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The Impact of Technological Research and Development on Economic Growth in Turkey: An Econometric Study for the Period (1990–2023)

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Abstract:
This study aims to evaluate and quantify the long-run impact of technological research and development (R&D) on economic growth in Turkey over the period 1990–2023. To achieve this objective, the analysis employs a range of econometric techniques, including unit root tests to examine the stationarity of time series data, as well as cointegration testing using the bounds testing approach within the Autoregressive Distributed Lag (ARDL) framework. The empirical findings indicate that high-technology exports, R&D expenditure, and patent application filings exert a positive and statistically significant effect on Turkey's long-term economic growth. In contrast, scientific and technical journal publications, as well as the labor force, demonstrate a negative impact on economic growth over the same period.

Keywords: Technological Research and Development, Economic Growth, ARDL Methodology, Turkey.
JEL Classification: O32, O40, C50, C52.

1. Introduction

Interest in scientific research and technological advancement is widely regarded as a fundamental indicator of societal progress and economic development. These elements play a critical role in stimulating economic growth by enhancing the technological level within an economics, thereby increasing aggregate output. Expenditure on research and development (R&D) constitutes one of the primary drivers of economic growth, particularly in advanced economies, due to its positive impact on productivity improvements and long-term expansion.

Schumpeter (1934) introduced a framework in which technological progress and innovation are considered the principal engines of economic growth. According to this perspective, economic advancement occurs when entrepreneurs introduce new innovations—such as products, processes, or organizational methods—into the market, thereby fostering competitive dynamics that propel growth (Attar, 2017, p. 133). In contrast, the Solow model (1956) emphasizes productivity growth through capital accumulation and exogenous technological progress. Within this framework, innovation and technological development are treated as external factors essential for achieving long-term economic growth, rather than outcomes of internal economic processes (Blanco, Prieger, & Gu, 2013, p. 05).

Subsequently, Romer (1986) developed a more comprehensive endogenous growth model, positing that economic growth can arise from internal activities, particularly investments in R&D. Such investments enhance total output and position innovation, human capital, and technology as central determinants of sustained economic expansion (Blanco, Prieger, & Gu, 2013, p. 05). Similarly, Grossman and Helpman (1991) highlighted the role of R&D in international trade and economic growth, arguing that R&D activities contribute to the creation of new products and the improvement of existing ones, thereby strengthening international competitiveness and fostering long-term growth (Blanco, Prieger, & Gu, 2013, p. 06).

In recent years, Turkey has emerged as a rapidly developing economy in the field of scientific research and technological innovation. Recognizing the strategic importance of R&D as a cornerstone for sustainable economic progress, the country has actively fostered a conducive investment environment by strengthening research infrastructure, increasing expenditure in higher education, and promoting collaboration among universities, research centers, and industrial firms. Additionally, Turkey has sought to integrate into advanced scientific research and technological development through international partnerships.

1.1. Research Problem:

Based on the foregoing discussion, the central research question can be formulated as follows: To what extent does technological research and development influence economic growth in Turkey over the period 1990–2023?

1.2. Research Hypothesis:

The study is grounded in the hypothesis that the impact of technological R&D indicators on economic growth in Turkey varies in magnitude and significance.

1.3. Research Objective:

The primary objective of this study is to measure the effect of technological research and development on economic growth in Turkey in both the short and long run over the period 1990–2023.

2. Econometric Analysis of the Impact of Technological R&D on Economic Growth in Turkey (1990–2023):

2.1. Methodology and Analytical Tools:

To address the research objectives, the study employs the Autoregressive Distributed Lag (ARDL) model, as developed by Pesaran, Shin, and Smith (2001). This approach is utilized to construct an econometric model that captures the relationship between technological R&D and economic growth in Turkey. Additionally, the bounds testing procedure is applied to examine the existence of a long-run equilibrium (cointegration) relationship among the study variables.The widespread application of the ARDL bounds testing methodology in recent empirical studies has led to several methodological refinements. Narayan (2005) introduced new critical values tailored for small sample sizes (30–80 observations), addressing limitations in the original critical values proposed by Pesaran et al. (2001). Shin, Yu, and Greenwood-Nimmo (2014) further extended the ARDL framework by developing the Nonlinear ARDL (NARDL) model, which captures asymmetric (positive and negative) effects among variables. Moreover, McNown, Sam, and Goh (2016) proposed an augmented ARDL bounds testing approach to address issues related to degenerate cointegration, particularly under assumptions concerning the stationarity of the dependent variable. Later, Sam, McNown, and Goh (2019) enhanced the bounds testing procedure by incorporating additional statistical tests, such as the T-test for the lagged dependent variable and the F-test for lagged independent variables, thereby improving the robustness of cointegration analysis.

2.1.1. Study Methodology:

The ARDL methodology involves both pre-estimation and post-estimation testing procedures. The pre-estimation stage includes unit root tests to assess the stationarity properties of the time series variables. A key advantage of the ARDL approach is that it does not require all variables to be integrated of the same order; it can accommodate variables that are stationary at level I(0), integrated of order one I(1), or a mixture of both. Following stationarity testing, the ARDL model is estimated, and the optimal lag structure is determined. The post-estimation phase involves conducting the bounds test for cointegration, estimating the Error Correction Model (ARDL-ECM), and performing diagnostic tests, including tests for serial correlation (LM test), heteroskedasticity, and structural stability of model parameters.

2.1.2. Variables and Model Specification:

The study incorporates a set of variables selected based on prior empirical literature. These variables are defined as follows:

- **Dependent Variable:**

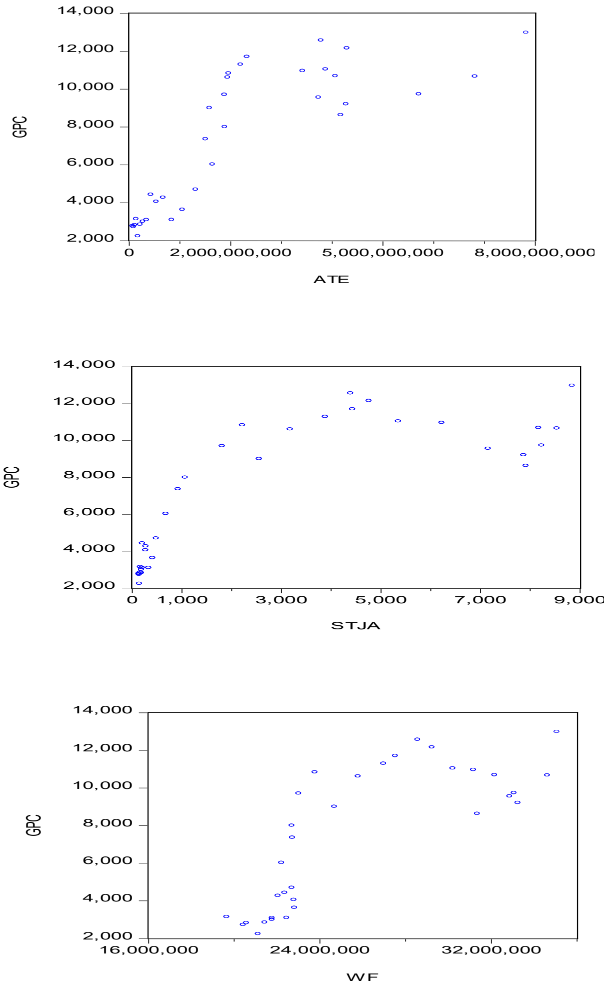
Economic growth is proxied by GDP per capita (GPC) in Turkey, expressed in current U.S. dollars, obtained from the World Bank database.

- **Independent Variables:**

Indicators of technological research and development in Turkey, also sourced from the World Bank database, include:

- High-technology exports (ATE)
- Expenditure on research and development (SRD)
- Scientific and technical journal articles (STJA)
- Patent applications (PRAR)
- Labor force (WF)

Based on these variables, an econometric model is specified to examine the impact of technological R&D on economic growth in Turkey during the period 1990–2023, as illustrated in the corresponding model framework.

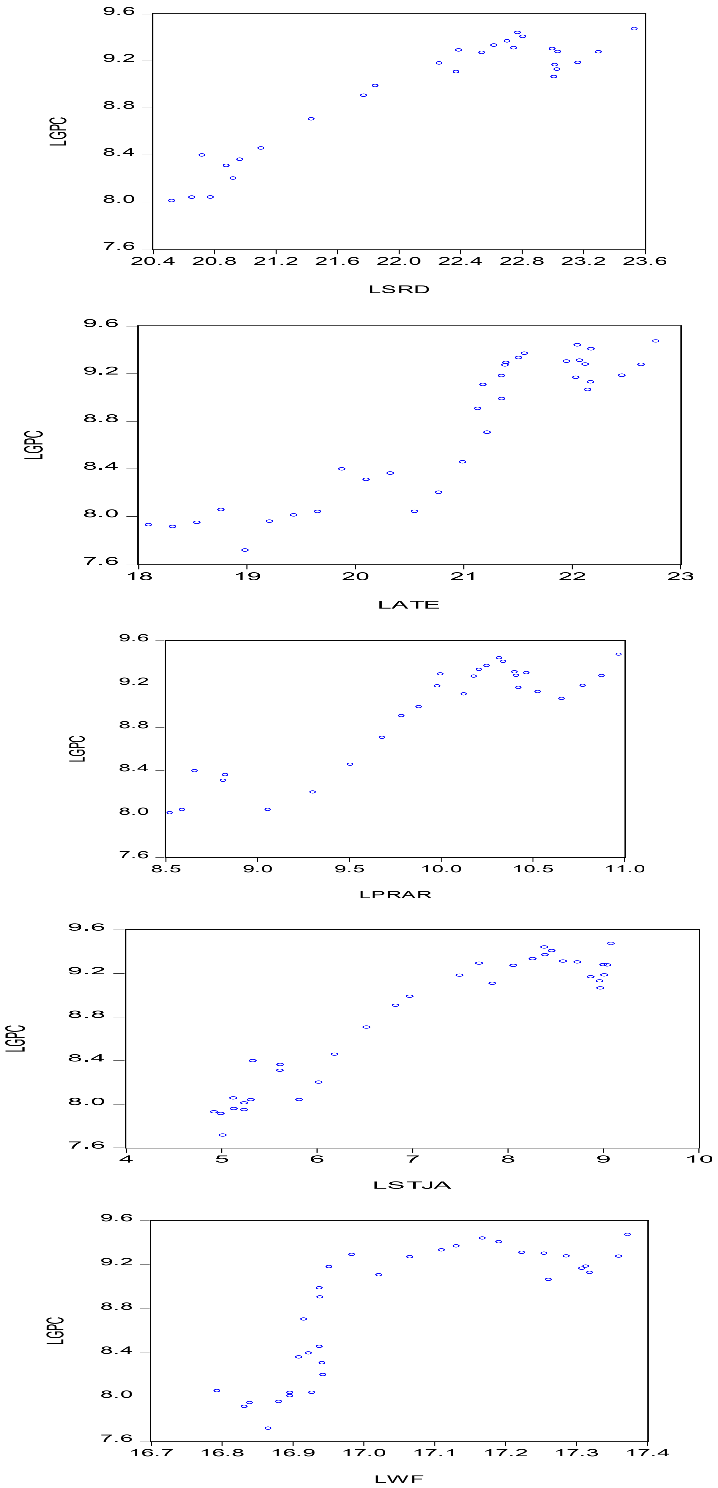


Source: Prepared by the authors based on outputs generated using EViews 12.

In examining the relationship between the independent variables—namely high-technology exports (ATE), research and development expenditure (SRD), scientific and technical journal articles (STJA), patent applications (PRAR), and labor force (WF)—and the dependent variable represented by GDP per capita (GPC), the initial scatter plot analysis indicates the presence of a linear relationship between the explanatory variables (technological R&D indicators) and economic growth.

However, after applying a logarithmic transformation to the study variables, this relationship becomes more pronounced and statistically tractable. The dispersion pattern of the data points exhibits greater homogeneity, with values appearing more closely clustered. Furthermore, the logarithmic transformation contributes to mitigating the influence of outliers and extreme values, thereby enhancing the robustness and interpretability of the model, as illustrated in the figure below.

Figure (02): Study Model after Logarithmic Transformation of Variables



Source: Prepared by the authors based on outputs generated using EViews 12.

Accordingly, the study model can be reformulated as follows:

$$\mathbf{LGPC_t = \beta_0 + \beta_1 LATE_t + \beta_2 LSRD_t + \beta_3 LSTJA_t + \beta_4 LPRAR_t + \beta_5 LWF_t + U_t}$$

3. Results Analysis and Discussion:

3.1. Time Series Stationarity Analysis: Examining the stationarity of the model's time series variables constitutes a fundamental prerequisite prior to conducting econometric modeling, primarily to avoid the issue of spurious regression between the dependent and independent variables. To assess stationarity and determine the order of integration, the study employs two widely recognized unit root tests: the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979) and the Phillips-Perron (PP) test (Phillips & Perron, 1988). These tests are used to investigate the presence of unit roots within the series under consideration. The following table presents the results of the unit root tests for the study variables.

Table (01): Time Series Stationarity Test

UNIT ROOT TEST TABLE (ADF)

	At Level						
		LGPC	LATE	LSRD	LSTJA	LPRAR	LWF
With Constant	t-Statistic	-0.9032	-2.5258	-0.9026	-0.5192	-1.7907	0.6187
	Prob.	***0.7746***	***0.1187***	***0.7717***	***0.8749***	***0.3765***	***0.9881***
		n0	n0	n0	n0	n0	n0
With Constant & Trend	t-Statistic	-1.6707	-1.8668	-1.2881	-0.8749	-1.8637	-1.7587
	Prob.	***0.7416***	***0.6488***	***0.8693***	***0.9472***	***0.6440***	***0.7009***
		n0	n0	n0	n0	n0	n0
Without Constant & Trend	t-Statistic	1.6600	5.2983	4.3735	4.8640	2.2746	3.4806
	Prob.	***0.9739***	***1.0000***	***1.0000***	***1.0000***	***0.9927***	***0.9997***
		n0	n0	n0	n0	n0	n0
	At First Difference						
		d(LGPC)	d(LATE)	d(LSRD)	d(LSTJA)	d(LPRAR)	d(LWF)
With Constant	t-Statistic	-5.8389	-5.0119	-4.2716	-4.5950	-3.0992	-5.7779
	Prob.	***0.0000***	***0.0003***	***0.0026***	***0.0009***	***0.0391***	***0.0000***
		***	***	***	***	**	***
With Constant & Trend	t-Statistic	-5.7627	-5.5069	-4.2077	-4.5453	-3.3807	-5.9461
	Prob.	***0.0002***	***0.0005***	***0.0139***	***0.0052***	***0.0760***	***0.0002***
		***	***	**	***	*	***
Without Constant & Trend	t-Statistic	-5.3840	-3.1534	-1.6077	-0.9611	-1.6631	-4.3265
	Prob.	***0.0000***	***0.0026***	***0.1003***	***0.2930***	***0.0902***	***0.0001***
		***	***	n0	n0	*	***

Notes: (*)Significant at the 10%; (**)Significant at the 5%; (***) Significant at the 1%. and (no) Not Significant
*MacKinnon (1996) one-sided p-values.

UNIT ROOT TEST TABLE (PP)

	At Level						
		LGPC	LATE	LSRD	LSTJA	LPRAR	LWF
With Constant	t-Statistic	-0.9032	-2.5927	-0.8945	-0.5409	-1.7114	0.6187
	Prob.	***0.7746***	***0.1046***	***0.7743***	***0.8704***	***0.4144***	***0.9881***
		n0	n0	n0	n0	n0	n0
With Constant & Trend	t-Statistic	-1.7811	-1.8650	-1.4674	-1.4665	-1.3721	-1.7263
	Prob.	***0.6910***	***0.6497***	***0.8159***	***0.8209***	***0.8462***	***0.7159***
		n0	n0	n0	n0	n0	n0
Without Constant & Trend	t-Statistic	1.6600	4.3644	4.1236	3.3782	4.2698	3.6118
	Prob.	***0.9739***	***1.0000***	***0.9999***	***0.9996***	***1.0000***	***0.9998***
		n0	n0	n0	n0	n0	n0
	At First Difference						
		d(LGPC)	d(LATE)	d(LSRD)	d(LSTJA)	d(LPRAR)	d(LWF)
With Constant	t-Statistic	-5.8389	-5.0405	-4.2690	-4.8172	-3.0464	-5.7822
	Prob.	***0.0000***	***0.0003***	***0.0027***	***0.0005***	***0.0436***	***0.0000***
		***	***	***	***	**	***
With Constant & Trend	t-Statistic	-5.7626	-5.5071	-4.2077	-4.7629	-3.3406	-5.9479
	Prob.	***0.0002***	***0.0005***	***0.0139***	***0.0030***	***0.0820***	***0.0002***
		***	***	**	***	*	***
Without Constant & Trend	t-Statistic	-5.4148	-3.0402	-2.6771	-3.0465	-1.4590	-4.4257
	Prob.	***0.0000***	***0.0035***	***0.0095***	***0.0035***	***0.1319***	***0.0001***
		***	***	***	***	n0	***

Source: Prepared by the authors based on outputs generated using EViews 12.

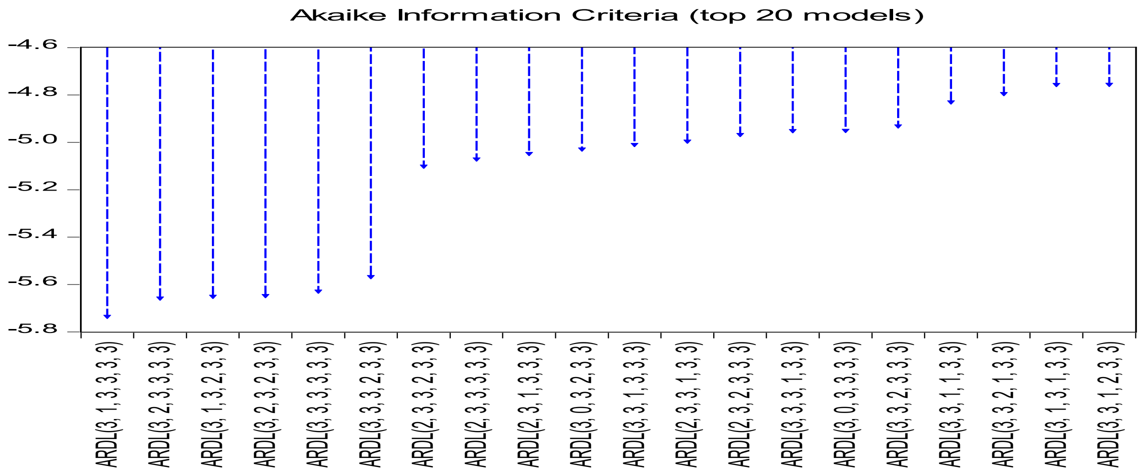
The results reported in the table indicate that all study variables are non-stationary at their levels according to both tests. This implies acceptance of the null hypothesis, which states that the data are non-stationary at level, as the calculated t-statistics are not statistically significant at the 5% significance level across all model specifications. However, upon taking the first difference of the variables, the results reveal that all series become stationary. Consequently, the null hypothesis is rejected in favor of the alternative hypothesis at the 5% significance level.

Based on these findings, it can be concluded that all variables are integrated of order one, I(1). This outcome justifies the use of the Autoregressive Distributed Lag (ARDL) model as an appropriate framework for testing the study hypothesis.

3.2. Estimation of the ARDL Model:

Prior to conducting the cointegration test, it is necessary to determine the optimal lag length of the ARDL model. According to the Akaike Information Criterion (AIC) (Akaike, 1973), the optimal specification is ARDL (3,1,3,3,3,3), which yields the lowest AIC value of (-5.735) compared to alternative estimated models. The following figure illustrates the optimal lag structure of the model.

Figure (03): Optimal Lag Length Selection



Source: Prepared by the authors based on outputs generated using EViews 12.

3.3. Bounds Testing Approach to Cointegration:

The ARDL methodology, initially developed by Pesaran and Shin (1995) and later extended by Pesaran (1997) and Pesaran, Shin, and Smith (2001), is based on testing for the existence of a long-run equilibrium (cointegration) relationship among variables. This is achieved through the bounds testing approach (Bounds Test), which offers several advantages over traditional cointegration techniques such as Engle and Granger (1987), Johansen (1988), Johansen and Juselius (1990), and Johansen (1991).

One of the key strengths of the ARDL bounds testing approach is its applicability regardless of whether the variables are integrated of order I(0), I(1), or a combination of both. Additionally, it allows for the simultaneous estimation of both short-run and long-run dynamics and generally provides unbiased long-run estimates.

Following the confirmation of an appropriate model specification, the analysis proceeds to the bounds test to verify the existence of a cointegration relationship. This is conducted using the F-statistic associated with the Bounds Test.

F (Bounds Test):

Given that the study investigates the impact of technological research and development on economic growth, the cointegration test based on the F-statistic is implemented within the framework of the Unrestricted Error Correction Model (UECM), as represented by the following equation:

$$\Delta LGPC_t = a_0 + b_1 LGPC_{t-1} + b_2 LATE_{t-1} + b_3 LSRD_{t-1} + b_4 LSTJA_{t-1} + b_5 LPRAR_{t-1} + b_6 LWF_{t-1} + \sum_{i=1}^{p-1} a_{1i} DLGPC_{t-i} + \sum_{i=0}^{p-1} a_{2i} DLATE_{t-i} + \sum_{i=0}^{p-1} a_{3i} DLSRD_{t-i} + \sum_{i=0}^{p-1} a_{4i} DLSTJA_{t-i} + \sum_{i=0}^{p-1} a_{5i} DLPRAR_{t-i} + \sum_{i=0}^{p-1} a_{6i} DLWF_{t-i} + U_t$$

Where:
D: first difference

P: lag order

U: stochastic error term

a_{1i}‘ a_{2i}‘ a_{3i}‘ a_{4i}‘ a_{5i}‘ a_{6i}: represent the short-run coefficients.

$\mathbf{b_6}$ ‘$\mathbf{b_4}$‘$\mathbf{b_5}$ ‘$\mathbf{b_3}$‘$\mathbf{b_2}$‘$\mathbf{b_1}$ **:**: represent the long-run parameters, which carry statistical rather than direct economic interpretation. By normalizing the coefficients $\mathbf{b_3}$‘$\mathbf{b_2}$ ‘$\mathbf{b_4}$‘$\mathbf{b_5}$‘$\mathbf{b_6}$ with respect to b1, the long-run coefficients corresponding to the variables (LSRD, LSTJA, LPRAR, LWF, LATE) are obtained. This allows for the derivation of the long-run equation, or cointegration equation, which will be presented subsequently.

Furthermore, the coefficient of the lagged dependent variable LGPCt−1, denoted by b1, represents the error correction term in the presence of a long-run equilibrium relationship among the variables. This will be verified based on the results of the Bounds Test, which relies on the Wald test by comparing the computed F-statistic with the tabulated critical values at the lower bound I(0) and upper bound I(1), given that the sample size falls within the range of 30 to 80 observations.

To implement this procedure, the general long-run ARDL model (3,1,3,3,3,3) is transformed into an Unrestricted Error Correction Model (UECM). Within this framework, the joint significance of the coefficients b_1 ‘b_3‘b_2 ‘b_4‘b_5‘b_6 is tested according to the following hypothesis:

$$\begin{cases} H_0: b_1 = b_2 = b_3 = b_4 = b_5 = b_6 = 0 \\ H_1: b_1 \neq b_2 \neq b_3 \neq b_4 \neq b_5 \neq b_6 \neq 0 \end{cases}$$

Null Hypothesis (H_0): No cointegration exists (i.e., no long-run equilibrium relationship). **Alternative Hypothesis (H_1):** Cointegration exists (i.e., a long-run equilibrium relationship is present).

t (Bounds Test):

This test is based on the following hypotheses:

- **Null Hypothesis (H_0):** No valid cointegration relationship exists.
- **Alternative Hypothesis (H_1):** A valid cointegration relationship exists.

Given that the study variables are integrated of order one, I(1), the computed t-statistic must exceed the upper critical bound I(1) at the 5% significance level in order to reject the null hypothesis and accept the alternative hypothesis, indicating the presence of a valid cointegration relationship. Conversely, if the computed t-statistic is lower than the upper critical bound, the null hypothesis is accepted, implying the absence of a valid long-run relationship.

The following table presents the results of both the F (Bounds Test) and t (Bounds Test):

Table (02): Results of the Bounds Test for Cointegration

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
		Asymptotic: n=1000		
F-statistic	22.13566	10%	2.26	3.35
k	5	5%	2.62	3.79
		2.5%	2.96	4.18
		1%	3.41	4.68
Actual Sample Size	25	Finite Sample: n=30		
		10%	2.578	3.858
		5%	3.125	4.608
		1%	4.537	6.37

t-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
t-statistic	-7.578851	10%	-2.57	-3.86
		5%	-2.86	-4.19
		2.5%	-3.13	-4.46
		1%	-3.43	-4.79

Source: Prepared by the authors based on outputs generated using EViews 12.

From the results shown in the table, it is evident that the calculated F-statistic, estimated at (22.1356), exceeds the upper critical bound values I(1) at the 1% significance level, as well as the critical values proposed by Narayan (2005), which are estimated at (6.040) at the same significance level. Additionally, the absolute value of the computed t-statistic (-7.5788) is greater than the absolute value of the upper critical Student's t value at the 1% significance level.

These findings lead to the rejection of the null hypothesis and acceptance of the alternative hypothesis for both the F (Bounds Test) and t (Bounds Test). This confirms the existence of a statistically significant and theoretically consistent long-run equilibrium relationship between technological research and development variables and economic growth. Accordingly, it can be concluded that a cointegration relationship exists among the study variables.

4. Estimation of the Error Correction Model (ARDL-ECM) and Cointegration Relationship: Following confirmation of a long-run relationship between the dependent variable and the explanatory variables in the ARDL (3,1,3,3,3,3) model, the Error Correction Model (ARDL-ECM) is estimated. Subsequently, the long-run cointegration relationship is derived.

Table (03): Estimation Results of the Error Correction Model (ARDL-ECM)

ARDL Error Correction Regression
Dependent Variable: D(LGPC)
Selected Model: ARDL(3, 1, 3, 3, 3, 3)
Case 3: Unrestricted Constant and No Trend
Sample: 1990 2023
Included observations: 25

ECM Regression
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	16.36403	0.879938	18.59679	0.0003
D(LGPC(-1))	0.650852	0.056535	11.51235	0.0014
D(LGPC(-2))	0.300625	0.040432	7.435412	0.0050
D(LATE)	0.217751	0.017099	12.73446	0.0010
D(LSRD)	0.114970	0.046007	2.498959	0.0878
D(LSRD(-1))	-0.717216	0.071887	-9.976967	0.0021
D(LSRD(-2))	-0.554034	0.061658	-8.985655	0.0029
D(LSTJA)	-0.156781	0.021941	-7.145441	0.0056
D(LSTJA(-1))	0.300757	0.028196	10.66661	0.0018
D(LSTJA(-2))	0.080673	0.026705	3.020887	0.0567
D(LPRAR)	-0.973084	0.088003	-11.05739	0.0016
D(LPRAR(-1))	-0.732959	0.129679	-5.652109	0.0110
D(LPRAR(-2))	-1.013078	0.083723	-12.10037	0.0012
D(LWF)	0.045465	0.114265	0.397888	0.7173
D(LWF(-1))	0.687649	0.100558	6.838363	0.0064
D(LWF(-2))	1.143950	0.120707	9.477048	0.0025
CointEq(-1)*	-0.759049	0.040333	-18.81942	0.0003

R-squared	0.998304	Mean dependent var	0.042988
Adjusted R-squared	0.994912	S.D. dependent var	0.141351
S.E. of regression	0.010083	Akaike info criterion	-6.135437
Sum squared resid	0.000813	Schwarz criterion	-5.306602
Log likelihood	93.69297	Hannan-Quinn criter.	-5.905554
F-statistic	294.3080	Durbin-Watson stat	3.222954
Prob(F-statistic)	0.000000		

* p-value incompatible with t-Bounds distribution.

Source: Prepared by the authors based on outputs generated using EViews 12.

Accordingly, the Error Correction Model (ARDL-ECM) equation can be expressed as follows:

$$\begin{aligned}\Delta \mathbf{LGPC_t} = {} & -0.759\mathbf{CointEq}(-1) + 0.6508\Delta \mathbf{LGPC_{t-1}} + 0.3006\Delta \mathbf{LGPC_{t-2}} + 0.2177\Delta \mathbf{LATE_t} \\ & + 0.1149\Delta \mathbf{LSRD_t} - 0.7172\Delta \mathbf{LSRD_{t-1}} \\ & - 0.554\Delta \mathbf{LSRD_{t-2}} - 0.1567\Delta \mathbf{LSTJA_t} + 0.3007\Delta \mathbf{LSTJA_{t-1}} + 0.0806\Delta \mathbf{LSTJA_{t-2}} \\ & - 0.973\Delta \mathbf{LPRAR_t} - 0.7329\Delta \mathbf{LPRAR_{t-1}} - 1.013\Delta \mathbf{LPRAR_{t-2}} + 0.045\Delta \mathbf{LWF_t} \\ & + 0.6876\Delta \mathbf{LWF_{t-1}} + 1.1439\Delta \mathbf{LWF_{t-2}} + 16.364\end{aligned}$$

Where:
CointEq(-1): the error correction term.

Table (04): Estimation Results of the Long-Run Parameters of the Study Model (Cointegration Relationship)

ARDL Long Run Form
Dependent Variable: D(LGPC)
Selected Model: ARDL(3, 1, 3, 3, 3, 3)
Case 3: Unrestricted Constant and No Trend
Sample: 1990 2023
Included observations: 25

Conditional Error Correction Regression

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	16.36403	6.848849	2.389310	0.0968
LGPC(-1)*	-0.759049	0.100154	-7.578851	0.0048
LATE(-1)	0.127519	0.048905	2.607491	0.0799
LSRD(-1)	0.040849	0.115531	0.353576	0.7470
LSTJA(-1)	-0.302887	0.162400	-1.865065	0.1590
LPRAR(-1)	1.026121	0.255322	4.018931	0.0277
LWF(-1)	-1.219610	0.344970	-3.535404	0.0385
D(LGPC(-1))	0.650852	0.144233	4.512500	0.0203
D(LGPC(-2))	0.300625	0.085664	3.509370	0.0392
D(LATE)	0.217751	0.041653	5.227747	0.0136
D(LSRD)	0.114970	0.130367	0.881900	0.4428
D(LSRD(-1))	-0.717216	0.276635	-2.592641	0.0809
D(LSRD(-2))	-0.554034	0.161032	-3.440519	0.0412
D(LSTJA)	-0.156781	0.073970	-2.119504	0.1242
D(LSTJA(-1))	0.300757	0.175865	1.710165	0.1858
D(LSTJA(-2))	0.080673	0.110060	0.732990	0.5166
D(LPRAR)	-0.973084	0.213453	-4.558766	0.0198
D(LPRAR(-1))	-0.732959	0.264054	-2.775788	0.0692
D(LPRAR(-2))	-1.013078	0.220453	-4.595426	0.0194
D(LWF)	0.045465	0.245360	0.185298	0.8648
D(LWF(-1))	0.687649	0.330413	2.081178	0.1289
D(LWF(-2))	1.143950	0.255702	4.473770	0.0208

* p-value incompatible with t-Bounds distribution.

Levels Equation
Case 3: Unrestricted Constant and No Trend

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LATE	0.167998	0.056856	2.954795	0.0598
LSRD	0.053816	0.150052	0.358649	0.7436
LSTJA	-0.399034	0.220741	-1.807702	0.1684
LPRAR	1.351851	0.372590	3.628252	0.0360
LWF	-1.606760	0.365879	-4.391504	0.0219

EC = LGPC - (0.1680*LATE + 0.0538*LSRD -0.3990*LSTJA + 1.3519*LPRAR -1.6068*LWF)

Source: Prepared by the authors based on outputs generated using EViews 12.

The long-run (cointegration) equation is expressed as follows:

$$\mathrm{LGPC_t} = 0.1679\mathrm{LATE_t} + 0.0538\mathrm{LSRD_t} - 0.399\mathrm{LSTJA_t} + 1.3518\mathrm{LPRAR_t} - 1.6067\mathrm{LWF_t}$$

5. Diagnostic Tests:

To ensure the validity and robustness of the estimated model and to confirm that it is free from econometric problems, several diagnostic checks are conducted. These include verifying that the residuals are normally distributed, ensuring the absence of serial correlation, confirming homoskedasticity (constant variance of residuals), and testing the structural stability of the model parameters, as well as the model’s predictive performance.

Ramsey RESET Test (Model Specification Test):

Based on the results of the Ramsey RESET test, which is used to assess the correctness of the model specification and the appropriateness of the functional form, it can be concluded that the model is correctly specified. The probability value of the test (0.4067) exceeds the 5% significance level, thereby confirming the validity of the functional form and the correctness of the relationship between the study variables. The following table presents the results of this test.

Table (05): Results of the Ramsey RESET Test

Ramsey RESET Test
Equation: UNTITLED
Specification: LGPC LGPC(-1) LGPC(-2) LGPC(-3) LATE LATE(-1) LSRD LSRD(-1) LSRD(-2) LSRD(-3) LSTJA LSTJA(-1) LSTJA(-2) LSTJA(-3) LPRAR LPRAR(-1) LPRAR(-2) LPRAR(-3) LWF LWF(-1) LWF(-2) LWF(-3) C
Omitted Variables: Squares of fitted values

	Value	df	Probability
t-statistic	1.042262	2	0.4067
F-statistic	1.086311	(1, 2)	0.4067

F-test summary:

	Sum of Sq.	df	Mean Squares
Test SSR	0.000286	1	0.000286
Restricted SSR	0.000813	3	0.000271
Unrestricted SSR	0.000527	2	0.000264

Source: Prepared by the authors based on outputs generated using EViews 12.

Residual Diagnostics and Analysis:

Within the framework of residual analysis, it is essential to test the independence of residuals (absence of autocorrelation), verify the constancy of their variance (homoskedasticity), and assess whether the residuals follow a normal distribution (white noise assumption). The results of these diagnostic tests are summarized in the following table.

Table (06): Residual Diagnostics and Analysis

Jarque Bera Test	JB	0.7338	Prob.ChiSquare(2)	0.6928
Breusch-Godfrey Serial Correlation LM(1) Test	F-statistic	4.4173	Prob	0.1703
Breusch-Godfrey Serial Correlation LM(2) Test	F-statistic	1.3648	Prob	0.5178
Heteroskedasticity Breusch-Pagan-Godfrey	F-statistic	2.2025	Prob	0.2828
Heteroskedasticity ARCH(1) Test	F-statistic	2.1270	Prob	0.1589
Heteroskedasticity ARCH(2) Test	F-statistic	1.4044	Prob	0.2687

Source: Prepared by the authors based on outputs generated using EViews 12.

From Table (06), the following observations can be made:

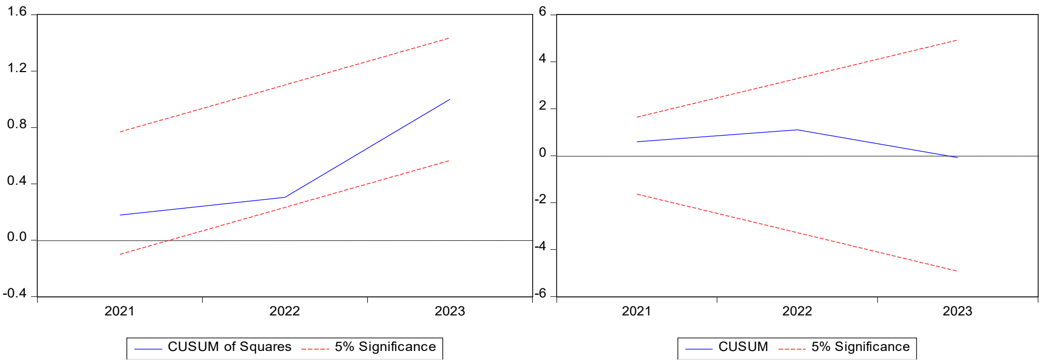
- The Jarque-Bera statistic indicates that the null hypothesis cannot be rejected at the 5% significance level, implying that the residuals are normally distributed within the model.
- The Breusch-Godfrey LM test suggests acceptance of the null hypothesis at the 5% significance level, indicating that the model is free from serial correlation in the residuals at both first and second orders.
- The Breusch–Pagan–Godfrey test and the ARCH test both confirm acceptance of the null hypothesis at the 5% significance level, which implies the presence of homoskedasticity (constant variance of the error term) in the estimated model.

Structural Stability Test of the ARDL-ECM Model Coefficients:

To examine the structural stability of both short-run and long-run coefficients, two tests developed by Brown, Durbin, and Evans (1975) are employed:

- The CUSUM test (Cumulative Sum of Recursive Residuals)
- The CUSUMSQ test (Cumulative Sum of Squares of Recursive Residuals)

Figure (04): Graphical Representation of CUSUM and CUSUMSQ Statistics for the Stability of the Error Correction Model (ARDL-ECM)



Source: Prepared by the authors based on outputs generated using EViews 12.

Based on Figure (04), it is evident that the coefficients of the ARDL-ECM model are structurally stable at the 5% significance level. This conclusion is supported by the fact that the plots of both CUSUM and CUSUMSQ statistics lie within the critical bounds, i.e., within the confidence interval.

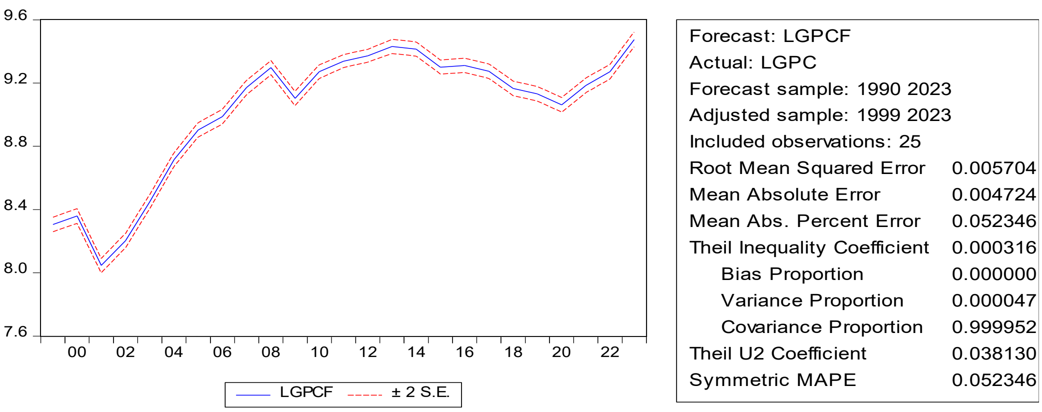
Predictive Performance Test of the Model:

The accuracy of the estimated results largely depends on the predictive performance of the estimated Unrestricted Error Correction Model. To assess the forecasting ability of the model, commonly used performance metrics in econometric studies are employed, including:

- Theil's Inequality Coefficient
- Mean Absolute Error (MAE)
- Mean Absolute Percentage Error (MAPE)
- Root Mean Square Error (RMSE)

The figure below illustrates the trajectory of the estimated values (LGPCF) generated by the ARDL model (3,1,3,3,3,3) for Turkey over the period 1990–2023.

Figure (05): Estimated Values Curve (LGPCF) in Turkey during the Period (1990–2023)

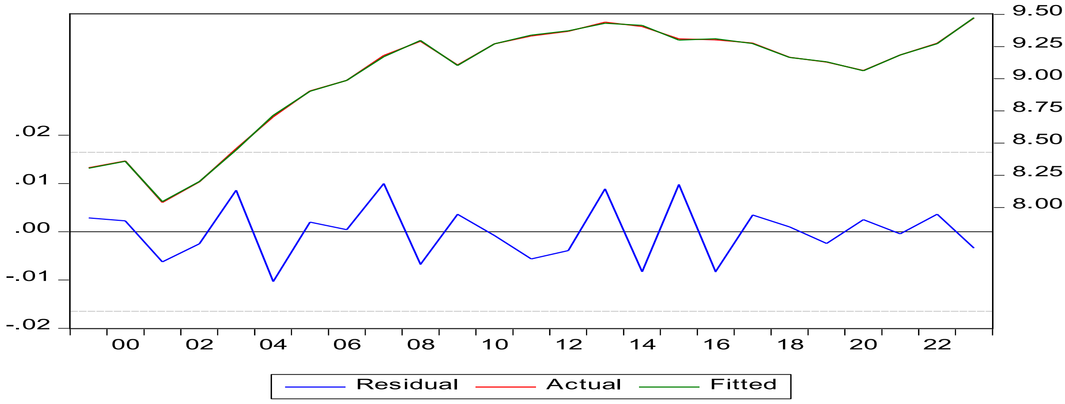


Source: Prepared by the authors based on outputs generated using EViews 12.

The above figure indicates that Theil's coefficient is extremely low, estimated at (0.0003). Similarly, the performance measures—MAE, MAPE, and RMSE—are reported as (0.0047, 0.0523, and 0.0057), respectively. These values are notably low and close to zero, reflecting a high level of predictive accuracy. Furthermore, it can be observed that the estimated values curve (LGPCF) lies within the critical bounds at the 5% significance level. Accordingly, it can be concluded that the Unrestricted Error Correction Model demonstrates strong forecasting capability.

Additionally, Figure (06) shows that the curve of the actual values (LGPC) closely aligns with the curve of the fitted values (LGPCF), which represents the long-run (cointegration) relationship (LRUN). This alignment further confirms the robustness and adequacy of the estimated model.

Figure (06): Fitted Values (LGPCF) and Actual Values (LGPC) in Turkey during the Period (1990–2023)



Source: Prepared by the authors based on outputs generated using EViews 12.

6.02.03 Results Analysis:

Statistical Analysis:
Based on Tables (03) and (04), the Error Correction Model (ARDL-ECM) equation and the long-run equation are derived as follows:

- **Error Correction Model (ARDL-ECM):**

$$\begin{aligned}\Delta \mathrm{LGPC_t} = {} & -0.759\mathrm{CointEq}(-1) + 0.6508\Delta \mathrm{LGPC_{t-1}} + 0.3006\Delta \mathrm{LGPC_{t-2}} + 0.2177\Delta \mathrm{LATE_t} + 0.1149\Delta \mathrm{LSRD_t} \\ & - 0.7172\Delta \mathrm{LSRD_{t-1}} \\ & - 0.554\Delta \mathrm{LSRD_{t-2}} - 0.1567\Delta \mathrm{LSTJA_t} + 0.3007\Delta \mathrm{LSTJA_{t-1}} + 0.0806\Delta \mathrm{LSTJA_{t-2}} \\ & - 0.973\Delta \mathrm{LPRAR_t} - 0.7329\Delta \mathrm{LPRAR_{t-1}} - 1.013\Delta \mathrm{LPRAR_{t-2}} + 0.045\Delta \mathrm{LWF_t} \\ & + 0.6876\Delta \mathrm{LWF_{t-1}} + 1.1439\Delta \mathrm{LWF_{t-2}} + 16.364\end{aligned}$$

Long-Run Equation (Cointegration Relationship):

$$\mathrm{LGPC_t} = 0.1679\mathrm{LATE_t} + 0.0538\mathrm{LSRD_t} - 0.399\mathrm{LSTJA_t} + 1.3518\mathrm{LPRAR_t} - 1.6067\mathrm{LWF_t}$$

It is observed that the error correction term, CointEq(−1)\text{CointEq}(-1)CointEq(−1), is equal to (-0.759), which is negative and statistically significant at the 1% level. This coefficient satisfies both essential statistical conditions: the necessary condition (statistical significance) and the sufficient condition (negative sign), confirming the existence of a long-run equilibrium relationship among the variables, as also supported by the Bounds Test results.

Moreover, the model demonstrates the capacity to correct short-run disequilibria and converge toward long-run equilibrium. The absolute value of the error correction coefficient (75.9%) represents the speed of adjustment, indicating that approximately 75.9% of short-run deviations are corrected within one time period. In practical terms, if a short-term shock occurs, about 75.9% of its impact is eliminated annually. Consequently, the time required to fully adjust and return to equilibrium is approximately the inverse of this coefficient (1/0.759), i.e., around one year and four months.

This implies that the adjustment speed of the model (75.9%) is relatively high and acceptable, reflecting its effectiveness in correcting short-term imbalances in GDP per capita and restoring long-run equilibrium.

The results further reveal a positive relationship between high-technology exports and GDP per capita in both the short and long run. Specifically, a 1% increase in high-technology exports leads to a 0.2177% increase in GDP per capita in the short run and a 0.1679% increase in the long run.

Similarly, research and development expenditure and patent applications exhibit a positive impact on GDP per capita in the long run. A 1% increase in R&D expenditure results in a 0.0538% increase in GDP per capita in the long run. However, in the short run, the relationship is mixed: a 1% increase in current R&D expenditure leads to a positive effect (0.1149%) in the current period but negative effects in the two preceding periods (-0.7172% and -0.554%, respectively).

In the case of patent applications, a 1% increase leads to a 1.3518% increase in GDP per capita in the long run. Conversely, in the short run, the relationship is negative: a 1% increase in patent applications results in a decrease in GDP per capita by 0.973% in the current period and by 0.7329% and 1.013% in the two preceding periods, respectively.

On the other hand, scientific and technical journal articles and labor force exhibit a negative relationship with GDP per capita in the long run. A 1% increase in scientific and technical publications leads to a 0.399% decrease in GDP per capita in the long run. In contrast, the short-run effects are mixed, with a negative impact in the current period (-0.1567%) and positive effects in the two preceding periods (0.3007% and 0.0806%, respectively).

Similarly, a 1% increase in the labor force results in a 1.6067% decrease in GDP per capita in the long run. However, in the short run, the relationship is positive: a 1% increase in the labor force leads to increases in GDP per capita of 0.0454% in the current period and 0.6876% and 1.1439% in the two preceding periods, respectively.

Overall, the coefficients of the estimated model are statistically significant at the 1% level, as indicated by the Fisher statistic (F-statistic), whose probability value is less than 1%. Nevertheless, the partial elasticities of technological research and development indicators exhibit heterogeneous effects on economic growth in Turkey across the short and long run.

Economic Analysis:

The results indicate a positive relationship between high-technology exports and GDP per capita, reflecting Turkey's capacity for innovation and its ability to export high value-added products. This is supported by improvements in technological infrastructure and increased investment in export-oriented sectors, which have enhanced the country's contribution to overall economic output.

Similarly, the positive relationship between research and development (R&D) expenditure and GDP per capita highlights the importance of allocating resources toward innovation and technological advancement. Investment in developing new technological solutions improves productivity and efficiency, thereby fostering long-term economic growth.

The positive association between patent applications and GDP per capita further underscores the critical role of innovation as a key driver of economic performance. An increase in patent activity reflects a more supportive environment for research and the development of new products and services, ultimately enhancing economic competitiveness.

Conversely, the findings reveal a negative relationship between scientific and technical journal publications and GDP per capita. This suggests that an increase in academic publications does not necessarily translate into immediate economic gains. This may be attributed to the predominance of theoretical and academic research that is not effectively transformed into practical applications or marketable technological outputs.

In addition, a negative relationship is observed between the labor force and GDP per capita in the long run. This may be associated with labor quality, as an increase in the size of the workforce without corresponding improvements in skills and qualifications can lead to lower productivity. Therefore, greater emphasis should be placed on vocational training and education to enhance workforce capabilities and support future economic growth.

Overall, in the long run, investment in technology appears to contribute positively to economic growth, highlighting the importance of adopting sustainable strategies to stimulate these sectors. While current investments in technology may yield future growth benefits, the uneven performance of certain indicators—such as scientific publications and labor force—emphasizes the need for structural reforms in Turkey to achieve sustainable development.

3. Conclusion:

Over the past two decades, developed countries have increasingly prioritized technological research and development. In an effort to keep pace, Turkey has expanded its investment in R&D. This study examined and analyzed the relationship between R&D activities and economic growth in Turkey over the period 1990–2023.

The findings reveal that high-technology exports, R&D expenditure, and patent applications have a positive impact on economic growth, as measured by GDP per capita, in the long run. In contrast, scientific and technical publications and the labor force exhibit a negative relationship with economic growth over the same period. These results suggest the need for Turkey to improve the quality of research outputs and enhance workforce skills to ensure more sustainable growth.

The study also highlights the importance of directing resources and policies toward supporting research and technological sectors, as these areas can serve as key drivers of productivity and economic competitiveness. Despite Turkey's progress in certain indicators, there remains a need to strengthen the linkage between scientific outputs and practical applications to maximize economic impact. Given the pivotal role of technological R&D in driving economic growth, the findings emphasize the importance of sustainable policies that promote innovation and integration across sectors to achieve comprehensive and sustainable development.

Recommendations:

Based on the findings, the following recommendations are proposed:

- Strengthen geographical outreach by expanding networks of collaboration and economic partnerships between universities and industries, with the aim of aligning scientific research with market needs and facilitating the transformation of research into commercially viable innovations.
- Increase investment in research and development, with a focus on priority sectors such as renewable energy and digital technologies.
- Support high-technology exports by providing incentives to domestic firms engaged in developing innovative products for global markets.
- Intensify efforts to enhance workforce skills through advanced training programs aimed at integrating labor into a knowledge-based economy, thereby improving productivity, competitiveness, and economic stability in line with national development goals.
- Foster an innovation-friendly environment by offering financial incentives for patent registration and the development of innovative projects, contributing to economic diversification and enhanced competitiveness.
- Improve the quality of scientific research by formulating effective policies, strategic plans, and operational programs that encourage international research collaboration and increase funding for economically viable research projects.

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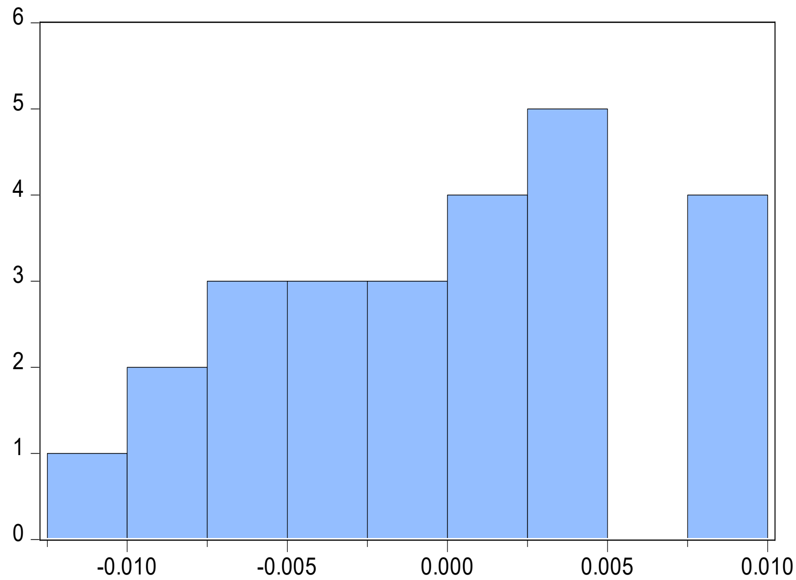
[22] 5. Appendix:

Appendix (01): Results of the Model Residual Diagnostic Tests



Series: Residuals	
Sample 1999 2023	
Observations 25	
Mean	-2.56e-15
Median	0.000422
Maximum	0.009984
Minimum	-0.010325
Std. Dev.	0.005821
Skewness	0.077017
Kurtosis	2.174907
Jarque-Bera	0.733860
Probability	0.692858

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	4.417363	Prob. F(1,2)	0.1703
Obs*R-squared	17.20864	Prob. Chi-Square(1)	0.0000

Breusch-Godfrey Serial Correlation LM Test:

F-statistic	1.364843	Prob. F(2,1)	0.5178
Obs*R-squared	18.29702	Prob. Chi-Square(2)	0.0001

Heteroskedasticity Test: Breusch-Pagan-Godfrey

F-statistic	2.202561	Prob. F(21,3)	0.2828
Obs*R-squared	23.47727	Prob. Chi-Square(21)	0.3191
Scaled explained SS	0.198602	Prob. Chi-Square(21)	1.0000

Heteroskedasticity Test: ARCH

F-statistic	2.127018	Prob. F(1,22)	0.1589
Obs*R-squared	2.115821	Prob. Chi-Square(1)	0.1458

Heteroskedasticity Test: ARCH

F-statistic	1.404435	Prob. F(2,20)	0.2687
Obs*R-squared	2.832407	Prob. Chi-Square(2)	0.2426

Appendix (02): Variables of the Econometric Study Model

	GPC	ATE	SRD	STJA	PRAR	WF
1990	2773.26976	72391060		138		
1991	2730.14338	90488826		148		20423991
1992	2825.91504	113111032		189		20579200
1993	3148.83644	141388790		169		19657574
1994	2240.60879	176735988		151		21126841
1995	2855.04055	220919985		170		21438138
1996	3009.67016	276149981	819475127	189	5040.7	21777881
1997	3098.66801	345187476	933613123	203	5389.78	21780014
1998	4433.35828	431484345	998854794	207	5770.4	22359924
1999	4057.82127	539355432	1168062982	276	6742.31	22791604
2000	4278.26311	674194290	1277060870	277	6815.4	22052875
2001	3100.459	842742862	1054099541	337	8591.94	22462109
2002	3640.76284	1053428577	1222963871	414	10971.39	22818051
2003	4704.77266	1316785722	1463876088	489	13463.11	22701681
2004	6031.79137	1645982152	2032592740	682	16025.99	22213390
2005	7369.43189	1510750135	2854652963	928	17794.68	22722966
2006	8003.81449	1888437669	3080185402	1072	19561.21	22701823
2007	9711.22376	1881587143	4674953217	1810	21637.21	23018367
2008	10843.5037	1962231378	5296144361	2221	22022.16	23770341
2009	9012.99946	1587643533	5217818746	2555	25022.23	24694136
2010	10622.702	1943251656	6166711696	3180	26424.46	25794958
2011	11300.7852	2202094015	6659368001	3885	27180.38	26981022
2012	11713.285	2327204095	7272951570	4434	28322.28	27535298
2013	12578.1879	3782388286	7777903520	4392	30326.35	28576887
2014	12165.2201	4292918460	8041036116	4766	31004.71	29245699
2015	11049.9951	3872098694	7579081404	5352	32968.6	30216096
2016	10970.0459	3421633945	9738621575	6230	35162.5	31174275
2017	10695.5502	4068849600	1.0104E+10	8175	33239.62	32167323
2018	9568.83619	3735725595	9906500739	7156	33686.23	32874112
2019	9215.44087	4280200491	1.0056E+10	7871	37430.02	33249207
2020	8638.73913	4172699768	9851133506	7920	42623.31	31361351
2021	9743.21313	5715250928	1.1507E+10	8234	47816	33070239
2022	10674.5042	6814962080	1.3153E+10	8540	53009	34630319
2023	12985.7531	7825364491	1.662E+10	8850	58202	35071478