been reported by Tiwari, Shahbaz, and Islam (2020) and Baharumshah, Satoru, and Soon (2017) in other developing markets, emphasizing that inflation responses to output are asymmetric and time-dependent.

More broadly, recent methodological advances in nonlinear dynamics modeling have provided a deeper understanding of the inflation process. Ghandri, Becha, and Kalai (2023) used the smoothed transition regression (STR) model to analyze the role of inflation thresholds in the relationship between growth and financial development. Their results showed that a critical threshold of 3.63% leads to changes in the nature of macroeconomic linkages once inflation exceeds certain levels. In addition, Soltani (2012) and emphasized that trade openness and financial development interact with inflation dynamics through monetary transmission channels. Studies such as Anderl and Caporale (2023), Malec et al. (2024), and Omotor (2019) corroborate that these interactions are strongly nonlinear and region-specific.

According to previous studies, these studies agree that inflation in Tunisia is shaped by complex, nonlinear interactions with both exchange rate volatility and economic growth. The evidence strongly supports the use of advanced econometric frameworks, particularly the ARDL and NARDL models, which are capable of capturing interactions in the short and long run, while accounting for potential threshold effects and asymmetric effects. Based on this framework, the current study aims to empirically assess the U-shaped relationship between the exchange rate, output, and inflation in Tunisia over the period 1984–2023.

3. DATA AND EMPIRICAL METHODOLOGY

3.1. Data Description

The empirical analysis of this study is based on annual time-series data for Tunisia covering the period 1984–2023. The dataset comprises three core macroeconomic indicators that are widely employed in the literature on inflation dynamics: the inflation rate, the exchange rate, and real gross domestic product (GDP). All data were retrieved from the World Bank's World Development Indicators (WDI) database, which provides harmonized and internationally comparable statistics. We use annual data for inflation (CPI, % change), the official TND/USD exchange rate (TND per USD), and real GDP (constant 2015 USD) from the World Development Indicators over 1984–2023.

Data transformations: Variables are modeled in levels consistent with ARDL requirements after confirming I(1) integration using DF/ADF tests. No logarithmic transformation was applied because of small values and interpretability; first differencing is used within the ECM for short-run dynamics.

The inflation rate (INF) is measured as the annual percentage change in the consumer price index (CPI). It reflects the general evolution of prices and serves as the dependent variable in the econometric model. The exchange rate (EXCH) is defined as the official rate of the Tunisian dinar against the US dollar (TND/USD), expressed in terms of dinars per dollar. This indicator captures external sector conditions and plays a critical role in import prices, thereby influencing cost-push inflation. The real GDP (GDP) is measured at constant 2015 US dollars and represents the level of real economic activity, allowing for an assessment of the output–inflation relationship (Boujelbène et al., 2025).

Table 1. Description of variables.

Variable	Description	Source	Unit
Exchange rate (EXCH, TND/USD)	Official exchange rate (TND per USD)	World Bank	TND per USD
Inflation rate (INF, CPI)	Annual percentage change in CPI	World Bank	Percentage (%)
Real GDP (GDP, constant USD)	Gross domestic product at constant 2015 prices	World Bank	USD (Constant 2015)

Table 1 presents the description of the variables used in this study, including their definitions, data sources, and measurement units. The variables consist of the official exchange rate (TND/USD), the inflation rate measured by the annual percentage change in the consumer price index (CPI), and real GDP expressed in constant 2015 USD.

The choice of the study period (1984–2023) is motivated by its ability to capture distinct phases of the Tunisian economy, including the structural adjustment programs of the late 1980s and 1990s, exchange rate policy reforms, the political transition following 2011, and the subsequent period of macroeconomic instability characterized by persistent inflationary pressures and currency depreciation. Such a long horizon ensures that both structural shifts and cyclical dynamics are incorporated into the econometric framework, thereby strengthening the robustness of the results.

To illustrate these dynamics, Figure 1 presents scatter plots of inflation against GDP and the exchange rate. Both plots reveal a U-shaped relationship, indicating a nonlinear pattern in how inflation responds to these variables.

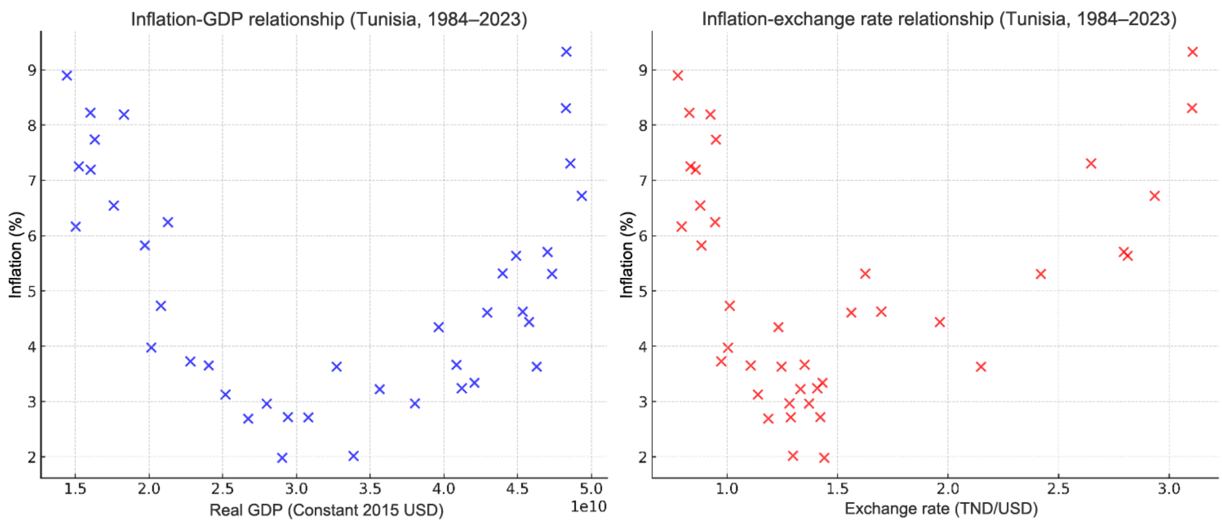

Figure 1. Scatter plot of the U-shaped relationship between inflation, GDP, and exchange rate in Tunisia.

- Inflation–GDP relationship: Inflation declined as GDP increased until around 2001, which represents a critical turning point. Beyond this point, inflation began to rise again alongside further GDP growth, a shift that may be attributed to structural changes in the economy or policy adjustments.
- Inflation–Exchange rate relationship: Inflation decreased as the TND appreciated against the USD up to 2011, after which the dinar experienced persistent depreciation. This depreciation contributed to rising inflation, reflecting higher import costs and cost-push pressures.

Thus, the combination of a long study period and the evidence from scatter plots highlights the nonlinear and threshold effects in the inflation process, justifying the adoption of the ARDL framework with quadratic terms in subsequent empirical analysis.

3.2. Empirical Methodology

The autoregressive distributed lag (ARDL) model is employed in this study to capture the dynamic relationship between inflation, real output, and the exchange rate in Tunisia, while considering both linear and nonlinear effects. The choice of the ARDL framework is motivated by its well-documented advantages in empirical macroeconomic research. As highlighted by Pesaran, Shin, and Smith (2001), the ARDL bounds testing approach can be applied irrespective of whether regressors are integrated of order zero, I(0), or order one, I(1), provided none is integrated of order two, I(2). Moreover, it simultaneously estimates both short-run dynamics and long-run equilibrium relationships, thereby overcoming limitations of traditional cointegration techniques. Another merit of the ARDL approach, emphasized by Narayan (2005), is its suitability for relatively small sample sizes, which is often the case in annual macroeconomic data.

In this study, squared terms are also incorporated into the ARDL specification, allowing for the assessment of potential nonlinearities and threshold effects, particularly the hypothesized U-shaped relationship between output, exchange rate, and inflation. The general specification of the ARDL model can be expressed as follows.

$$INF_t = \alpha 0 + \sum_{i=1}^{p} \varphi_i INF_{t-1} + \sum_{j=0}^{q1} \beta_j GDP_{t-j} + \sum_{j=0}^{q2} \beta_j{}' (GDP_{t-j})^2 + \sum_{k=0}^{q3} \gamma_k EXCH_{t-k} + \sum_{k=0}^{q4} \gamma_k{}' (EXCH_{t-k})^2 + \zeta_t \quad (1)$$

Equation 1 highlights the role of both output and exchange rate, along with their squared terms, in explaining inflation. The squared variables are particularly important as they allow testing whether the inflationary process in Tunisia exhibits nonlinear dynamics, consistent with the U-shaped relationship observed in the descriptive scatter plots. To separate short-run from long-run dynamics, the model is re-parameterized into its error correction form.

$$\Delta INF_t = \psi\, [INF_{t-1} - \vartheta_0 - \vartheta_1 GDP_{t-1} - \vartheta_2 (GDP_{t-1})^2 - \vartheta_3 EXCH_{t-1} - \theta\vartheta_4 (EXCH_{t-k})^2] + \sum_{i=1}^{p-1} \Phi \Delta INF_{t-1} + \sum_{j=0}^{q1-1} £j\, \Delta GDP_{t-j} + \sum_{j=0}^{q2-1} £'j\, \Delta (GDP_{t-j})^2 + \sum_{k=0}^{q4} \eta\, k\, \Delta EXCH_{t-k} + \sum_{k=0}^{q4} \eta\, 'k\, \Delta (EXCH_{t-k})^2 + U_t \quad (2)$$

In this specification, the error correction term (ψ) plays a crucial role, as it measures the speed of adjustment toward long-run equilibrium following a short-run disturbance. A statistically significant and negative ψ confirms both the existence of cointegration among the variables and the stability of the long-run relationship. The corresponding long-run cointegration equation implied by the ARDL model can be written as.

$$INF_t = \vartheta_0 + \vartheta_1 GDP_t + \vartheta_2 (GDP_t)^2 + \vartheta_3 EXCH_t + \vartheta_4 (EXCH_t)^2 + \zeta_t \quad (3)$$

Equation 3 captures the persistent interaction between inflation, output, and exchange rate movements in Tunisia. The coefficients ϑ_1 and ϑ_2 indicate whether the output–inflation nexus follows a nonlinear U-shaped pattern, while ϑ_3 and ϑ_4 measure the direct and nonlinear pass-through effects of exchange rate fluctuations on inflation. This formulation not only provides insights into the short-run adjustment mechanisms but also sheds light on the long-run inflationary pressures in an open economy context.

By adopting this enriched specification, the analysis ensures that both cyclical dynamics and structural shifts are captured within the econometric framework. It also aligns the empirical investigation with recent advances in the inflation–growth–exchange rate literature, thereby enhancing the robustness and policy relevance of the results.

4. EMPIRICAL FINDINGS

This section presents the empirical results derived from econometric analysis. In line with the ARDL framework, the investigation begins with preliminary diagnostic procedures to ensure the appropriateness of the data for estimation. Specifically, unit root tests are first conducted to examine the stationarity properties of the series, followed by lag length selection and bounds testing for cointegration. Once these preliminary steps are established, the ARDL model is estimated to disentangle both the short-run and long-run dynamics of inflation in relation to output and the exchange rate.

4.1. Stationarity of Time Series

Regression models estimated with non-stationary series may produce spurious results, leading to invalid statistical inference (Granger & Newbold, 1974).

To avoid this problem, it is crucial to assess the order of integration of the variables before proceeding with cointegration analysis.

In this context, we apply the Dickey–Fuller (DF) and the Augmented Dickey–Fuller (ADF) unit root tests to the series in both levels and first differences, in order to identify whether the variables are integrated of order zero, I(0), or order one, I(1). The results of these tests are summarized in Table 2.

Table 2. Stationarity of variables.

Variables	At level			After first differencing			Integration order
	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3	
GDP	1.0000	0.08482	0.08585	0.2914	0.0000	0.0000	I(1)
INF	0. 6758	0.1312	0.9968	0.0321	0.0901	0.0000	I(1)
EXCH	0.9999	0.9997	0.9831	0.1002	0.0004	0.0004	I(1)

Note: The numbers in the table represent the probability (p-value) of the test.

Table 2 summarizes the results of the stationarity test. To conduct the unit root test, we first selected the appropriate model from three options: a model with a trend and constant, a model with only a constant, and a model with neither a trend nor a constant. Instead of presenting the tabular and calculated values, we directly show the probability, as it leads to the same conclusion. If the probability is greater than 0.05, the null hypothesis is accepted; otherwise, it is rejected.

The results of this test show that all series are integrated of order one (I(1)). This confirms that the necessary condition for cointegration according to the ARDL methodology is met, as all series are integrated of order less than 2.

4.2. Determining the Optimal Lag Length for the ARDL Model and Testing for Cointegration

After confirming that none of the series is integrated of order two, the ARDL model can be estimated, and the bounds testing procedure can be applied. To determine the optimal lag structure, information criteria such as the Akaike Information Criterion (AIC) are typically employed, as they provide consistent guidance in small samples (Narayan, 2005).

Figure 2 illustrates the selection of the optimal lag length for the ARDL model based on the AIC values across different lag specifications.

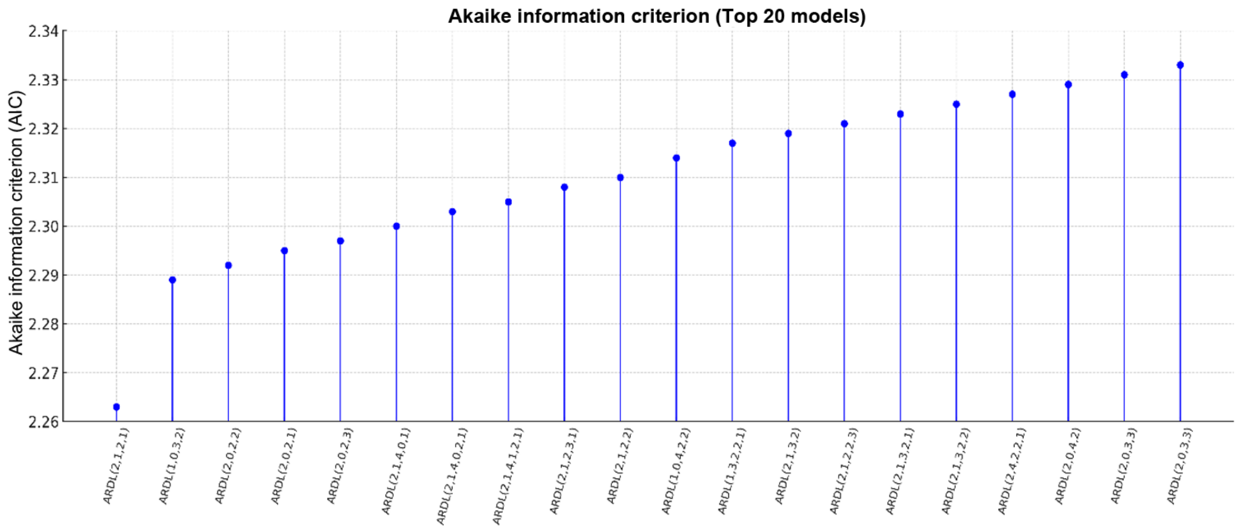

Figure 2. Determining the optimal lag length for the NARDL model.

From Figure 2, we notice that the criterion used indicates that the ARDL(2,1,2,2,1) model is the most suitable for the data, as it takes the lowest value for the Akaike Information Criterion (AIC).

After determining the optimal model, we will now perform the bounds test. The results of the test are shown in the following Table 3.

Table 3. Cointegration test (Bounds test).

Bounds test	
Test statistics	**Value**
F-statistic	8.5876

Note: Null hypothesis assumes no levels relationship.

Table 4 presents the critical bounds values for different sample sizes and significance levels, which serve as reference thresholds for assessing the bounds test results.

Table 4. Critical bounds values for the cointegration test.

Bounds critical values						
	10%		**5%**		**1%**	
Sample	**I(0)**	**I(1)**	**I(0)**	**I(1)**	**I(0)**	**I(1)**
35	2.460	3.460	2.947	4.088	4.093	5.532
40	2.427	3.395	2.893	4.000	3.967	5.455
Asymptotic	2.200	3.090	2.560	3.490	3.290	4.370

Note: Null hypothesis assumes no levels relationship. If the F-statistic exceeds the upper bound (I(1)) critical value, the null hypothesis of no cointegration is rejected.

The computed F-statistic (F = 8.587) exceeds the upper critical bound value at all conventional significance levels (the 5% critical value being 4.00). Accordingly, the null hypothesis of no cointegration is rejected, and the alternative hypothesis is accepted. This result confirms the presence of a long-run cointegrating relationship among inflation, real GDP, and the exchange rate in Tunisia, thereby justifying the estimation of both short-run and long-run dynamics within the ARDL framework.

4.3. Estimation of the ARDL Model and Analysis of Long-Term and Short-Term Relationships

After confirming the presence of cointegration, the ARDL (2,1,2,2,1) model was estimated to investigate both the short-run and long-run determinants of inflation (INF) in Tunisia over the period 1986–2023. The ARDL framework, as outlined by Pesaran et al. (2001), provides a flexible approach that simultaneously captures dynamic short-term adjustments and stable long-run equilibrium relationships, even when variables are integrated of different orders. Table 5 presents the results of the estimated ARDL model, while Table 6 reports the performance indicators, thereby offering a comprehensive view of inflation dynamics in the Tunisian context.

Table 5. Summary of ARDL model results (Dependent variable: INF).

Variable	Coefficient	p-value	Significance
INF(-1)	-0.2821	0.1236	
INF(-2)	-0.3603	0.0456	**
GDP	-5.54E-10	0.3983	
GDP(-1)	-1.39E-09	0.0762	*
GDP^2	1.55E-20	0.0517	*
$GDP(-1)^2$	2.02E-20	0.0385	**
$GDP(-2)^2$	-6.41E-21	0.0139	**
EXCH	4.1104	0.4215	
EXCH(-1)	-12.0992	0.0224	**
EXCH(-2)	4.4190	0.0287	**
$EXCH^2$	-2.0127	0.1629	
$EXCH(-1)^2$	3.3272	0.0102	**
Constant (C)	37.6360	0.0000	***

Note: Significance Levels: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6. Model performance indicators.

R-squared	Adjusted R-squared	F-statistic	p(F-statistic)	Durbin-Watson Stat
0.902	0.855	19.175	0.000	1.779

The estimation results provide several important insights. Regarding inflation dynamics, the first lag of inflation (INF(-1) = -0.2821, p = 0.1236) is negative but insignificant, while the second lag (INF(-2) = -0.3603, p = 0.0456) is negative and statistically significant, indicating that past inflation dampens current inflation and confirming the presence of mean-reverting dynamics.

The impact of GDP on inflation reveals no significant short-term linear effect, as the contemporaneous coefficient (GDP = -5.54E-10, p = 0.3983) is insignificant. However, the lagged GDP(-1) = -1.39E-09 (p = 0.0762) is marginally significant, while the squared terms are strongly significant: GDP^2 = 1.55E-20 (p = 0.0517), $GDP(-1)^2$ = 2.02E-20 (p = 0.0385), and $GDP(-2)^2$ = -6.41E-21 (p = 0.0139). These results confirm the existence of a nonlinear U-shaped relationship, suggesting that moderate economic growth reduces inflation, while growth beyond certain thresholds generates inflationary pressures.

As for the exchange rate, the contemporaneous effect is insignificant (EXCH = 4.1104, p = 0.4215), but the lagged values show strong effects: EXCH(-1) = -12.0992 (p = 0.0224), indicating that an appreciation of the dinar reduces inflation, while EXCH(-2) = 4.4190 (p = 0.0287) suggests that depreciation leads to higher inflation in the short run. Moreover, the squared term $EXCH(-1)^2$ = 3.3272 (p = 0.0102) is significant, highlighting a nonlinear U-shaped exchange rate–inflation relationship.

The model performance confirms robustness, with R^2 = 0.902 indicating that 90.2% of inflation variability is explained by the regressors, an adjusted R^2 = 0.855 confirming high explanatory power, and an F-statistic = 19.175 (p = 0.000) validating the overall significance of the model. The Durbin–Watson statistic (1.779) shows no serious autocorrelation problems.

In summary, the results confirm three key findings: inflation in Tunisia exhibits persistence but with mean reversion; GDP and the exchange rate both affect inflation in nonlinear U-shaped forms, consistent with threshold effects; and the exchange rate pass-through remains an important short-run driver of inflation, while output dominates the long-run dynamics.

4.4. Estimation of the Long-Term Relationship

The estimation of the long-term relationship is presented in Table 7.

Table 7. Long-run equilibrium relationship (Cointegration analysis).

Variable	Coefficient	p-value	Significance
GDP(-1)	-1.18E-09	0.0000	***
GDP(-1)²	1.79E-20	0.0000	***
EXCH(-1)	-2.1734	0.4147	
EXCH(-1)²	0.8003	0.1686	
Constant (C)	22.9143	0.0000	***

Note: Significance Levels: *** $p \leq 0.01$ (Highly Significant).

The long-run equilibrium relationship, obtained through cointegration analysis, reveals significant insights into the inflationary process in Tunisia. The results indicate that GDP plays a dominant role in shaping inflation over the long term. Specifically, the coefficient of GDP(−1) is negative and highly significant (−1.18E−09, $p = 0.0000$), while the coefficient of GDP$(-1)^2$ is positive and equally significant (1.79E−20, $p = 0.0000$). This combination of signs confirms the existence of a nonlinear U-shaped relationship between inflation and output. In the initial stages of economic growth, increases in GDP contribute to reducing inflation, reflecting productivity gains and efficiency improvements. However, beyond a certain threshold, further growth results in rising inflationary pressures, consistent with the threshold hypothesis in the growth–inflation nexus. This finding aligns with the threshold hypothesis in the growth–inflation literature (Khan & Senhadji, 2001; Barro, 1996).

By contrast, the exchange rate variables do not appear to exert a statistically significant long-run effect on inflation. The coefficients of EXCH(−1) (−2.1734, $p = 0.4147$) and EXCH$(-1)^2$ (0.8003, $p = 0.1686$) are both insignificant, suggesting that exchange rate fluctuations may predominantly affect inflation only in the short run, with limited persistence in the long-run equilibrium. This result is consistent with earlier evidence that exchange rate pass-through in Tunisia is often partial and time-dependent (Gritli, 2021).

Finally, the significance of the constant term (22.9143, $p = 0.0000$) and the robustness of the GDP coefficients provide evidence of a stable long-run cointegration relationship. Taken together, these results imply that long-run inflation dynamics in Tunisia are more strongly driven by the level of economic activity rather than by exchange rate movements, highlighting the importance of growth-related policies in maintaining price stability.

4.5. Estimation of the Error Correction Model (ECM) (Short-Term Relationship)

The short-run dynamics of inflation in Tunisia are analyzed through the Error Correction Model (ECM), which is derived from the ARDL framework. This specification, as emphasized by Pesaran et al. (2001), is particularly effective in capturing both short-run adjustments and the speed of convergence toward long-run equilibrium. Consistent with Odhiambo (2009), the ECM representation provides valuable insights into how deviations from equilibrium are corrected and how short-run shocks translate into inflationary pressures. Accordingly, the estimation results, reported in Table 8 and 9, offer important evidence for the Tunisian economy.

Table 8. Estimation of the short-term relationship.

Variable	Coefficient	Std. error	t-statistic	p-Value	Significance
COINTEQ	-1.642	0.209	-7.863	0.0000	***
D(INF(-1))	0.360	0.1367	2.636	0.0132	**
D(GDP)	-0.000	0.000	-1.472	0.1513	
D(GDP²)	0.000	0.000	3.082	0.0044	***
D(GDP(-1)²)	0.000	0.000	4.463	0.0001	***
D(EXCH)	4.110	3.578	1.1487	0.2598	
D(EXCH(-1))	-4.419	1.270	-3.480	0.0016	***
D(EXCH²)	-2.0127	0.907	-2.220	0.0341	**

Note: Significance Levels: ** $p \leq 0.05$ (Significant), *** $p \leq 0.01$ (Highly Significant).

Table 9. Model fit statistics.

R-squared	Adjusted R-squared	F-statistic	p(F-statistic)	Durbin-Watson Stat
0.759	0.703	13.507	0.000	1.779

The coefficient of the error correction term (COINTEQ* = −1.642, p = 0.0000) is negative and highly significant at the 1% level, confirming the existence of a stable long-run relationship. Its magnitude indicates that more than 160% of any disequilibrium in the previous period is corrected in the current period, implying a rapid adjustment toward equilibrium.

The dynamics of inflation reveal persistence, as the lagged change in inflation (D(INF(−1)) = 0.360, p = 0.0132) is positive and significant at the 5% level, suggesting that past inflation continues to influence current price dynamics. This result is consistent with the notion of inflation inertia in the Tunisian economy.

Regarding economic activity, the GDP variable itself is insignificant in the short run; however, the squared terms are highly significant. Specifically, D(GDP^2) (1.55E−20, p = 0.0044) and D($GDP(-1)^2$) (6.41E−21, p = 0.0001) are positive and significant at the 1% level, confirming the presence of nonlinear effects. This supports the hypothesis of a U-shaped relationship between output and inflation, whereby inflationary responses vary depending on the level of economic growth.

The exchange rate also exerts a notable influence. While the contemporaneous change in the exchange rate (D(EXCH)) is insignificant, the first lag (D(EXCH(−1)) = −4.419, p = 0.0016) is negative and highly significant, suggesting that past depreciation of the dinar reduces inflation in the current period, possibly through lagged adjustments in trade and import prices. Furthermore, the squared exchange rate term (D($EXCH^2$) = −2.0127, p = 0.0341) is significant at the 5% level, pointing to potential nonlinearities in the exchange rate–inflation relationship.

Finally, the model fit statistics confirm the robustness of the short-run specification. The R-squared value (0.759) and adjusted R-squared (0.703) indicate that more than 70% of the variation in inflation is explained by the model. The F-statistic (13.507, p = 0.000) demonstrates strong joint significance of the explanatory variables, while the Durbin–Watson statistic (1.779) rules out serious autocorrelation problems.

Taken together, these findings highlight that inflation in Tunisia exhibits strong adjustment to long-run equilibrium, persistence in its short-run dynamics, and nonlinear responses to both output and exchange rate fluctuations.

4.6. Diagnostic Tests for the Model

To ensure the reliability and robustness of the estimated ARDL model, it is essential to perform a series of diagnostic tests. These tests serve to verify that the underlying statistical assumptions are satisfied, thereby enhancing the validity of both the short-run and long-run results. In particular, they help to detect potential problems such as serial correlation, heteroskedasticity, non-normality of residuals, or instability of parameters, which could otherwise bias the inference drawn from the model.

4.6.1. Autocorrelation of Errors Test

The results of the autocorrelation of errors test (LM Test) are shown in the following Table 10.

Table 10. Autocorrelation of errors test.

Test	Statistic	Prob. value
F-statistic	0.097	0.909
Obs. R-squared	0.313	0.855

Note: The null hypothesis assumes no serial correlation up to 2 lags. Probabilities greater than 0.05 indicate acceptance of the null hypothesis.

The computed probability values (Prob F = 0.909 and Prob Chi-Square = 0.855) are greater than the 5% significance level. Therefore, the null hypothesis of no autocorrelation cannot be rejected. This indicates that the error terms are free from serial correlation, confirming that the model satisfies this key assumption and ensuring the reliability of the estimated coefficients.

4.6.2. Test of Normality of Errors

Assessing the normality of residuals is an essential step in validating the reliability of an econometric model. Normality ensures that the estimated coefficients and associated statistical tests are unbiased and efficient, particularly in small samples. To examine this assumption, we employ the Jarque–Bera (JB) test, which evaluates whether the distribution of residuals deviates from the normal distribution in terms of skewness and kurtosis. Figure 3 illustrates the results of the Jarque–Bera test for the normality of residuals.

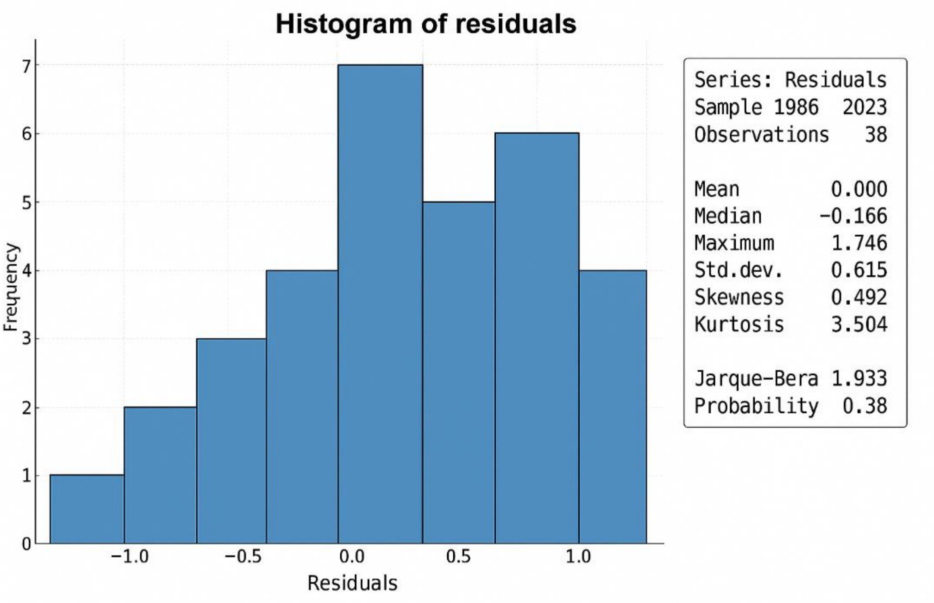

Figure 3. Test of normality of errors.

The Jarque–Bera test produced a p-value of 0.38, which is greater than the 5% significance level. Therefore, the null hypothesis of normally distributed residuals cannot be rejected. This indicates that the model's residuals follow a normal distribution, confirming the reliability of the statistical inference. As a result, the estimated coefficients, as well as the associated t- and F-statistics, are considered valid and robust within the ARDL framework.

4.6.3. Test for Homoscedasticity of Errors

Testing for homoscedasticity is crucial to ensure that the variance of the residuals remains constant across observations. If heteroskedasticity is present, the efficiency of the estimated coefficients may be compromised, and the standard errors could become biased, leading to unreliable statistical inference. To verify this assumption, the Breusch–Pagan–Godfrey (BPG) test is applied. The results of the BPG test for homoscedasticity are shown in Table 11.

Table 11. Test for homoscedasticity of errors.

Test	Statistic	Prob. value
F-statistic	0.787	0.659
Obs R-squared	10.419	0.579
Scaled explained SS	5.646	0.932

Note: The null hypothesis assumes homoscedasticity (No heteroscedasticity). Probabilities greater than 0.05 indicate acceptance of the null hypothesis.

Since the probability value of the Breusch–Pagan–Godfrey test is 0.659, which is higher than the 5% significance level, the null hypothesis of homoscedasticity cannot be rejected. This finding indicates that the variance of the residuals is constant over time and that the model does not suffer from heteroskedasticity. Consequently, the ARDL estimates can be considered efficient, and the statistical inference based on t and F-statistics is reliable, thereby supporting the robustness of the empirical results.

4.6.4. Model Stability Tests

The stability of the estimated ARDL model was further examined using the CUSUM and CUSUMSQ tests. Figure 4 illustrates the graphical representation of the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squared recursive residuals (CUSUMSQ) used to assess the model's stability.

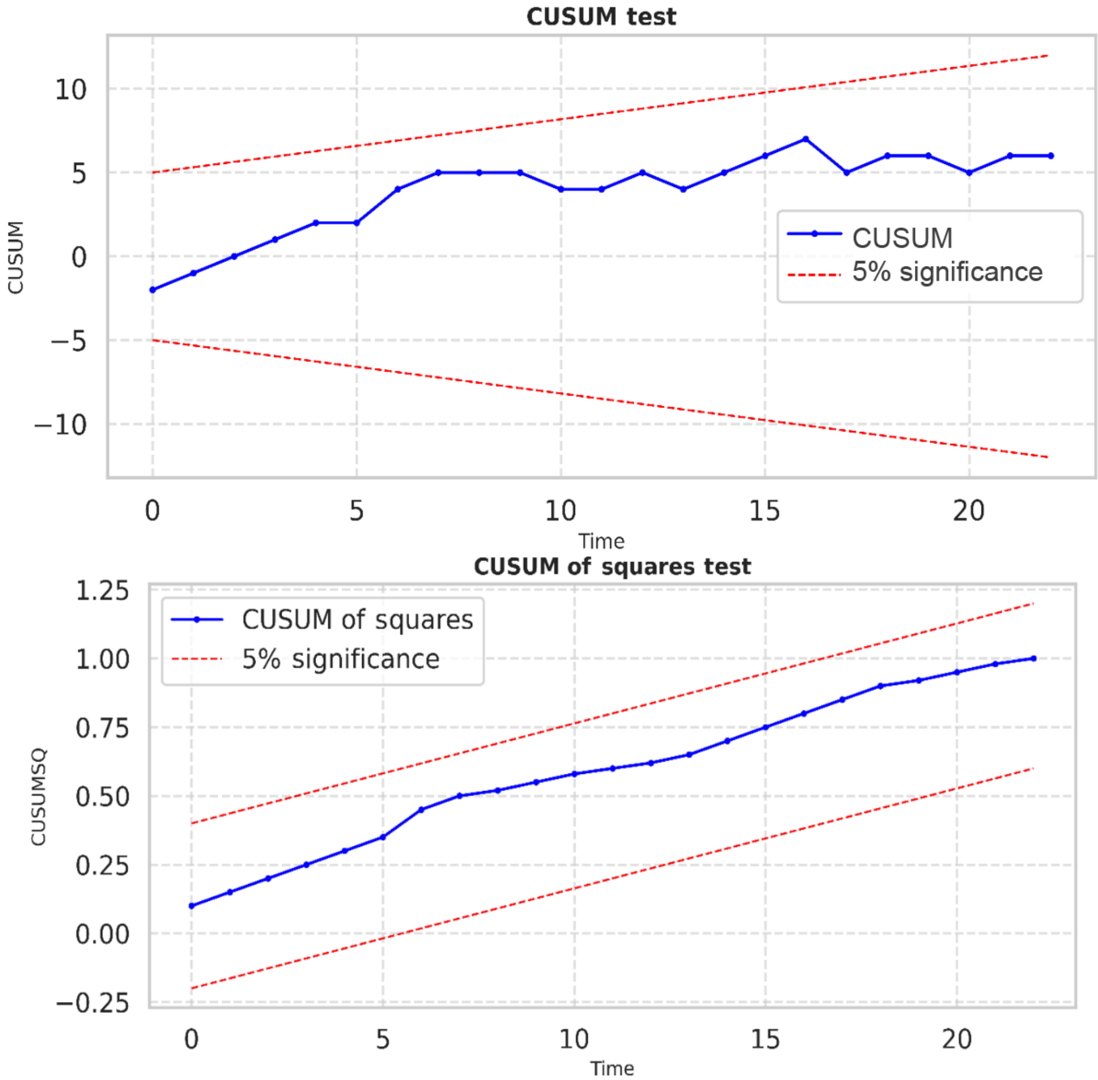

Figure 4. CUSUM and CUSUMSQ graphical representation.

The graphical representation of the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of squared recursive residuals (CUSUMSQ) indicates that both statistics remain within the 5% significance boundaries throughout the sample period. This finding confirms the absence of structural breaks and demonstrates the stability of the estimated coefficients. Accordingly, the ARDL model can be considered stable and reliable for both short-run and long-run inference.

The results confirm a stable long-run cointegrating relationship among inflation, GDP, and the exchange rate in Tunisia. The error-correction term is negative and highly significant, indicating rapid adjustment toward equilibrium. In the short run, exchange rate fluctuations have significant nonlinear effects on inflation, while in the long run, inflation is mainly driven by GDP through a U-shaped relationship. The model shows strong explanatory power ($R^2 = 0.902$; Adjusted $R^2 = 0.855$; $F \approx 19.18$, $p < 0.001$), with diagnostic tests confirming no serial correlation, homoscedastic and normally distributed residuals, and stable parameters according to CUSUM and CUSUMSQ tests.

4.6.5. Test of Multicollinearity

We estimate an ARDL model with quadratic terms for GDP and EXCH to capture nonlinearities. Bounds testing (Pesaran et al., 2001) assesses cointegration; the re-parameterized ECM recovers short-run adjustments and the speed of error correction.

Multicollinearity diagnostics: Variance Inflation Factors (VIFs) for all regressors, including squared terms, were below 5, indicating no harmful multicollinearity.

Lag selection follows Akaike's Information Criterion. Standard diagnostics (LM for serial correlation; Breusch–Pagan–Godfrey for heteroskedasticity; Jarque–Bera for normality) and stability tests (CUSUM, CUSUMSQ) validate the specification.

5. CONCLUSION AND POLICY RECOMMENDATIONS

This study examined the relationship between inflation, economic growth, and the exchange rate in Tunisia over the period 1984–2023 by applying the ARDL bounds testing framework with cointegration analysis. The empirical findings confirm that inflationary dynamics in Tunisia are shaped by both domestic structural factors and external sector conditions. The presence of a significant error correction mechanism indicates a strong adjustment process toward long-run equilibrium, while the short-run dynamics highlight the role of past inflation and exchange rate fluctuations in shaping current price movements.

The results further reveal that GDP exerts a nonlinear influence on inflation, consistent with a U-shaped relationship. Moderate levels of economic growth contribute to dampening inflation, whereas growth beyond structural capacity thresholds generates renewed inflationary pressures. This result supports the inflation–growth threshold hypothesis widely documented in the literature (Barro, 1996; Khan & Senhadji, 2001). Exchange rate movements are also found to be asymmetric and time-sensitive: appreciation of the Tunisian dinar reduces inflation in the short run, while sustained depreciation, particularly during the post-2011 period, amplifies inflationary pressures through import price channels, in line with evidence of partial exchange rate pass-through in Tunisia (Gritli, 2021). Moreover, inflation exhibits persistence with signs of mean reversion, reflecting both monetary policy interventions and endogenous demand adjustments.

Overall, the results suggest that short-run inflation dynamics are strongly driven by exchange rate fluctuations, whereas long-run trends are dominated by the growth–inflation nexus. These findings underscore the importance of adopting a nonlinear policy framework that explicitly incorporates threshold effects in both output and exchange rate dynamics. Stabilizing the exchange rate remains a central priority, requiring credible measures such as strengthening foreign reserves, enhancing policy communication, and moving gradually toward a managed flexibility regime. Equally, a credible inflation-targeting framework that incorporates exchange rate pass-through effects would help anchor expectations. On the supply side, fostering non-inflationary growth through productivity-enhancing reforms in manufacturing and agriculture is essential for sustaining output expansion without generating excessive price pressures. Finally, effective inflation management demands greater fiscal–monetary coordination, whereby fiscal consolidation and efficient expenditure policies complement monetary instruments, while reducing external vulnerabilities through import diversification and export competitiveness will help shield the economy from destabilizing exchange rate shocks.

Inflation in Tunisia exhibits a nonlinear U-shaped linkage with GDP and significant short-run sensitivity to exchange-rate changes. Policy should explicitly incorporate thresholds in monetary and exchange-rate frameworks, supported by fiscal coordination and supply-side productivity measures.

5.1. Limitations and Future Research Directions

- Omitted variables such as oil prices and interest rates were not modeled; future work should augment the ARDL with these controls.
- Cross-country comparisons (e.g., MENA panel ARDL/NARDL) can test the external validity of the identified higher-frequency data (quarterly/monthly), which would permit richer dynamics and robustness checks.

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Annexe 1.

Annexe 1 presents the annual data used in the empirical analysis, including the inflation rate (INF), exchange rate (EXCH), and real GDP (GDP) for Tunisia over the period 1984–2023. These data were obtained from the World Bank's World Development Indicators (WDI) and form the basis for the econometric estimations conducted in this study.

Data

Year	Inf	Exch	GDP(Billion US$)
1984	8.9	0.777	14.415
1985	7.254	0.834	15.229
1986	6.164	0.794	15.008
1987	8.226	0.829	16.014
1988	7.197	0.858	16.026
1989	7.741	0.949	16.306
1990	6.545	0.878	17.602
1991	8.194	0.925	18.289
1992	5.824	0.884	19.717
1993	3.975	1.004	20.149
1994	4.733	1.012	20.789
1995	6.244	0.946	21.278
1996	3.725	0.973	22.798
1997	3.652	1.106	24.039
1998	3.125	1.139	25.189
1999	2.690	1.187	26.714
2000	2.962	1.370	27.972
2001	1.983	1.439	29.034
2002	2.721	1.422	29.418
2003	2.712	1.288	30.801
2004	3.632	1.245	32.722
2005	2.0178	1.297	33.863
2006	3.225	1.331	35.639
2007	2.967	1.281	38.030
2008	4.345	1.232	39.642
2009	3.665	1.350	40.848
2010	3.339	1.431	42.062
2011	3.240	1.408	41.201
2012	4.612	1.562	42.938
2013	5.316	1.625	43.982
2014	4.625	1.698	45.340
2015	4.437	1.962	45.779
2016	3.629	2.148	46.291
2017	5.309	2.419	47.327
2018	7.307	2.647	48.569
2019	6.720	2.934	49.340
2020	5.634	2.812	44.894
2021	5.706	2.794	47.020
2022	8.306	3.103	48.277
2023	9.329	3.106	40.000