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Determinants of Sustainable Economic Growth in Türkiye: An ARDL Bounds Testing Approach (1996–2024)

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ABSTRACT

This study investigates the relationships among real income per capita, research and development (R&D) expenditures, gross fixed capital formation (GFCF), the unemployment rate (UNEMP), and inflation (INF) in the Turkish economy over the period 1996–2024 using the Autoregressive Distributed Lag (ARDL) bounds testing approach. The bounds test results confirm the existence of a long-run cointegration relationship and indicate that R&D expenditures and GFCF have a positive, statistically significant effect on economic growth, while UNEMP and INF negatively affect growth. The short-run findings suggest that investments stimulate economic growth, while R&D expenditures, despite generating a short-term cost-effect, contribute positively to economic growth in the long run.

Keywords: R&D expenditures, Economic growth, gross fixed capital formation, unemployment, inflation, ARDL bounds testing approach

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1. INTRODUCTION

In recent decades, the transition toward knowledge-driven production structures has significantly reshaped the determinants of economic growth in all economies. Within this transformation process, R&D activities have emerged as one of the most influential components supporting technological progress, innovation capacity, and long-term productivity improvements. Therefore, R&D expenditures are no longer considered only as an outcome of economic expansion but also as a strategic instrument shaping sustainable growth dynamics.

Although a substantial body of literature evaluates the contribution of R&D activities to economic growth, many studies focus primarily on bilateral relationships and overlook the simultaneous interaction between growth and other macroeconomic indicators. However, economic growth is influenced not only by technological progress but also by capital accumulation, labor-market conditions, and macroeconomic stability indicators such as inflation. For this reason, analyzing growth within a broader macroeconomic framework provides more comprehensive insights into structural development processes.

Industrial production dynamics also play a crucial role in strengthening economic performance through scale economies, productivity gains, and technology-intensive production structures. Conversely, persistent unemployment reflects inefficient utilization of labor resources and may restrict output expansion potential. Accordingly, evaluating economic growth together with indicators representing real-sector activity and labor-market performance contributes to a more holistic understanding of macroeconomic adjustment mechanisms.

Since the 1990s, the Turkish economy has experienced substantial structural transformation processes shaped by trade liberalization policies, institutional reforms, and integration into global markets. Particularly after the early 2000s, policy initiatives encouraging industrial upgrading and technological innovation have accelerated the expansion of R&D investments and strengthened production capacity. Nevertheless, the magnitude and direction of these developments may differ between short and long-run equilibrium nexus. Thus, investigating these dynamics using an appropriate econometric framework remains essential.

Despite the growing empirical literature on economic growth in Türkiye, studies simultaneously evaluating R&D expenditures, capital formation, unemployment, and inflation within a unified time-series framework remain relatively limited. In addition, empirical applications utilizing the ARDL bounds testing methodology to capture both short-term adjustments and long-term equilibrium relationships are still scarce in the national context.

Accordingly, the basic target of this paper is to spill the dynamic relationships between growth, R&D expenditures, gross fixed capital formation, unemployment, and inflation in Türkiye utilizing yearly data covering the period 1996–2024. The ARDL bounds testing approach is employed to identify both short-run and long-run interactions among these variables. This methodology is principally fit for the analysis since it permits the estimation of cointegration relationships among variables integrated at different orders while producing reliable results in relatively small samples.

This study contributes to the empirical field in some respects. First, it evaluates multiple macroeconomic determinants of growth simultaneously within a unified analytical framework. Second, it distinguishes between short-term adjustment mechanisms and long-term equilibrium dynamics using the ARDL modeling strategy. Finally, by examining the interaction between technological investment, capital accumulation, labor-market conditions, and price stability indicators, the study provides policy-relevant implications for sustainable growth strategies in Türkiye.

2. LITERATURE REVIEW

The determinants of economic growth have been widely examined in the empirical literature by focusing on macroeconomic variables such as research and development expenditures, capital

accumulation, unemployment, and inflation. Existing studies indicate that the magnitude and direction of these relationships differ depending on country characteristics, estimation periods, and methodological approaches. In this respect, time-series techniques, particularly the ARDL bounds testing approach, have frequently been preferred because they enable simultaneous investigation of both short and long-run equilibrium nexus.

Early theoretical contributions emphasize that innovation-driven technological progress constitutes one of the primary engines of sustainable economic expansion. For instance, Segerstrom (2000) argues that policy-based R&D incentives can support long-term growth performance, although their effectiveness may vary depending on structural parameter configurations. Similarly, empirical findings reported by Peng (2010) demonstrate that increases in R&D expenditures significantly contribute to GDP growth in the Chinese economy.

A number of studies examine the influence of UNEMP and INF on economic growth within developping country contexts. Jaradat (2013) identifies a statistically significant negative relationship between unemployment and economic growth in Jordan, while inflation appears to have a supportive role during the analyzed period. In contrast, Shahid (2014) reports that both INF and UNEMP exert adverse effects on growth performance in Pakistan, although only unemployment is statistically significant.

Using an ARDL modeling framework, Mohseni and Jouzaryan (2016) provide evidence that both INF and UNEMP negatively influence long-term growth in Iran. But, empirical findings are not always consistent across countries. For example, Ademola and Badiru (2016) report a positive association between INF, UNEMP, and economic growth in Nigeria, suggesting that macroeconomic transmission mechanisms may differ depending on country-specific structural characteristics.

Recent empirical contributions focusing on Türkiye also highlight the interaction between macroeconomic instability indicators and growth performance. Dayıoğlu and Aydın (2020) show that unemployment exerts a contractionary influence on growth, particularly during crisis periods, while asymmetric causal relationships exist between inflation shocks and output fluctuations.

More recent contributions further emphasize the importance of education expenditures, investment dynamics, and innovation capacity in shaping growth performance. For example, Esen et al. (2023) demonstrate that public education spending positively affects real GDP per capita in the long run within the Turkish economy. Similarly, Mahfoudh et al. (2024) confirm the presence of long-term relationships among unemployment, inflation, and growth indicators in selected MENA economies, although the magnitude of these effects differs across countries.

Recent cross-country evidence also suggests that the contribution of R&D expenditures to growth performance in developing economies may depend on institutional capacity and financial development levels. In this respect, Fayyaz and Bartha (2025) indicate that innovation-related investments do not always generate immediate growth benefits in lower-middle-income countries.

Overall, the empirical literature largely supports the view that capital accumulation and innovation-related expenditures promote economic growth, whereas unemployment generally constrains output expansion by reflecting underutilized labor resources. However, the relationship between inflation and growth appears more ambiguous and context-dependent. Therefore, the present study expects positive long-run effects from R&D expenditures and capital formation, together with negative effects from unemployment and inflation, while acknowledging that empirical outcomes may vary depending on macroeconomic conditions.

3. MODEL SPECIFICATION AND DATA

3.1 Model Specification

To find out the dynamic interactions among economic growth and its macroeconomic determinants, this study employs the ARDL modeling framework. The ARDL framework provides a flexible

structure that enables the estimation of both short and long-run adjustment relationships among variables that are integrated at different orders, provided that none of them are integrated beyond the first difference.

Prior to forecasting the ARDL model, the time-series characteristics of the variables are examined utilizing conventional unit root testing procedures. Identifying the integration order of each variable is essential to ensure the suitability of the ARDL bounds testing technique. The Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests are applied to determine whether the series are stationary at their levels or after first differencing.

Within this framework, the empirical nexus between real GDP per capita and the selected explanatory variables is represented through a log-linear specification. Real GDP per capita is treated as the dependent variable, while research and development expenditures, gross fixed capital formation, unemployment, and inflation are incorporated as explanatory variables reflecting technological investment, capital accumulation, labor-market conditions, and macroeconomic stability, respectively.

Within this framework, the econometric model is specified as follows:

$$\ln GDP_{pct}=\alpha_0+\alpha_1 \ln GDP_{pct-1}+\beta_1 RD_t+\beta_2 GFCF_t+\beta_3 UNEMP_t+\beta_4 INF_t+\varepsilon_t$$

In the model, the natural logarithm of real GDP per capita (lnGDPpc) is the dependent variable. At the same time, RD, GFCF, UNEMP, and INF are independent variables. Within this framework, the determinants of economic growth are analyzed both theoretically and empirically.

After confirming the integration characteristics of the data, the bounds testing method investigated by Pesaran, Shin, and Smith (2001) is implemented to probe the existence of a long-run link among the variables. Once cointegration is verified, long-run parameters are estimated and an error-correction representation of the model is constructed to capture short-term dynamics around the equilibrium path. A statistically significant and negative coefficient indicates that deviations from long-run equilibrium are gradually adjusted over time.

3.2. Data

This study utilizes annual observations covering the period from 1996 to 2024 to analyze the macroeconomic determinants of economic growth in Türkiye. The dataset is compiled from the World Bank database, which provides internationally comparable macroeconomic indicators.

Table 1. *Definition of Variables*

Variable	Abbreviation	Description	Transformation
Real GDP per capita	lnGDPpc	Real GDP per capita at constant prices (USD)	Natural logarithm
R&D expenditures	RD	Share of GDP (%)	Level
Unemployment rate	UNEMP	Percentage of total labor force (%)	Level
Inflation rate	INF	Annual percentage change in the Consumer Price Index (CPI)	Level
Gross fixed capital formation	GFCF	Share of GDP (%)	Level

Real GDP per capita is employed as a proxy for economic growth and transformed into its natural logarithmic form to abate scale differences and improve the interpretability of estimated coefficients. Research and development expenditures are measured as the percentage share of total R&D spending in gross domestic product and represent technological investment capacity within the economy. The unemployment rate reflects labor-market conditions by capturing the proportion of unemployed individuals in the total labor force. Inflation is represented by the annual percentage change in the CPI which offers as a gauge of macroeconomic stability. Finally, GFCF is included as a representative for physical capital accumulation and measured as a percentage of GDP.

Overall variables are expressed in annual frequency. While most explanatory variables are used in their original level form, the dependent variable is transformed into logarithmic form to ensure consistency with standard empirical growth specifications.

4. METHODOLOGY

The empirical framework of this study is based on the ARDL bounds testing methodology, which consents the contemporaneous investigation of short and long-run relationships within a unified modeling structure. One of the major benefits of the ARDL approach is its applicability to variables integrated at different orders, providing that none of them exhibit second-order integration.

The estimation procedure begins with testing the stationarity properties of the variables using unit root tests. This step ensures that the integration orders satisfy the methodological requirements of the ARDL framework. Following this preliminary stage, the bounds technique is performed to identify whether a long-run equilibrium nexus consists among the factors included in the model.

Once the presence of cointegration is confirmed, long-run coefficients are estimated in order to evaluate equilibrium interactions between economic growth and its determinants. In addition, short-run dynamics are examined through an error-correction representation that captures the speed at which the system adjusts back toward equilibrium following temporary shocks.

Appropriate lag lengths are selected using conventional information criteria to guarantee the robustness of the estimated model. Furthermore, different diagnostic procedures are handled to evaluate model adequacy, including tests for serial correlation, heteroskedasticity, and normality. Stability properties of the estimated coefficients are also assessed to verify the consistency of parameter estimates over the sample period. All estimations are performed using EViews econometric software.

5. EMPIRICAL RESULTS AND DISCUSSION

5.1. Unit Root Tests

The stationarity properties of the series are examined utilizing the ADF and PP unit root tests, and the results are given in Table 2. According to the ADF test results, the test statistic for real GDP per capita at the level is -6.273, with a p-value of 0.0002, confirming that the series is stationary at the level. But, the PP test results for the same variable yield a test statistic of -2.520 with a p-value of 0.3169, suggesting the existence of a unit root at the level. When the results of the two tests differ, a more conservative approach is adopted, and the first difference of the variable is used. Accordingly, the PP test statistic for the first difference of real GDP per capita is -4.993, with a p-value of 0.0022, accepting that the series is stationary at the first difference.

The R&D expenditure variable is found to be non-stationary at the level; however, when its first difference is taken, the ADF test statistic is -5.430 (p=0.0001) and the PP test statistic is -5.459 (p=0.0007). These results remark that the variable is stationary at the 1% significance level according to both tests. Similarly, for the unemployment rate, the ADF test statistic for the first difference is -4.379 (p=0.0019), while the PP test statistic is -4.567 (p=0.0060), confirming stationarity at first difference based on both tests.

For the inflation rate, the ADF test statistic for the first difference is -4.994 (p=0.0004), and the PP test statistic is -16.255 (p=0.0000), showing strong stationarity. Likewise, for gross fixed capital formation, the ADF test statistic for the first difference is -5.122 (p=0.0003) and the PP test statistic is -5.122 (p=0.0003), confirming that this variable is also stationary at first difference.

The time-series properties of the variables are considered utilizing both ADF and PP tests to determine their integration orders. Determining whether the factors are stationary at level or after first differencing is a crucial step before implementing the ARDL bounds testing framework.

The empirical results remark that several variables are not stationary at their level values but turn into stationary after first differencing. This finding implies that the variables are integrated of order one. Importantly, none of the variables exhibit second-order integration, which satisfies the main precondition for applying the ARDL methodology.

Since the variables are integrated at either level or first difference, the ARDL bounds testing approach can be implemented reliably to probe the existence of long-run relationships among the selected indicators.

Table 2. *Results of ADF and PP Unit Root Tests*

Variable	ADF (t-stat, p-value)		PP (t-stat, p-value)		Order of Integration
	Level	First Difference	Level	First Difference	
lnGDPpc	-6.273 (0.0002)	–	-2.520 (0.3169)	-4.993 (0.0022)	I(1)
RD	–	-5.430 (0.0001)	–	-5.459 (0.0007)	I(1)
UNEMP	–	-4.379 (0.0019)	–	-4.567 (0.0060)	I(1)
INF	–	-4.994 (0.0004)	–	-16.255 (0.0000)	I(1)
GFCF	–	-5.122 (0.0003)	–	-5.122 (0.0003)	I(1)

Note: *The values in parentheses represent probability (p-values). The symbol (–) indicates that the test was not applied or the series was non-stationary at the level.*

A comprehensive evaluation of the findings indicates that all indicators in the model exhibit unit root properties at their level values, but turn into stationary after first differencing. This implies that all series are integrated of order I (1), and none of the variables require second differencing to turn into stationarity. These results corroborate that the variables do not exhibit higher-order integration, thereby supporting the key preconditions for the use of the ARDL method. Accordingly, the ARDL methodology is deemed appropriate, as it consents for the forecast of both short-run and long-run relationships in the presence of variables integrated at various orders, ensured that none of the indicators are integrated of order I(2) or higher.

5.2. ARDL Bounds Testing Approach

Following the unit root analysis, the ARDL bounds is performed to peruse whether a long-run equilibrium nexus consists among economic growth and its macroeconomic determinants. The bounds testing framework interpret the joint significance of lagged level variables via F-statistic that is compared with critical value bounds provided in the literature.

The estimated F-statistic passes the upper critical bound at conventional significance levels, indicating rejection of the null hypothesis of no cointegration. This result affirms the presence of a stable long-run equilibrium link among real GDP per capita, research and development expenditures, GFCF, unemployment, and inflation.

The presence of cointegration allows the forecast of long-run coefficients and supports the construction of an error-correction representation to analyze short-run adjustment mechanisms.

The unit root tests point out that all factors in the equation are integrated of order I(1), thereby fulfilling the required preconditions for the application of the ARDL bounds testing. Within this framework, the ARDL bounds test is run to view the presence of a long-run nexus among the variables.

Table 3. *ARDL Bounds Test Results*

Test Statistic	Value	Significance Level	Lower Bound I(0)	Upper Bound I(1)
F-statistic	14.49	10%	2.2	3.09
	5%	2.56	3.49	
	2.50%	2.88	3.87	
	1%	3.29	4.37	

Note: *Critical values are based on Pesaran et al. (2001).*

According to the bounds test given in Table 3, the calculated F-statistic is 14.49. This value is substantially higher than the upper bound (4.37) at the 1% significance level. Accordingly, the null hypothesis of no cointegration among the variables is rejected, confirming the presence of a long-run cointegration nexus.

This finding indicates that real GDP per capita, R&D, UNEMP, INF, and GFCF act together in the long run and maintain a stable equilibrium relationship. Cointegration allows estimation of long-run coefficients and the construction of an ECM to analyze short-run dynamics.

5.3. Long-Run ARDL Estimation Results

The long-run coefficients from the ARDL model show a statistically significant equilibrium relationship between real GDP per capita and research and development (R&D) expenditures, GFCF, the UNEMP, and INF. According to the estimation results, R&D expenditures (RD) and GFCF have a positive influence on growth in the long-time frame. In contrast, the UNEMP and INF exert adverse, statistically significant effects. Moreover, the fact that all probability values are below the 5% significance level suggests that the long-run relationships are statistically robust.

Table 4. *Long-Run ARDL Estimation Results*

Variable	Coefficient	Std. Error	t-statistic	Probability (p-value)
GFCF	0.0343	0.0037	9.315	0
INF	-0.0027	0.0007	-4.141	0.0012
RD	0.6651	0.041	16.214	0
UNEMP	-0.0321	0.0085	-3.779	0.0023
C	8.1914	0.1255	65.279	0

Note: *The dependent variable is the natural logarithm of real GDP per capita in Table.4 and Table.5*

The positive (0.665) and statistically significant coefficient R&D expenditures indicates that technological development and knowledge accumulation are key determinants of growth in the long run. R&D spending enhance innovation capacity, increase total factor productivity, improve the efficiency of production processes, and expand the economy's potential output level. This finding is parallel with the endogenous growth theory framework, which declares technology and knowledge as internal determinants of growth. Therefore, R&D activities are a fundamental structural factor supporting long-term economic growth in the Turkish economy.

The positive (0.034) and statistically significant coefficient of gross fixed capital formation indicates the supportive function of physical capital accumulation in long-run economic growth. Gross fixed capital formation enhances production capacity, increases the capital–labor ratio, improves labor productivity, and thereby promotes higher per capita income. This result is parallel with the neoclassical growth literature, which identifies capital accumulation as a fundamental determinant of economic growth. In the context of Türkiye, it suggests that sustaining investment levels is critical for achieving long-term growth and income expansion.

The negative (-0.032) and statistically significant coefficient for the unemployment rate represents that idle labor capacity exerts downward pressure on economic growth in the long run. An increase in unemployment reduces the effective use of labor in production, leading to underutilization of human capital. It may also weaken household income and aggregate demand, thereby adversely affecting growth performance. This finding is consistent with the literature emphasizing the relationship between employment and output, as well as the importance of labor market efficiency for economic growth.

The negative (-0.0027) and statistically significant coefficient of inflation indicates that price instability constrains economic growth in the long run. Rising inflation increases uncertainty, adversely influences investment decisions, reduces the efficiency of financial markets, and distorts resource allocation. In this context, the findings are consistent with empirical evidence emphasizing the importance of macroeconomic stability for sustainable economic growth. From the perspective of the Turkish economy, maintaining price stability is a fundamental prerequisite for supporting long-term growth.

Overall, the long-run estimation results indicate that technological progress (R&D) and capital accumulation are key determinants of increases in real GDP per capita in Türkiye. In contrast, labor

market inefficiencies (unemployment) and macroeconomic instability (inflation) exert downward pressure on growth. From a policy perspective, strengthening R&D incentives, improving the investment climate, implementing employment-enhancing structural reforms, and maintaining price stability are critical areas for fostering long-term economic growth and improving welfare.

The estimated long-run coefficients obtained from the ARDL model reveal statistically significant relationships between economic growth and its selected determinants. In particular, research and development expenditures and gross fixed capital formation exhibit positive and significant effects on real GDP per capita, suggesting that both technological investment and physical capital accumulation contribute to strengthening long-term production capacity.

From a theoretical perspective, increased R&D expenditures enhance innovation capability, improve production efficiency, and support productivity growth through knowledge accumulation processes. These mechanisms are consistent with the predictions of endogenous growth theory, which emphasizes the central role of technological progress in sustaining long-term economic expansion.

Similarly, the positive contribution of gross fixed capital formation indicates that investment in physical infrastructure and productive capacity plays an important role in supporting output growth over time. Higher capital accumulation improves the capital–labor ratio and increases overall production efficiency.

In contrast, unemployment and inflation are found to exert negative effects on economic growth in the long run. Persistent unemployment reflects underutilization of labor resources and weakens aggregate production capacity, while inflation may create uncertainty in economic decision-making processes and reduce investment efficiency.

5.4. Short-Run ARDL Results and ECM Analysis

The results of the ECM is given in Table 5. The coefficient of the EC term is -0.483, which is statistically significant at the 1% level. The fact that this coefficient is negative and significant reflects that short-term imbalances are adjusted towards the long-term equilibrium value. According to the findings, approximately 48% of the deviations occurring in the system are corrected within a period. This implies that the model is dynamically stable and converges to a long-term equilibrium.

An examination of the short-run coefficients reveals that gross fixed capital formation is positive and statistically significant both in the current period (0.0184) and with a one-period lag (0.0128). This finding indicates that investments support economic growth in the short run and that the effect of capital accumulation on growth persists with a lagged effect.

Table 5. *Short-Run ARDL and Error Correction Model (ECM) Results*

Variable	Coefficient	Std. Error	t-statistic	Probability (p-value)
ΔlnGDPpc(-1)	-0.8524	0.1184	-7.197	0
ΔGFCF	0.0184	0.0014	13.356	0
ΔGFCF(-1)	0.0128	0.002	6.567	0
ΔINF	0.0002	0.0002	0.779	0.4498
ΔRD	-0.1792	0.0406	-4.412	0.0007
ΔRD(-1)	-0.3189	0.0697	-4.576	0.0005
ΔUN	-0.0063	0.0025	-2.523	0.0255
ΔUN(-1)	0.0076	0.0028	2.715	0.0177
ECM(-1)	-0.483	0.044	-10.972	0

Note: *ECM(-1) denotes the error correction term.*

The short-run coefficients of R&D expenditures are adverse and statistically significant both in the current period (-0.1792) and at the first lag (-0.3189), indicating that these expenditures initially act as a cost factor. The short-run restraining effect of R&D on growth can be explained by the delayed realization of its benefits, which tend to materialize over the long term. Indeed, the long-run coefficients confirm that R&D expenditures have a positive influence on growth.

The negative, significant coefficient for the unemployment rate in the current period (-0.0063) suggests that labor market contractions exert downward pressure on short-run growth. In contrast, the positive and significant coefficient for its lagged value (0.0076) indicates that labor market adjustments may partially compensate for growth over time.

The inflation's short-run coefficient is statistically insignificant, implying that price movements do not have a pronounced influence on growth in the short run, and that their effects are more evident in the long run.

The adverse and significant coefficient of the lagged dependent variable (-0.8524) represents the existence of a short-run adjustment mechanism, indicating that previous increases in growth are partially corrected in subsequent periods.

Overall, the short-run findings suggest that investment supports economic growth, unemployment exerts a negative influence, and R&D expenditures generate a short-run cost effect. The magnitude and statistical significance of the EC term further indicate a relatively rapid adjustment of the system toward long-run equilibrium.

5.5. Diagnostic Test Results and Model Validity

The unit root and ARDL bounds procedure results remark the existence of a long-run cointegration link between the variables, that the long-term coefficients are statistically significant, and that the EC term is negative and significant. Whereas these results relieve the theoretical validity of the model, diagnostic tests are managed to consider the reliability of the estimation results. The results of the diagnostic tests are given in Table 6.

Table 6. *Diagnostic Test Results*

Test	Statistic	Probability (p-value)	Conclusion
Breusch–Godfrey LM (F)	3.2129	0.0796	No autocorrelation
Breusch–Godfrey LM (Obs*R^2)	9.9562	0.0069	–
Breusch–Pagan–Godfrey (F)	6.4225	0.001	–
Breusch–Pagan–Godfrey (Obs*R^2)	23.3624	0.0375	–
Breusch–Pagan–Godfrey (Scaled SS)	3.2853	0.9967	No heteroskedasticity
Jarque–Bera	0.7168	0.6987	Residuals are normally distributed.

Note: *Conclusions are based on the 5% significance level.*

The diagnostic test in Table 6 support the validity of the ARDL model. According to the Breusch–Godfrey serial correlation test, the p-value for the F-statistic (0.0796) goes beyond the 5% significance level, gauging that the null hypothesis of no autocorrelation cannot be rejected. Considering the small sample size, the evaluation is primarily based on the F-statistic.

Regarding heteroskedasticity, the results of the Breusch–Pagan–Godfrey test represent that the p-value for the scaled explained sum of squares statistic is 0.9967. This value is well above the 5% significance level, suggesting the absence of heteroskedasticity. Therefore, the assumption of homoskedasticity is satisfied.

The Jarque–Bera normality test yields a probability value of 0.6987, gauging that the residuals are normally distributed. This finding further supports the model's statistical reliability.

Overall, the diagnostic test results reported in Table 6 imply that the ARDL model does not exhibit autocorrelation or heteroskedasticity, and that the residuals are suited a normal distribution. These results confirm the econometric validity of the model and indicate that both the short and long-run coefficients can be judged with confidence.

To assess parameter stability, the CUSUM and CUSUMSQ tests are utilised, and the corresponding plots are presented in Figures 1 and 2. The CUSUM test results show that the cumulative sum remains within the critical bounds at the 5% significance level, indicating that the model coefficients are stable over the sample period and that no structural breaks are present.

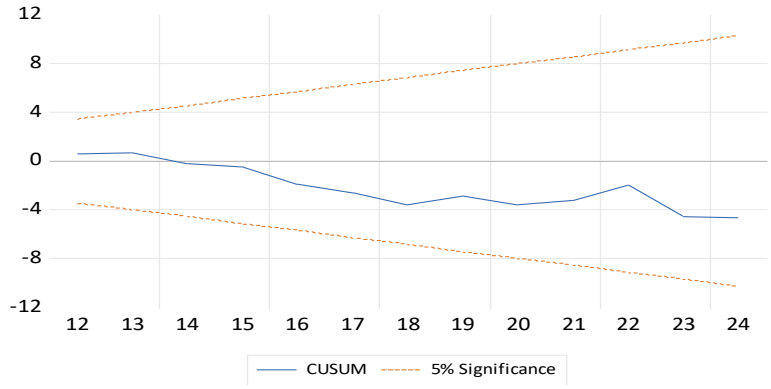

Figure 1. *CUSUM Test Results*

The CUSUMSQ plot points out that the cumulative sum of squared residuals maintains within the critical bounds, commenting that the model does not exhibit variance instability. This finding alludes that the forecasted coefficients do not exhibit significant structural changes over time and remain stable throughout the sample period.

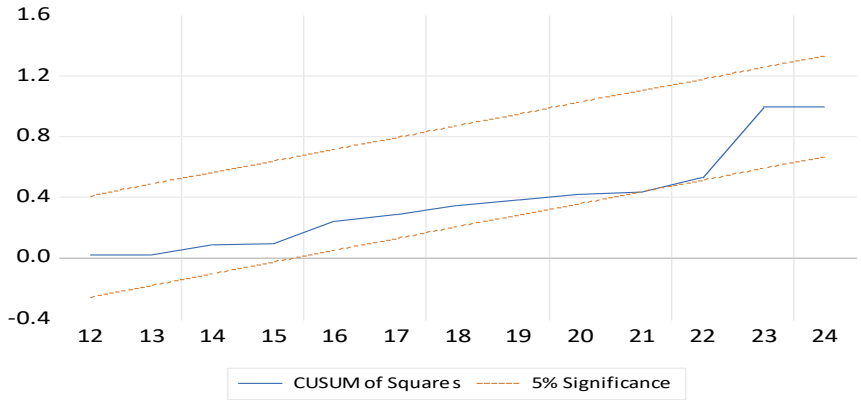

Figure 2. *CUSUMSQ Test Results*

When the results of both tests are considered jointly, it can be concluded that the ARDL model maintains parameter stability throughout the sample period and does not exhibit any structural breaks. This finding, together with the cointegration relationship established through unit root and bounds test results, further supports the validity of the ECM and indicates that the estimated long-run and short-run parameters can be appraised with confidence.

6. CONCLUSION

This study analyzes the short- and long-term relationships between real per capita income, R&D expenditures, GFCF, UNEMP, and INF in the Turkish economy using the ARDL bounds test approach. Findings from unit root tests imply that the variables are integrated of order 1, while bounds test results give the existence of a long-term cointegration relationship between the variables. The negative, statistically significant error-correction coefficient indicates that short-term imbalances are corrected towards the long-term equilibrium value and that the model is dynamically stable.

The long-run results reveal that R&D expenditures and GFCF have a positive and significant impact on economic growth. This finding is consistent with endogenous growth theory, which emphasizes technology, knowledge accumulation, and innovation as internal drivers of growth. R&D activities enhance total factor productivity, improve production efficiency, and contribute to sustainable long-term growth. Similarly, the positive effect of GFCF aligns with neoclassical growth theory, which

empasizes the role of capital accumulation in expanding production capacity and increasing per capita income.

The negative impact of unemployment on growth suggests that inefficient labor utilization limits output, consistent with Okun's Law. Increased idle capacity in the labor market not only reduces production but also weakens aggregate demand, thereby hindering economic growth. The negative effect of inflation on growth supports theoretical perspectives emphasizing the importance of macroeconomic stability and the role of inflation-induced uncertainty in discouraging investment.

Short-run findings indicate that gross fixed capital formation continues to support economic growth. In contrast, the negative short-run effect of R&D expenditures reflects their initial cost nature, with their benefits materializing over time. This result is consistent with the literature emphasizing the delayed impact of R&D activities. The negative short-run effect of unemployment further highlights the direct influence of labor market fluctuations on production.

Diagnostic test results confirm that the model does not suffer from autocorrelation or heteroskedasticity, that the residuals are normally distributed, and that the CUSUM and CUSUMSQ tests indicate parameter stability. These findings demonstrate that the estimated coefficients are reliable and that the model is econometrically valid.

From a policy perspective, the findings suggest that strengthening R&D activities and enhancing innovation capacity should be prioritized. In this regard, increasing R&D incentives, supporting technology-oriented investments, and fostering university–industry collaboration are critical. Furthermore, improving the investment climate, expanding access to finance for productive sectors, and increasing infrastructure investments will support long-term growth performance. In the labor market, implementing employment-enhancing structural reforms, improving workforce skills through education policies, and reducing youth unemployment through targeted programs are essential for sustaining growth. Additionally, maintaining price stability and controlling inflation will reduce uncertainty in investment and savings decisions, thereby providing a stable macroeconomic environment for sustainable growth.

In conclusion, achieving sustainable economic growth in Türkiye requires the coordinated implementation of technology- and innovation-driven policies alongside structural reforms to enhance capital accumulation and employment. Accelerating the transition toward a knowledge- and technology-based economic structure, as suggested by endogenous growth theory, and maintaining macroeconomic stability are crucial for long-term growth and welfare improvement.

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