Technological Innovation, Investment in Research and Development, Human Capital and Their Impact on Economic Growth

Abdul Rehman Asif [1] and Abdul Ghafoor Awan[2]

https://doi.org/10.62345/jads.2026.15.3.29

Abstract

The aim of this study is to investigate the impact of technological innovation, research and development investment, and human capital on economic growth using 25-year time-series data from 2000 to 2024, sourced from the World Bank's World Development Indicators. The study employed various econometric techniques; descriptive statistics were used to report the mean, median, and mode, as well as the Jarque-Bera test values and the data's skewness. The unit root test (Augmented-Dickey Fuller) was used to test the stationarity of the values of selected variables. Some values were stationary at a level, while others were stationary on first differences. The ARDL (Auto-Regressive Distributed Lag) model was selected as the most suitable method for this study. Variance Inflation Factor, Heteroscedasticity test, and Ramsay RESET were used to identify multicollinearity, heteroscedasticity, and issues with the model's variable specification. The findings from ARDL and Error Correction Models reveal a positive and significant association between technological innovation, investment in R&D, human capital, and economic growth. The study suggests that policymakers must focus on technological innovation, increase investment in R&D, and build human capital to accelerate economic growth. These results can be generalised to other developing countries facing similar issues of low technological innovation, low investment in R&D, underdeveloped human capital, and stagnant economic growth.

Keywords: Technological Innovation, Investment in R&D, Human Capital, Economic Growth.

Introduction

Pakistan's economic growth trajectory has remained volatile, marked by recurrent balance-of-payments pressures, low productivity growth, and limited structural transformation. Although short-term economic growth spurts many times, these have neither been translated into improvements in people's living standards nor enhanced technological capability (Awan, 2019). In this context, technological innovation has recently gained prominence as a key driver of long-term development, boosting productivity, industrial development, and competitiveness. Global evidence indicates that countries with a sound innovation system, characterised by sustained research and development (R&D) investment and strong knowledge dissemination, tend to achieve higher and more stable growth (Awan, 2013; Zhang, 2024). However, current international trends offer a challenging competitive environment for innovation-led development. The evidence reported by the World Intellectual Property Organisation indicates a clear deceleration in the global R&D expenditure uplift, falling to 2.9% in 2023, following poor performance since the 2008 global

[1]*Research Scholar, Department of Economics, University of Southern Punjab, Multan, Pakistan. Email: abdulrehman6632048@gmail.com*
[2]*Dean, Faculty of Social Sciences, University of Southern Punjab, Multan, Pakistan. Corresponding Author Email: drabdulghafoorawan@gmail.com ORCID https://orcid.org/0000-0001-5767-6229*

Compliance with ethical standards: There are no conflicts of interest (financial or non-financial). This study did not receive any funding.

financial crisis (Awan, 2011). In countries like Pakistan, where investment in innovation and technology is already modest, this slowdown demands an urgent understanding of how technological inputs translate into economic consequences. Empirical evidence suggests that the growth effects of innovation are not automatic but depend on contextual factors such as absorptive capacity, institutional effectiveness and human capital endowments (Awan, 2016; Nițu, 2025). Human capital plays a crucial role in mediating the innovation-growth linkage. Current academic evidence emphasises that it is not only educational attainment but also the quality of skills that determine whether countries can effectively adopt and exploit new technologies (Awan, 2015; Carillo, 2024). Without continuous improvements in health and education, the significance of human capital to long-term growth is expected to deteriorate substantially over time (Vashakmadze et al., 2025). For Pakistan, where skill mismatches and digital inequality persist, these dynamics raise questions about the long-term effectiveness of innovation-driven economic growth strategies (Bashir & Awan, 2025).

Rationale of the Study

Although a growing body of literature recognises technological advancement as a key factor in economic growth, empirical evidence for Pakistan remains very limited and inconclusive. Latest studies mainly rely on short-run analyses that fail to identify the dynamic and potentially asymmetric nature of the innovation–growth nexus. Moreover, the link between innovation, investment in R&D, human capital, and economic growth has rarely been investigated in a unified empirical framework that differentiates between short-run adjustments and long-run equilibrium relationships. This study is therefore motivated by the need to apply a dynamic time-series approach to examine how technological advancement and human capital affect economic growth in the short- and long-run.

Main Research Problem

The primary research problem addressed in this study is the limited understanding of the long-run and short-run effects of technological advancement on economic growth in Pakistan. Despite numerous policy initiatives aimed at promoting innovation and digitalisation, the economic consequences remain uneven, suggesting that innovation alone may be insufficient without complementary factors, such as human capital quality and absorptive capacity. The study aims to explain why innovation-related investments have generated modest returns and whether these effects differ across time horizons.

Objectives of the Study

The study aims to achieve the following objectives:

- To examine the short run and long run impact of technological innovation on economic growth in Pakistan using an ARDL framework.
- To assess the role of R&D investment in shaping growth dynamics.
- To analyze the moderating effect of human capital on the innovation-growth relationship.
- To offer clear policy recommendation supporting innovation-led and human capital.

Research Questions

In line with these objectives, the study addresses the following research questions:

- Does technological innovation exert a significant long-run effect on economic growth in Pakistan?

- What is the role of research and development (R&D) in economic growth?
- What role does human capital play in strengthening or weakening the growth effects of innovation?
- What actionable steps can policymakers in Pakistan take to enhance the effectiveness of innovation-driven growth, such as increasing R&D funding, supporting knowledge transfer, and improving education outcomes?

Contribution of the Study

This study contributes to the literature of development economics by offering a dynamic, Pakistan-specific analysis of technological innovation and economic development using the ARDL approach. Unlike static or cross-sectional approaches, this research captures both short-run fluctuations and long-run equilibrium linkages, providing a more nuanced understanding of growth dynamics. By including human capital as a key determinant, the research aligns with recent empirical evidence that emphasises absorptive capacity and skill quality as critical factors in innovation effectiveness (Carillo, 2024). Aligning with World Development's policy orientation, this study's findings are expected to provide evidence-based strategies to transform innovation investments into sustained, inclusive economic growth in Pakistan. The results of this study can be generalised to other countries facing similar economic issues of stagnant growth.

Literature Review

Technological innovation has long been considered a fundamental factor of sustained economic growth, particularly within the scope of endogenous growth theory. Early studies argue that innovation enhances productivity by introducing new technologies and improving production processes, thereby creating long-run growth effects (Aghion & Howitt, 1992). Recent empirical evidence confirms this view by demonstrating that countries with stronger innovation capacity experience higher growth trajectories (Aghion et al., 2021; Mokyr, 2023; Bashir & Awan, 2025) also urges that technological progress works through cumulative knowledge creation, where institutional quality and fiscal incentives for innovation play a key role in transforming innovations into economic growth. Contemporary evidence from both developed and emerging countries suggests that innovation-driven development is more effective when supported by competitive markets and effective governance structures (Aghion & Bunel, 2024).

Investment in research and development (R&D) is widely accepted as a critical source through which technological progress influences economic growth. Empirical research indicates that higher R&D investment positively affects total factor productivity and long-term GDP growth, though the magnitude of the effect varies across countries and sectors (Awan, 2012). Recent panel studies relating to G7 economies find that sustained public and private R&D investment significantly increases economic growth by fostering innovation spillovers and technological diffusion. Similarly, time-series evidence from East Asian economies indicates that R&D investment strengthens growth when accompanied by complementary factors such as skilled labour and financial development (Awan, 2011). However, studies on developing economies caution that weak institutional structure and low absorptive capacity may lessen the growth-enhancing effects of R&D spending (Zhang et al., 2024).

Human capital plays a crucial role in linking technological innovation and R&D investment to economic growth, as it facilitates an economy’s ability to generate, adopt, and efficiently utilise new technologies (Awan & Mukhtar, 2019). Theoretical and empirical studies consistently show that education and skill accumulation enhance the productivity of R&D activities and signify the returns from technological advancement. Recent empirical evidence from Pakistan and other developing countries confirms that improvements in human capital significantly contribute to economic growth, particularly when aligned with technological progress and an innovation-oriented policy framework (Ahmed et al., 2025). In technology-intensive sectors, skilled human capital strengthens the transformation of R&D inputs into productive outputs, reinforcing the complementarities between human capital, innovation, and growth.

The reviewed literature mainly emphasises that technological innovation, investment in research and development (R&D), and human capital are the core factors of sustained economic growth (Awan, 2012). Most empirical studies, conducted in both developed and developing countries, predict that innovation-based productivity growth encourages industrial development and supports long-run growth. Similarly, R&D expenditure has been widely recognised as a key source of technological progress and knowledge production, leading to higher output and competitiveness (Awan, 2011). The role of human capital, represented by education, training, and skill development, is also highlighted as an important driver that facilitates innovation and the effective utilisation of new technologies within an economy (Awan, 2016). However, despite these general uniform views, the patterns and directions of these relationships vary across studies due to differences in methodology, data periods, and country contexts. Some studies suggest that R&D investment translates into growth only when supported by strong institutional quality and adequate human capital, while others find that innovation outcomes mainly depend on a nation’s absorptive capacity and financial development. Furthermore, a few studies are based on panel or cross-country data, which often ignore the structural and policy-specific characteristics of individual countries. Overall, the literature suggests that sustainable economic growth requires coordinated investment in technological innovation, R&D, and human capital development.

Research Hypotheses (ARDL-Based)

Grounded in Endogenous growth theory (Romer, 1990) and recent empirical evidence on innovation-led growth, the study proposes the following hypotheses, explicitly distinguishing between long-run equilibrium associations and short-run dynamics as captured by the ARDL model.

H1 (Long-run effect of technological innovation): Technological innovation has a positive and statistically significant long-run effect on economic growth in Pakistan (Zhang, 2024; Li et al., 2024).

H2 (Short-run dynamics of innovation): Technological innovation has a significant short-run impact on economic growth, though the direction may vary from the long-run effect due to structural rigidities (Caicedo & Pearce, 2024).

H3 (Role of R&D investment): Research and development investment contributes positively to economic growth in the long run, as it fosters knowledge accumulation, while its short-run effects may be weak or insignificant (Nițu, 2025).

H4 (Human capital as a growth driver): Human capital has a positive and significant long-run relationship with economic growth in Pakistan (Carillo, 2024; Hanushek & Woessmann, 2020).

The objective of this research is to investigate the relationship between technological innovation, Research and Development (R&D) expenditures, Human capital, and economic growth using 25 years of data from 2000 to 2024. Economic growth serves as the dependent variable while all other variables act as independent variables. This study uses an Autoregressive Distributed Lag (ARDL) modelling approach to examine the relationship between technological innovation and economic growth in Pakistan. The ARDL approach is particularly valid due to its flexibility in handling regressors integrated of order I (0) and I (1) and its capability to distinguish between short-run dynamics and long-run equilibrium relationships. The baseline functional form of the growth model is specified as:

$GDP_t = f(INNOV_t, R\&D_t, HC_t, Z_t)$

where GDP_t depicts real economic growth, $INNOV_t$ represents technological innovation, $R\&D_t$ captures research and development expenditure, HC_t denotes human capital, and Z_t is a vector of control variables commonly used in growth literature.

ARDL Model Formulation

The ARDL (p, q_1, q_2, q_3) specification is expressed as:

$$\Delta GDP_t = \alpha_0 + \sum_{i=1}^{p} \alpha_i \, \Delta GDP_{t-i} + \sum_{j=0}^{q_1} \beta_j \, \Delta INNOV_{t-j} + \sum_{k=0}^{q_2} \gamma_k \, \Delta R\&D_{t-k} + \sum_{l=0}^{q_3} \delta_l \, \Delta HC_{t-l} + \lambda_1 GDP_{t-1} + \lambda_2 INNOV_{t-1} + \lambda_3 R\&D_{t-1} + \lambda_4 HC_{t-1} + \varepsilon_t$$

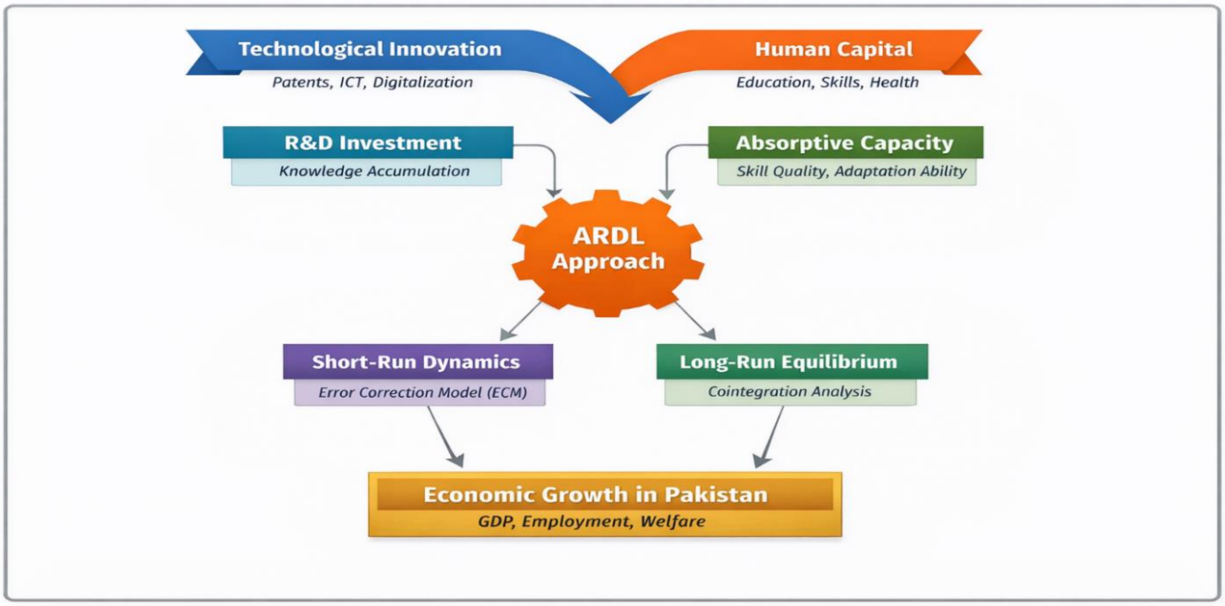
where Δ denotes the first difference operator and ε_t is a white-noise error term.

Further**,** prior to estimation, the stationarity properties of the variables are examined using standard unit root tests, including the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests. These tests ensure that none of the variables are integrated of order I (2), a necessary condition for the application of the ARDL bounds testing approach. We used ARDL bounding testing approach to identify long-run relationship between variables. The null hypothesis of no long-run relationship is tested against the alternative hypothesis of cointegration by comparing the calculated F-statistic with the critical bounds values. The rejection of the null hypothesis implies the existence of a stable long-run equilibrium relationship between economic growth, technological innovation, R&D investment, and human capital.

After confirming cointegration, long-run coefficients are estimated to test the long-run significance of innovation and human capital on economic growth. The short-run dynamics are modeled using an Error Correction Model (ECM), which includes the speed of adjustment towards long-run equilibrium. The coefficient of the error-correction term is expected to be negative and significant, implying convergence after a short-run shock. We also use a set of diagnostic tests such as tests for serial correlation, heteroskedasticity, functional form misspecification and normality of residuals to validate the results and goodness of fit of the model. The stability of parameters is checked using CUSUM and CUSUMSQ tests to ensure that the estimated relationships are stable during the sample period. The existence of a long-run relationship among the variables is assessed using the ARDL bounds testing approach to cointegration. The null hypothesis of no long-run relationship is tested against the alternative hypothesis of cointegration by comparing the computed F-statistic with the critical bounds values. Rejection of the null hypothesis indicates the presence of a stable long-run equilibrium relationship between economic growth, technological innovation, R&D investment, and human capital.

The ARDL model is particularly suitable for Pakistan's macroeconomic setting, which is characterized by policy shifts, external shocks, and structural breaks. By differentiating between short-run fluctuations and long-run growth trajectory, the methodology offers a comprehensive analysis of how technological innovation and human capital influence economic growth in the long-term. This dynamic perspective aligns closely with the policy-oriented strategies of *development* and offers actionable insights for innovation-led growth strategies. Figure 1 demonstrates the conceptual model based on the study' s independent and dependent variables and their relationships.

Figure 1: Research Model



Results

Descriptive statistics are used to summarize data and to perform key characteristics like central tendency, dispersion and normality. Descriptive statistics also highlight the outliers in the data but in our dataset, there was not any outlier that may lead to disturbance in our results. The summary of results is presented in Table 1.

Table 1: Descriptive statistics outcomes

	GDP	TI	R_D	HC	TO
Mean	3.995366	1.728064	0.287418	1.941032	28.45198
Median	4.217942	1.669593	0.227620	2.001010	28.60258
Maximum	7.831256	2.302697	0.546687	2.417212	34.34896
Minimum	-1.274087	1.429433	0.066096	1.061625	21.45996
Std. Dev.	2.162462	0.250025	0.154830	0.364701	3.610227
Skewness	-0.407543	0.707398	0.519450	-0.863937	-0.120240
Kurtosis	3.098486	2.579087	1.899454	2.906677	1.950086
Jarque-Berra	0.702150	2.269602	2.385953	3.119021	1.208489
Probability	0.703931	0.321486	0.303317	0.210239	0.546487
Sum	99.88415	43.20160	7.185453	48.52579	711.2995
Sum Sq. Dev.	112.2298	1.500295	0.575336	3.192159	312.8098
Observations	25	25	25	25	25

Source: Author own calculations

The data of this study was time series nature having only 25 years from 2000-2024 in which descriptive statistics were applied to check the statistics of the data. In these statistics, central tendency measured by the mean, median, average and range of dispersion was measured by variance of the data, skewness and kurtosis of the data, symmetry of the data, Jarque-Berra value, probability value, sum and sum of square deviations to check whether the data is normally distributed or not. Skewness and kurtosis are used to check how the results deviate from the average line or not. Similarly, Jarque-Berra value is used to check how skewed the data is, which is also latterly used to check whether the data is normally distributed or not. A small value of the Jarque –Berra indicates that the data is normally distributed and there is no serious skewness or kurtosis problem, while the large value of the Jarque-Berra shows that the data is not normally distributed. Variance is used to check the average spread of the data around the mean, and the sum of squared deviation is used to check the total spread of the data around points of mean. In the above table, the values of standard deviation, that is called variance, are relatively small. That means the average spread points are around the mean, that means the data is normally distributed. While in the sum of squared deviation, that is also called variance (total), only two values are high, and rest is close to mean. Similarly, Jarque-Berra values are small, not so high. That is also states, our is perfectly normally distributed and we can make further analysis.

Correlation Matrix

The correlation matrix provides key insights into the linear associations among economic growth (GDP), technological innovation (TI), research and development (R&D), human capital (HC), and trade openness (TO) in Pakistan. As expected, GDP indicates weak and negative correlations with technological innovation (–0.22), human capital (–0.10), and trade openness (–0.16), while its association with R&D is negligible (0.02). These weak correlations suggest that, in the short run, increases in innovation-related variables do not translate directly into higher output growth, reflecting Pakistan's structural rigidities, adjustment costs, and lagged returns to innovation investments. Importantly, the absence of strong correlations reinforces the appropriateness of a dynamic ARDL framework that distinguishes between short-run effects and long-run equilibrium relationships. Conversely, high positive correlation values are found among the innovation variables themselves. Technological innovation is found to be moderately and positively correlated with human capital (0.57) and R&D (0.16), which suggests that innovation activities tend to expand in skill-rich and knowledge accumulation environments. Likewise, R&D is found to be substantially and positively correlated with human capital (0.51) and trade openness (0.54), which suggests that international market exposure and high skill levels can facilitate research intensity and knowledge diffusion. Trade openness is also found to be positively correlated with human capital (0.48), which suggests that trade openness can facilitate skill upgrading in technology transfer and learning-by-doing approaches. In sum, the correlation matrix reveals that innovation, human capital, and trade openness are highly interconnected, but their contributions to economic growth are not instantaneous. This finding is consistent with the hypothesis that innovation-driven economic growth in Pakistan occurs through long-term channels, rather than through short-term co-movements, which thereby validates the application of ARDL cointegration and ECM methodologies to model delayed and cumulative growth effect. The estimated results are presented in Table 2.

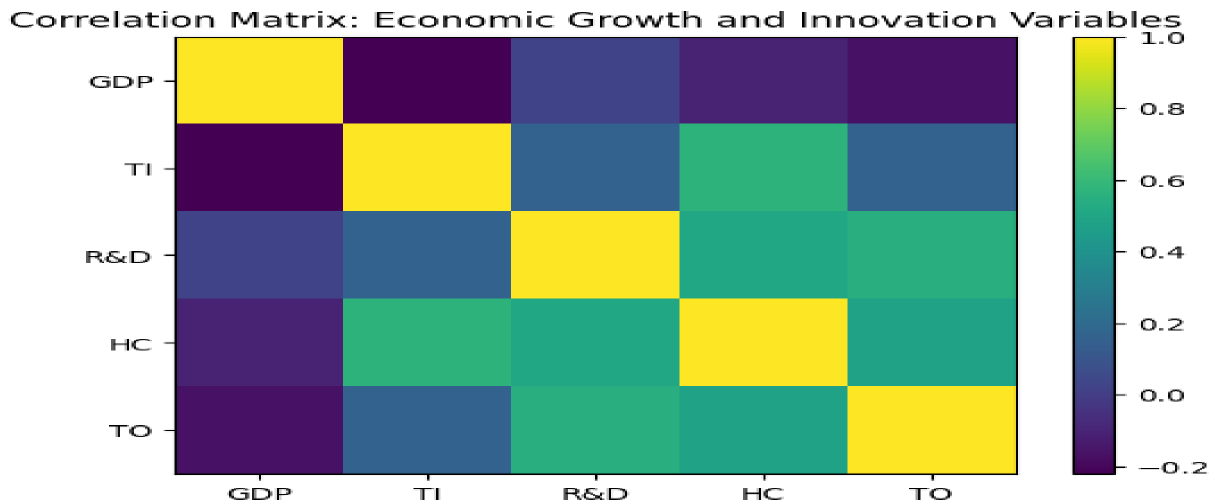
Table 2: Correlation Matrix outcomes

	GDP	TI	R_D	HC	TO
GDP	1.000000				
Technological innovations	-0.221780	1.000000			
Research & Development	0.022008	0.161516	1.000000		
Human Capital	-0.104023	0.566509	0.507314	1.000000	
Trade openness	-0.163918	0.160226	0.542915	0.482698	1.000000

Source: Author own calculations

The results of correlation Matrix are displayed in Figure 2.

Figure 2: Heat map of Correlation Matrix



Unit Root Test

To check the stationarity of explanatory variables, we used Augmented Dickey Fuller (ADF) test and Phillips-Perron test. The findings of these tests are presented in Table 3.

Table 3: Results of ADF and PP Test

	ADF		PP	
Variables	**Level**	**1st Difference**	**Level**	**1st Difference**
TI	0.1027	0.0006	0.1027	0.0005
R&D	0.4331	0.0000	0.0477	0.0000
HC	0.4655	0.0000	0.4458	0.0000
GDP	0.0109	0.0001	0.0116	0.0000
TO	0.1464	0.0005	0.1517	0.0004

Source: Author own calculations

Table 3 shows the Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) test results for the variables used in this study for their time series. In their level form, most of the series have probability values above the conventional significance thresholds, implying that the null hypothesis regarding a unit root cannot be rejected. This shows that the variables in question behave non-stationarily at the level. The results, however, take a completely different turn upon first difference. The ADF and PP tests now give very high probability values, allowing for rejection of the unit root hypothesis at the standard levels of confidence. The series thus becomes stationary after one differencing. The result of two different procedures gives one result, and that increases one's confidence that one's findings concerning stationarity are robust. Taken together, these results suggest that the variables are integrated in order one, I (1) and that none are integrated at higher orders. This integration constitutes the necessary condition for implementing the ARDL approach, which postulates that the variables must be either level-stationary or first-differenced-stationery. Therefore, the unit root test results provide an empirical base upon which the ARDL estimation strategy may follow.

ARDL-Bound Test Approach

In this context, the ARDL bounds testing approach to cointegration was applied under Case 2 (restricted constant and no trend) to test for any long-run equilibrium relationship among the variables. The calculated F-statistic from the bounds test is 4.18, which passes the upper critical bounds at 10, 5, and 2.5% significance levels but is marginally below the upper 1% bound. This indicates statistically meaningful evidence against the null hypothesis of no levels relationship.

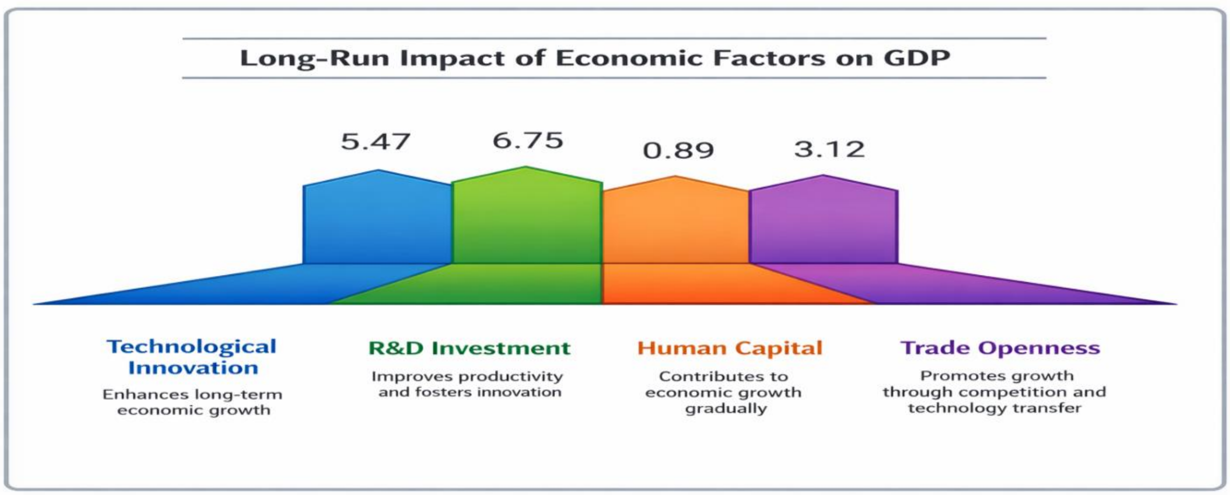
Accordingly, the results confirm the presence of long run cointegration among gross domestic products (GDP), technological innovation, investment in research and development, human capital, and trade openness. The existence of cointegration implies that these variables move together over time and that deviations from long-run equilibrium are temporary rather than permanent. Hence, the ARDL framework is appropriate for estimating both long-run coefficients and short-run adjustments.

Table 4: Bound testing outcomes

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
			Asymptotic: n=1000	
F-statistic	8.519294	10%	2.2	3.09
k	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

The long-run estimates indicate that technological innovation (TI) exerts a strong and statistically significant positive effect on GDP. The coefficient value of 5.47 suggests that improvements in innovation capacity substantially enhance long-term economic growth, highlighting the importance of technology-driven growth. Similarly, investment in research and development (R&D) demonstrates a positive and significant relationship with GDP, with a coefficient of 6.75. This finding underscores the role of sustained R&D expenditure in improving productivity, fostering innovation spillovers, and supporting long-term economic expansion. Human capital (HC) also depicts a positive coefficient, indicating that improvements in education, skills, and workforce quality contribute to economic growth in the long run. However, the relatively high p-value implies that this effect is weaker compared to other explanatory variables, suggesting that the growth benefits of human capital may materialize gradually or depend on complementary institutional and technological factors. Trade openness (TO) shows a positive and statistically significant impact on GDP, confirming that greater integration with international markets promotes economic growth through enhanced competition, technology transfer, and access to larger markets. The constant term captures the base level of GDP when explanatory variables are held constant and reflect underlying structural and institutional factors influencing economic performance. Overall, the long-run results confirm that GDP is positively influenced by technological innovation, R&D investment, human capital accumulation, and trade openness, validating the theoretical expectations of endogenous growth and openness-led development. Figure 3 shows long-term individual impact of independent variables on dependent variables.

Figure 3: ARDL long-term findings



Vector Error Correction Model Results

The short-run results estimated through the Vector Error Correction Model (VECM) offers significant insights into both the short-term effects of independent variables on economic growth and the speed of adjustment at which deviations from the long-run equilibrium are corrected. The error correction term, CointEq (−1), shows a negative and highly significant coefficient (−2.49, p = 0.0005), suggesting the presence of a stable long-run association among the variables. The magnitude of this coefficient means that any short-run disequilibrium in GDP is rectified rapidly, with more than full adjustment taking place in a single period. This demonstrates a strong trend of the system to converge back to its long-run trajectory in case of short-term shocks.

In the short run, technological innovation, with a statistically significant and positive coefficient in the current period and with a one-period lag, indicates that innovation activities create immediate and short-lived momentum in output performance. Research and development investment has a delayed but strong effect, as the first and second lagged differences are positive and significant, emphasizing that R&D expenditures take time to convert into tangible economic performance. Human capital has a significant and strong short-run effect; although the change in the current period is significant, the impact becomes stronger at longer lags, indicating that skill and education capital contribute to economic growth after an adjustment period. Trade openness has consistent and significant positive impacts in the current and lagged periods, emphasizing the importance of external integration in creating immediate economic activity in the short run through market access, efficiency gains, and technology transfer. The ECM analysis indicates that the short-run GDP variability is determined by innovation, R&D, human capital, and trade openness, while the highly significant and negative error correction term emphasizes the fast convergence of the system to the long-run equilibrium. The results confirm the appropriateness of the ARDL-ECM approach and emphasize the sensitivity of economic growth to policy-relevant factors in both the short and long run. The estimates of ECM are presented in Table 5.

Table 5: Error Correction Model outcomes

ECM Regression				
Case 2: Restricted Constant and No Trend				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(TI)	-3.694085	0.871319	-4.239645	0.0014
D(TI(-1))	1.442350	0.990672	1.455931	0.1734
D(R_D)	5.000359	1.279123	3.909210	0.0024
D(HC)	26.80180	10.07839	2.659333	0.0222
D(TO)	-0.087068	0.083595	-1.041550	0.3200
D(TO(-1))	0.532739	0.137020	3.888028	0.0025
CointEq(-1)*	-0.561545	0.181098	-8.622656	0.0000

Diagnostic Tests and Model Adequacy

Several post-estimation diagnostic tests are conducted to examine the statistical adequacy of the ARDL specification and to ensure the reliability of the estimated coefficients. First, multicollinearity among the regressors is examined using the Variance Inflation Factor (VIF). The centered VIF values for all explanatory variables remain well below conventional cutoff levels, indicating that the regressors do not exhibit problematic linear dependence. This result suggests that the estimated parameters are not inflated due to multicollinearity and that the individual effects of the explanatory variables can be meaningfully distinguished.

Second, the stability of the error variance is assessed through the Breusch–Pagan–Godfrey test for heteroskedasticity. The test statistics yield probability values far above standard significance levels, leading to non-rejection of the null hypothesis of homoscedastic disturbances. This finding implies that the variance of the residuals is constant across observations, supporting the efficiency of the estimated standard errors and the validity of statistical inference.

Finally, the presence of serial correlation in the residuals is investigated using the Breusch–Godfrey LM test. The F-statistics do not indicate statistically significant autocorrelation at the specified lag length, suggesting that the error terms are not systematically related over time. Although the chi-square statistics signal mild sensitivity, the F-form of the test—which is more appropriate for small samples—supports the conclusion that serial correlation does not materially affect the model.

Although the chi-square statistic indicates mild sensitivity, the F-form of the test—which is more adequate for small samples—supports the conclusion that serial correlation does not significantly affect the model. Overall, the diagnostic tests findings show that the estimated ARDL model satisfies the basic assumptions required for consistent and efficient estimation. The absence of core issues such as multicollinearity, heteroskedasticity, and serial correlation strengthens confidence in the reported long-run and short-run results and supports the empirical procedure with established practices in applied development economics. The results of diagnostic test are presented in Table 6.

Table 6: Results of Diagnostic Tests for the ARDL Model

Diagnostic Test	Test Statistic	Probability Value	Decision (5% level)	Interpretation
Variance Inflation Factor (VIF)	Centered VIF values range from **1.08 to 2.52**	—	No multicollinearity	Explanatory variables are not strongly correlated
Breusch–Pagan–Godfrey (Heteroskedasticity)	F-statistics = **0.3188**	**0.9455**	Accept H_0	Residuals exhibit constant variance
	$Obs*R^2$ = **3.5447**	**0.8957**	Accept H_0	
Breusch–Godfrey LM (Serial Correlation)	F-statistics = **2.7736**	**0.1023**	Accept H_0	No serial correlation up to lag 2
	$Obs*R^2$ = **7.2710**	**0.0264**	Mixed but acceptable	Overall dynamics remain stable

Source: Author's own calculations.

Ramsey RESET test

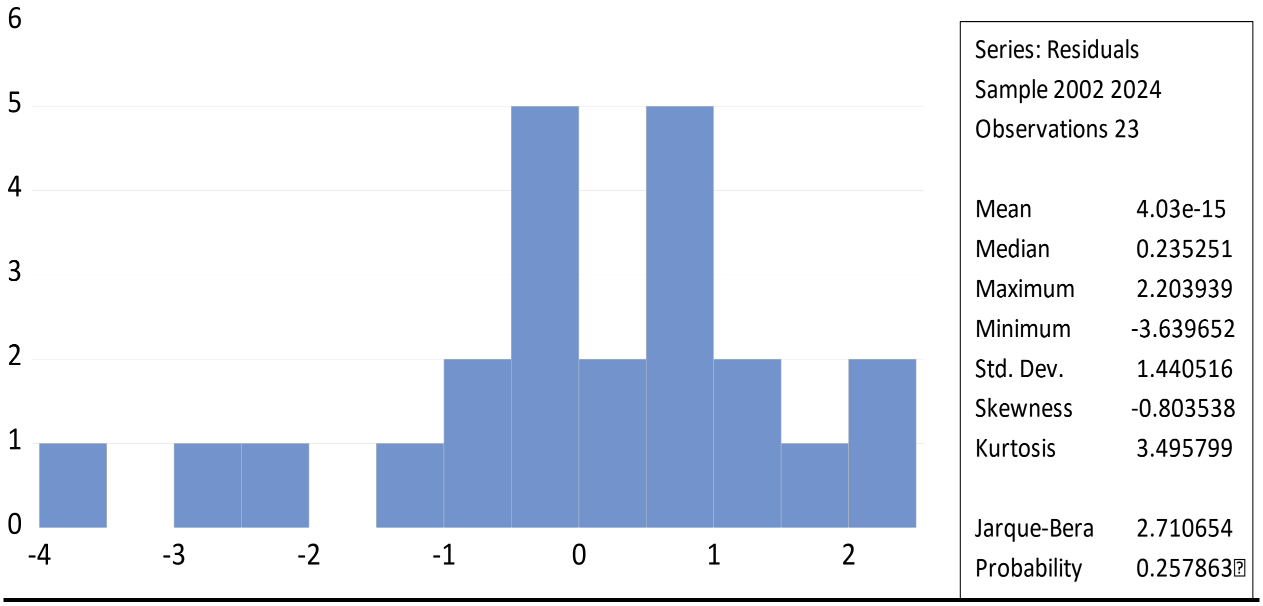
To check whether there is misspecification of variables or any variable has been omitted, we used Ramsey RESET test. RESET is Regression Equation Specification Error Test which was presented by James B. Ramsey in 1969.

Table 7: Results of Ramsey RESET Test

Ramsey RESET Test			
Equation: UNTITLED			
Omitted Variables: Squares of fitted values			
Specification: GDP (-1) TI R_D HC TO C			
	Value	**df**	**Probability**
t-statistic	0.651811	17	0.5232
F-statistic	0.424858	(1, 17)	0.5232
Likelihood ratio	0.592427	1	0.4415

As the probability value of t-statistics is 0.5232, which is in-significant and suggest that model is correctly specified and the rule of thumb for null hypothesis with 5% level of significance was that null hypothesis cannot be accepted because there is no misspecification of variables in the model.

Figure 4: Histogram, Normality test

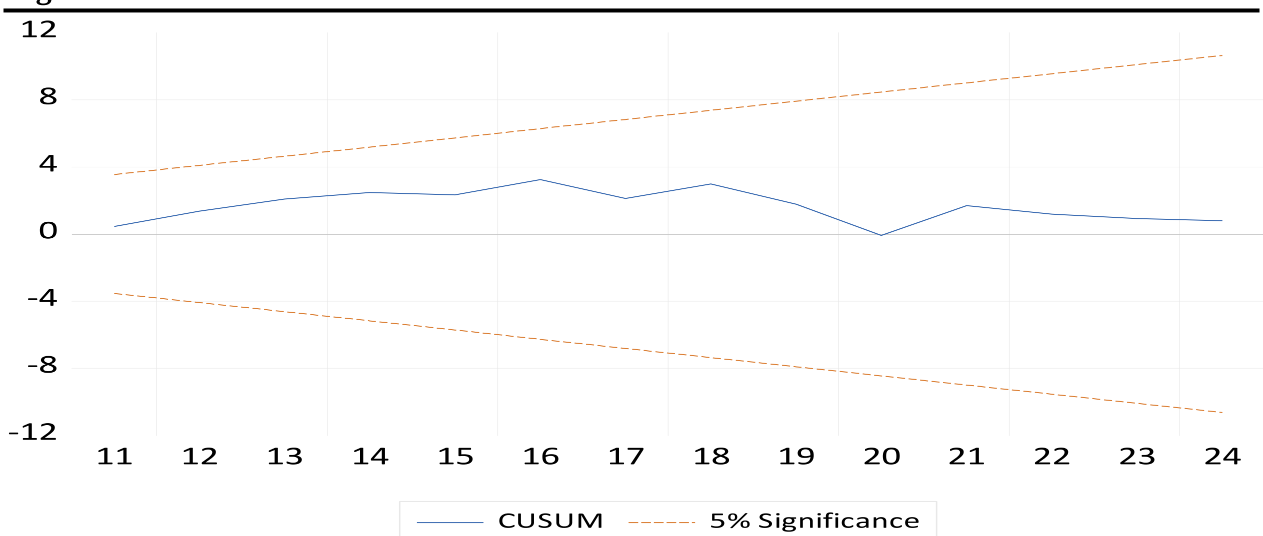


Source: Author draws this diagram through E-view software.

The study used histogram to check normal distribution of residuals. Its results are plotted in Figure 4. The histogram normality test indicates that the residuals or the error terms of the model are normally distributed as the Jarque-Berra statistic value (2.71) with a probability value of 0.25 exceeds the 5% (0.05) significance level, implying that the null hypothesis of normality cannot be rejected. While the null hypothesis was that error terms are normally distributed. Furthermore, the skewness (–0.80) is close to zero, and kurtosis (3.49) is near to the normal benchmark of 3, confirming that the residuals are symmetrically distributed without excessive peaks or fat tails. Therefore, the model confirms that the residuals are normally distributed.

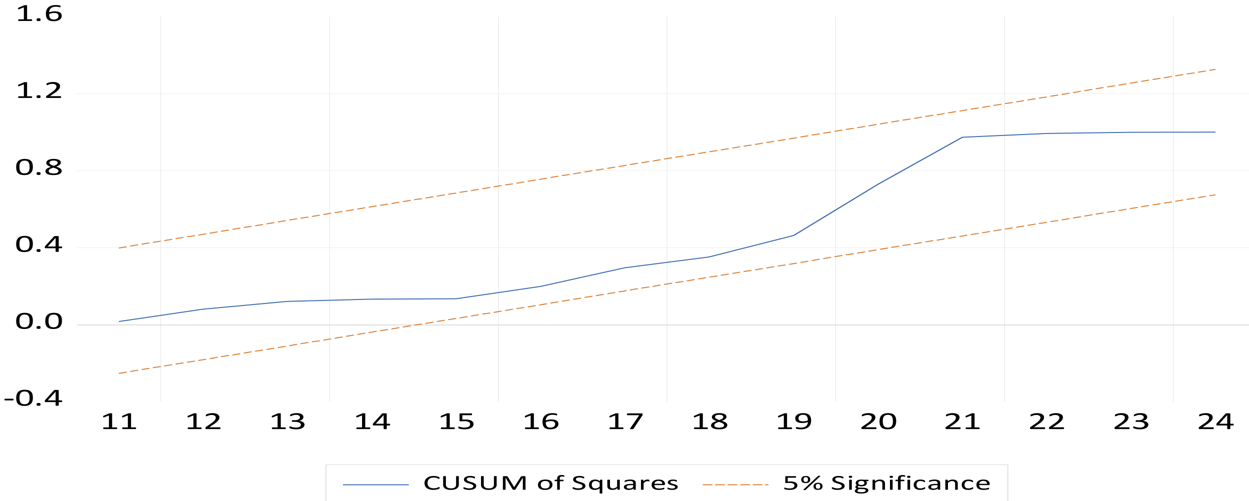
CUSUM and CUSUM Squared Test

Figure 5: CUSUM Test results



As we know that, the CUSUM test is used to check that the variables are stable and can provide reliable forecasts or not. It means the variables are providing long run relationship or short run. To show this check, this test uses blue line, and this blue line is not straight but remained closer to average over the period.

Figure 6: CUSUM Squared Test



Discussion

This research aimed to investigate the interplay between technological innovation, research and development, human capital, trade openness, and economic growth in Pakistan. The findings of this research offer a few insights into the growth process in a developing country with structural constraints, institutional frictions, and time lags in the returns to productive investment.

The results of the long-run estimates show that technological innovation and research and development are the most important determinants of economic growth. This result is consistent with the endogenous growth model, which highlights knowledge creation and technological change as the key drivers of aggregate output growth. The results for the Pakistani economy imply that the effects of innovation and R&D are of a transformative rather than a marginal nature. Most importantly, the strength of the long-run coefficients indicates that innovation and R&D follow cumulative and reinforcing processes, where productivity advances emerge in a gradual but persistent manner.

Trade openness also emerges as a statistically significant contributor to long-run growth. This result reflects the role of international integration in facilitating technology transfer, expanding market access, and enhancing competitive pressures. However, the relatively smaller coefficient compared to innovation-related variables shows that openness alone is not sufficient to create sustained growth unless it is backed up by domestic absorptive capacity. Without appropriate innovation systems and research structure, the benefits of trade openness may remain partial or uneven.

Human capital has a positive but relatively weaker long-run impact on economic growth. This result does not mean that human capital is less significant; instead, it indicates that the potential of human capital in promoting economic growth in Pakistan is contingent upon other complementary variables like technology adoption, labor market optimization, and institutional factors. In settings where the use of skills is limited or mismatched, advances in education and training may not necessarily lead to enhanced productivity in the short run, thereby reducing their macroeconomic significance.

The short-run dynamics also offer interesting insights. Innovation and trade openness have immediate and significant effects on economic growth, while R&D and human capital have lagged effects. These results are consistent with the view that innovation-related investments take time to be commercialized and disseminated, whereas trade-related shocks can generate activity gains more quickly through demand and efficiency effects. The error correction term is negative, large, and highly significant, suggesting that the economy adjusts quickly to its long-run equilibrium in response to short-run shocks. This result indicates that although the economy may experience short-run turbulence, its long-run trajectory is still guided. While growth can be temporarily enhanced through openness and innovation, long-term economic growth depends on sustained investment in research and development (R&D) and technological advancement.

Conclusion

This study has found sound evidence that the economic growth of Pakistan is essentially fueled by long-term investment in technological innovation and research & development activities, facilitated by trade openness and human capital accumulation. With a dynamic ARDL-ECM approach, this research work has been able to identify both the equilibrium and short-run relationships of growth-relevant variables, providing a holistic perspective of the interplay of growth-related variables over time. The results of this research work have clearly highlighted that innovation-driven growth in developing countries is neither an immediate nor an automatic process. Rather, it is a process that takes place through a series of slow-moving processes of knowledge accumulation, institutional learning, and technological diffusion. Though trade openness can accelerate these processes, it is not an effective process if the domestic capabilities of countries are not able to absorb and adapt external knowledge. Similarly, human capital accumulation is most effective when it is integrated with innovation systems and employment op.

In terms of policy implications, the results show that a growth policy strategy targeting either stabilization or trade reform alone is not likely to produce lasting results. Rather, for long-term growth, a continued emphasis on innovative ecosystems, such as research institutions, technology-based firms, and innovation-supportive policies, is necessary. The rapid adjustment speed implied by the result of the error correction test also provides further evidence that once the structural context is improved, the economy can respond to supportive policies relatively quickly.

While the results of this study have important policy implications, the study has limitations in terms of data availability and the use of aggregate indicators, which may mask differences at the sectoral and institutional levels. Future studies can extend this study by incorporating indicators of governance quality, digital infrastructure, and innovation dynamics at the sectoral level, and by focusing on cross-country evidence in the developing country context.

In conclusion, the results of this study provide support for the argument that Pakistan's economic growth must be grounded in the improvement of its innovation capacity and research infrastructure, while also ensuring that trade openness and human capital development are promoted.

Reference

- Acheampong, A. O., Dzator, J., Dzator, M., & Salim, R. (2022). Unveiling the effect of transport infrastructure and technological innovation on economic growth, energy consumption and CO_2 emissions. *Technological Forecasting and Social Change, 182*, 121843. https://doi.org/10.1016/j.techfore.2022.121843

- Adak, M. (2015). Technological progress, innovation and economic growth: The case of Turkey. *Procedia - Social and Behavioral Sciences, 195*, 776–782. https://doi.org/10.1016/j.sbspro.2015.06.478
- Aghion, P., & Howitt, P. (1992). A model of growth through creative destruction. *Econometrica, 60*(2), 323–351. https://doi.org/10.2307/2951599
- Al-Shaikh, F. N., & Hagen, A. (2023). The impact of investing in research and development on performance: Evidence from Jordan. *Information Sciences Letters, 12*(5), 1831–1840. https://doi.org/10.18576/isl/120527
- Arana-Barbier, P. J. (2023). The relationship between scientific production and economic growth through R&D investment: A bibliometric approach. *Journal of Scientometric Research, 12*(3), 596–602. https://doi.org/10.5530/jscires.12.3.057
- Awan, A. G. (2011). Changing world economic and financial scenario. *Asian Accounting and Auditing Advancement, 1*(1), 146–175.
- Awan, A. G. (2012). Emerging versus aging economies: A comparative study of advanced and emerging economies. *International Journal of Management Research and Emerging Sciences, 2*(1), 45–65.
- Awan, A. G. (2012). Human capital: Driving force of economic growth in selected emerging economies. *Global Disclosure of Economics and Business, 1*(1), 9–30.
- Awan, A. G. (2013). China’s economic growth—21st century puzzle. *Global Disclosure of Economics and Business, 2*(2), 9–29.
- Awan, A. G. (2015). Analysis of the impact of the 2008 financial crisis on economic, political and health systems and societies of advanced countries. *Global Journal of Management and Social Sciences, 1*(1), 1–16.
- Awan, A. G. (2016). Wave of anti-globalization and capitalism and its impact on world economy. *Global Journal of Management and Social Sciences, 2*(4), 1–21.
- Awan, A. G., & Mukhtar, S. S. (2019). Causes of trade deficit and its impact on Pakistan’s economic growth. *Global Journal of Management, Social Sciences and Humanities, 5*(3), 480–498.
- Awan, A. G., & Riffat, N. (2019). The impact of government expenditures on economic development in Pakistan. *Global Journal of Management, Social Sciences and Humanities, 5*(1), 562–565.
- Balasubramanian, P., Burchi, F., & Malerba, D. (2023). Does economic growth reduce multidimensional poverty? Evidence from low- and middle-income countries. *World Development, 161*, 106119. https://doi.org/10.1016/j.worlddev.2022.106119
- Bashir, F., & Awan, A. G. (2025). Impact of green innovation, institutional quality, natural resources and GDP on sustainable development in Pakistan. *Journal of Asian Development Studies, 14*(2).
- Bawono, S. (2021). Human capital, technology, and economic growth: A case study of Indonesia. *The Journal of Asian Finance, Economics and Business, 8*(5), 29–35. https://doi.org/10.13106/jafeb.2021.vol8.no5.0029
- Broughel, J., & Thierer, A. D. (2019). Technological innovation and economic growth: A brief report on the evidence. *Mercatus Research Paper*. https://doi.org/10.2139/ssrn.3346495

- Carillo, M. F. (2024). Human capital composition and long-run economic growth. *Economic Modelling*, *137*, 106760. https://doi.org/10.1016/j.econmod.2024.106760
- Clark, A. E., Flèche, S., & Senik, C. (2016). Economic growth evens out happiness: Evidence from six surveys. *Annals of Economics and Statistics*, *121/122*, 237–266. https://doi.org/10.15609/annaeconstat2009.121-122.237
- Coccia, M. (2009). Measuring the impact of sustainable technological innovation. *International Journal of Technology Intelligence and Planning*, *5*(3), 276–288. https://doi.org/10.1504/IJTIP.2009.026749
- Égert, B., de la Maisonneuve, C., & Turner, D. (2024, October 17). Quantifying the link between educational policies and macroeconomic productivity. *VoxEU, CEPR*. https://cepr.org/voxeu/columns/quantifying-link-between-educational-policies-and-macroeconomic-productivity
- Evangelista, R., & Vezzani, A. (2010). The economic impact of technological and organizational innovations: A firm-level analysis. *Research Policy*, *39*(10), 1253–1263. https://doi.org/10.1016/j.respol.2010.08.004
- Gerguri, S., & Ramadani, V. (2010). The impact of innovation into economic growth (MPRA Paper No. 22270). *Munich Personal RePEc Archive*. https://mpra.ub.uni-muenchen.de/22270/
- Goi, C. L. (2017). The impact of technological innovation on building a sustainable city. *International Journal of Quality Innovation*, *3*(1), Article 6. https://doi.org/10.1186/s40887-017-0014-9
- Gong, Y., Zhang, S., Zhang, C., & Yang, J. (2024). An empirical analysis of the impact of innovative human capital on economic growth. In *Proceedings of the 3rd International Conference on Mathematical Statistics and Economic Analysis (MSEA 2024)*. https://doi.org/10.4108/eai.24-5-2024.2350091
- Habib, M., Abbas, J., & Noman, R. (2019). Are human capital, intellectual property rights, and research and development expenditures important for total productivity? *International Journal of Social Economics*, *46*(6), 756–774. https://doi.org/10.1108/IJSE-09-2018-0472
- Hanushek, E. A., & Woessmann, L. (2020). Education, knowledge capital, and economic growth. In S. Bradley & C. Green (Eds.), *The economics of education* (2nd ed., pp. 171–182). Academic Press.
- Khan, I., Zhong, R., Khan, H., Dong, Y., & Nuţă, F. M. (2024). Examining the relationship between technological innovation, economic growth and carbon dioxide emission: Dynamic panel data evidence. *Environment, Development and Sustainability*, *26*(7), 18161–18180. https://doi.org/10.1007/s10668-023-03384-w
- Kihombo, S., Ahmed, Z., Chen, S., Adebayo, T. S., & Kirikkaleli, D. (2021). Linking financial development, economic growth, and ecological footprint: What is the role of technological innovation? *Environmental Science and Pollution Research*, *28*(43), 61235–61245. https://doi.org/10.1007/s11356-021-14993-1
- Kocoglu, M., Jahanger, A., Awan, A., Barak, D., & Balsalobre-Lorente, D. (2023). Examining the nonlinear impact of human capital on environmental degradation in N-11 countries. *Environmental Science and Pollution Research*, *30*(29), 74265–74279. https://doi.org/10.1007/s11356-023-27426-y
- Lau, A. K., Yam, R. C., & Tang, E. P. (2010). The impact of technological innovation capabilities on innovation performance. *Journal of Science and Technology Policy in China*, *1*(2), 163–186. https://doi.org/10.1108/17585521011059893

- Liu, C., & Xia, G. (2018). Research on the dynamic interrelationship among R&D investment, technological innovation, and economic growth in China. *Sustainability, 10*(11), 4260. https://doi.org/10.3390/su10114260
- Matousek, R., & Tzeremes, N. G. (2021). The asymmetric impact of human capital on economic growth. *Empirical Economics, 60*(3), 1309–1334. https://doi.org/10.1007/s00181-019-01789-z
- Matusiewicz, M. (2025). Endless growth does not bring joy: Income inequality, human development, and happiness. *American Journal of Economics and Sociology, 84*(5), 683–694. https://doi.org/10.1111/ajes.12625
- Mohamed, M. M. A., Liu, P., & Nie, G. (2022). Causality between technological innovation and economic growth. *Sustainability, 14*(6), 3586. https://doi.org/10.3390/su14063586
- Ngepah, N. (2024). Asymmetric response of poverty to growth and inequality in South Africa. *Journal of African Economies*. Advance online publication. https://doi.org/10.1093/jae/ejae020
- Nguyen, H. T. (2021). The impact of investments on economic growth: Evidence from Vietnam. *The Journal of Asian Finance, Economics and Business, 8*(8), 345–353. https://doi.org/10.13106/jafeb.2021.vol8.no8.0345
- Qenaat, B., Taj, S., Khan, Z. U., Ahmad, M., & Rehman, A. (2025). Toward inclusive growth: Technology in development economics through the lens of bibliometric analysis. *Future Business Journal, 11*, Article 49. https://doi.org/10.1186/s43093-025-00474-1
- Qasim, H., & Awan, A. G. (2020). Impact of external debt on economic growth of Pakistan. *Global Journal of Management, Social Sciences and Humanities, 6*(1), 30–61.
- Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5, Part 2), S71–S102. https://doi.org/10.1086/261725
- Sarwar, A., Khan, M. A., Sarwar, Z., & Khan, W. (2021). Financial development, human capital and economic growth. *Asian Journal of Economics and Banking, 5*(1), 86–100. https://doi.org/10.1108/AJEB-06-2020-0015
- Shahbaz, M., Song, M., Ahmad, S., & Vo, X. V. (2022). Does economic growth stimulate energy consumption? *Energy Economics, 105*, 105662.
- Shen, F., Liu, B., Luo, F., Wu, C., Chen, H., & Wei, W. (2021). The effect of economic growth target constraints on green technology innovation. *Journal of Environmental Management, 292*, 112765. https://doi.org/10.1016/j.jenvman.2021.112765
- Vashakmadze, T., Khandelwal, P., Kolo, J., & Winkler, H. (2025, February 5). The fading dividend of past human capital reforms. *World Bank Blogs*. https://blogs.worldbank.org/en/developmenttalk/the-fading-dividend-of-past-human-capital-reforms
- Wang, Q., & Zhang, F. (2020). Does increasing investment in R&D promote economic growth decoupling from carbon emissions? *Journal of Cleaner Production, 252*, 119853. https://doi.org/10.1016/j.jclepro.2019.119853
- Zhang, H. (2024). The impact of technological innovation on economic growth: A case-based study. *Advances in Economics, Management and Political Sciences, 139*, 130–136. https://doi.org/10.54254/2754-1169/2024.19289