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The Role of Technology in Pakistan's Economic Development

Sana Ullah
M.Phil. Scholar at Institute of Southern Punjab University, Multan, Pakistan
sunny7885750@gmail.com
Dr. Muhammad Ali Gardezi (Corresponding Author)
Assistant Professor of Economics
University of Southern Punjab University, Multan, Pakistan
aligardezi@usp.edu.pk
ORCID: 0000-002-7350-458X

Abstract
This dissertation examines how technology and macro-economic factors influenced economic growth in Pakistan in the period 1990-2023. Using classical and modern growth frameworks such as the Solow Model and endogenous growth theory, the study applies the Autoregressive Distributed Lag (ARDL) approach, supported by descriptive statistics, correlation matrices, unit root tests, bounds testing for cointegration, and the Error Correction Model (ECM). Empirical evidence demonstrates that the technological advancements have a great and a positive impact on both short- and long-term economic growth. The positive effects are also observed to be strong on capital formation, labor force participation and trade openness and inflation has negative impacts on GDP per capita. The ARDL bounds test establishes the presence of the long-term equilibrium relationship between the variables and diagnostic tests show the model stability, normality, and no heteroscedasticity and serial correlation. The findings underscore the fact that technology has been a major factor of economic growth in Pakistan in terms of productivity, efficiency, and competitiveness. Nevertheless, technological potential is not fully realized due to structural obstacles like regulatory inefficiencies, digital divides and insufficient R&D investment. The research proposes investing more on innovation and digital infrastructure and to allow enabling policy frameworks to give impetus to sustainable economic development in Pakistan.

Keywords: *Technology, Capital, labor force, trade, inflation, Economic Growth and ARDL*

1. Introduction

Recent advancements in technology have marked an area of interest in the economic development policies of countries in the twenty-first century and a country like Pakistan being in the developing nation category. Being a developing country with a distinct structure of social and economic systems and issues, Pakistan is now in a crucial position where adopting modern technologies can boost its economy largely (World Bank, 2023). This

country, with more than 240 million population nowadays (Pakistan Bureau of Statistics [PBS], 2024), has the chance to use the technologies to solve problems of poverty, unemployment, and insufficient infrastructure that have existed for many years in the development of a sustainable economy. With the current trend of moving towards a digital economy, Pakistan's economic growth entails the use of technology in its agricultural, manufacturing, service, and educational sectors (UNDP, 2022).

In the past, the growth rate in the economy of Pakistan has been slowed down by challenges like political instability, poor infrastructure, and low literacy levels (Khan & Hussain, 2021). Unfortunately, these barriers are still present today but at the same time, the introduction of digital technologies allows for the elimination of these barriers. For instance, mobile technology has transformed communication and business in a way that has seen many of the country's citizens, who were left out of the formal financial system, formally join the financial sector (GSMA, 2023).

However, it was noted that technology is an important tool in increasing efficiency in different industries. For instance, in farming, precision farming solutions involving farming systems powered by data analytics and mobile applications help farmers to make better decisions on the proper management of crops hence improving yields while practicing sustainable agriculture (FAO, 2023). In Pakistan, Dr. A.Q. Khan's Research Laboratories along with various private sectors are being used for the introduction of advanced technologies in Agriculture and this has helped in food security and the development of rural communities (Ministry of National Food Security & Research, 2023). Through the adoption of appropriate technologies in this sector, Pakistan has an opportunity to not only increase production in the agricultural sector but also overcome barriers such as a shortage of food and malnutrition (FAO, 2023).

Another area that is crucial for the growth of manufacturing is technological enhancement which is very pertinent for the industrial sector of Pakistan. The use of automation, artificial intelligence, and IOT can help in making production faster, and cheaper and come up with better quality products. Recently, increased attention has been paid to the commercialization and further development of technological sectors like textiles, electronics, and pharma. These policies encompass the Special Economic Zones (SEZs) and the China-Pakistan Economic Corridor (CPEC) which aims to address the problem of bringing foreign investment and transfer of technology to update the current industrial base and generate employment chances (Planning Commission of Pakistan, 2023).

Besides agriculture and manufacturing industries, the growth of technology is affecting all sectors including education and health sectors in Pakistan. This kind of emergency was also useful in facilitating the adoption of online educational platforms by making education more accessible to students across the United States and the world due to the COVID-19 pandemic (UNESCO, 2021). The model of the Tele School has shown that through the use of technology, it is possible to reduce education inequalities, especially in the developing world. Likewise, telemedicine has also emerged as a field as it has served as a means through which patients especially in rural areas can access health care (WHO, 2022). The government of Pakistan needs to invest in technology in sectors of education and healthcare to ensure that every citizen of this country has access to the best healthcare solutions as well as a qualified workforce to suit future market demands through technology.

Therefore, it can be said that technology is the key to economic development in Pakistan and it is mandatory too. The application of technology in various fields has the benefit of increasing efficiency, creating employment opportunities, and generally improving the standard of living of the people. Hence, this potential cannot be fully realized unless the challenges of the digital divide are tackled, citizenship practices are improved in the field of digital media in Pakistan, the intensity of regulation is increased, and partnerships between the public and the private sectors are developed. As a result, embracing technology and building an inclusive technology landscape in Pakistan would open vast opportunities for growth in essence for the creation of tremendous potential for a prosperous future of the country. This is because the country is at the level of embracing this technological revolution in a way that would enable it to participate fully in the new world economy, thus warranting the benefits of its economic growth to be enjoyed by all the people.

2. Review of Literature and Theoretical Framework

The literature review critically studies the scientific literature on the technology and economic development in Pakistan. A case is made to show how technology has enhanced productivity and economic resilience across all sectors of the economy but also exposes some key hurdles that inhibit the uptake of the technology. The review deploys itself into several sections including the effect of technology on general economic development, and what's been done in the fields of agriculture, manufacturing, fintech, and public governance.

Nowadays, it has been well appreciated that technology is one of the important agents to drive the world's economic growth. Technological investments have made great contributions in countries like South Korea, China, and Canada towards industrial expansion, and improved trade and employment opportunities. On the other hand, Pakistan has not been able to compete with the advances in the same field globally for quite some time now because of a low level of investment in R&D and a lack of infrastructure systems that support digital transformation at a large scale.

Similarly, the comparative analysis of Pakistan's situation with Canada and South Korea presented by Haq (2018), reveals that Pakistan is still far behind the developed countries, particularly in terms of investing in R&D. Canada and South Korea invest 2.5 %of its gross domestic product in research and development whereas Pakistan invests only 0.3 percent. Thus, such striking inequality results in a lack of industrial development, low levels of production, and weak economic performance. Pakistan has to focus on increasing its R&D funding and more importantly, it has to review some of its governmental policies to foster private sector innovation with a view of competing in the global market.

Second, on the topic of internationally comparable ICT sector expenditure, Javed (2020) analyzed the relationship between ICT Sector investment and economic growth in Pakistan and established that ICT investment increases the GDP by 0.7 percent up to an extent of one percent. This finding has a lot of potential and will greatly assist the ICT sector in driving economic growth in areas such as e-commerce, software solutions, and other industries involving digital services. The study also pointed out that the IT Sector in Pakistan is not as advanced as compared to the other neighboring countries like India and Malaysia where IT contributes more than 10% of GDP but in Pakistan it is only 3.2%.

Moreover, Abbasi et al. (2022) explained how technological advancement plays an essential role in environmental management. Green technologies, energy-efficient manufacturing, and renewable energy were applied in the study both as a tool for economic development and environmental conservation. In their opinion, Pakistan should not only improve industrial performance and per-capita use of energy but should also avoid the impact of climate change through utilizing clean technologies.

A study by Bhatti et al. (2018) on the effects of mobile applications and digital advisory services on smallholder farmers in Pakistan demonstrates that access to real-time market prices, their real-time weather information, and agricultural best practices empowers farmers m2 to make better decisions that can help them to optimize the crop yield. It turned out that the use of mobile-based precision farming techniques led to an increase in agricultural output of up to 20 to 30%. While these benefits exist, however, rural farmers have little or no access to digital literacy programs that can help them take full advantage of modern agricultural tools. To increase digital literacy programs for farmers, government agencies and private sector organizations are recommended to work together.

Rahman and Iqbal (2022) in a similar way also covered how drones and IoT-based irrigation systems contributed to water conservation and improved fertilizer application efficiency. They found that having IoT-based irrigation systems in place can save 40% of the water being used while simultaneously boosting crop yield by 25%, which could offer salvation through technology-based agriculture efforts in Pakistan in the fight against water scarcity. However, the authors concluded that subsidizing smart irrigation technologies could help increase adoption by small-scale farmers, contributing to increasing the country's food security and rural incomes.

Hussain et al. (2021) also explored how the use of AI-driven pest detection systems and solar-powered irrigation can make agriculture more sustainable. AI-based pest detection was found to reduce crop losses by 18% while solar-powered irrigation systems lowered the energy cost by 30%, making them a cost-effective and environmentally sustainable way of farming compared to conventional methods. These technologies could be widely implemented to add $3 billion or more to Pakistan's agricultural GDP annually.

The digital divide is one of the most pressing challenges in the technological landscape of Pakistan where only the urban population has almost easy access to technology while rural populations, on the other hand, are struggling to get access to digital infrastructure and internet services. While in urban centers, the broadband penetration goes over 80%, in rural Pakistan only 35 percent of the population has access to high-speed internet according to Ahmed et al. (2021). The digital services gap in rural areas prevents rural communities from enjoying the advantages of digital financial services, online education, e-commerce, and telemedicine, aggravating economic inequality.

Poor telecommunication infrastructure, unreliable electricity, high internet access costs, and the presence of virtual fencing are other determining factors that limit internet penetration in many remote areas. For instance, companies in those regions find it difficult to digitize their functions, farmers cannot benefit from precision farming tools and video job markets are inaccessible to many people. Digital exclusion has been a result of the lack of government initiatives to provide affordable broadband services in underserved areas and thereby aggravating their socio-economic imbalances (Ahmed et al., 2021).

To bridge the digital divide, it takes a string of strategic interventions for all citizens to have equitable access to digital resources. It is important to invest in nationwide expansion projects for broadband internet expansion in rural and underdeveloped regions. In subsidizing developing digital infrastructure in remote locations, for example, public-private partnerships can potentially make technology more affordable and available to larger numbers. It is also important for the government to help promote mobile-based financial services as well as digital education programs to allow people, particularly in underserved places, to fully participate in the digital economy. At the same time, if these additional measures are implemented eloquently, Pakistan can significantly increase its internet penetration rate, making more people approach digital services, and thus increasing the productivity of local industries and accordingly enhancing the whole economic growth of the country.

3. Data and Methodology

This section presents the methodological framework employed to investigate the determinants of Gross Domestic Product (GDP) in Pakistan over the period 1990 to 2023. The primary focus of this research is to understand how Technology (IT), Gross Fixed Capital (GFCF), Labor force (LF), Trade openness (TO) influence Pakistan's economic output. The section is organized into a few major items: model specification, data type and sources and analytical methods applied to an empirical study. Reliability and the validity of study findings are achieved by appropriate econometric tools and theoretical models used in the study.

Table 1. Description of the variables

Variable Code	Variable Name	Description	Measurement / Proxy (WDI Indicator)
LNGDPPC	Log of GDP per capita	Measures the level of economic development per person.	GDP per capita (constant 2015 US$)
LNTEC	Log of Technology	Total Residential Patent applications	Patent applications, residents
LNGFCF	Log of Gross Fixed Capital Formation	Represents investment in physical capital such as infrastructure and machinery.	Gross fixed capital formation (% of GDP)
LNLF	Log of Labor Force	Indicates the total labor supply available in the economy.	Total labor force (in millions)
LNTO	Log of Trade Openness	Reflects the degree of economic integration with the world economy.	(Exports + Imports)/GDP deflator as % of GDP
LNINFL	Log of Inflation	Measures price stability and macroeconomic performance.	Inflation, consumer prices (annual %)

3.1. Economic Model

The empirical analysis has the economic model as its theoretical basis. The general form of the model is represented as:

$$GDPC = f(TEC, GFCF, LF, TO, INF)$$

Where:

- **GDPC** = Gross Domestic Product per capita
- **TEC** = Technology
- **GFCF** = Gross Fixed Capital Formation
- **LF** = Labor Force
- **TO** = Trade Openness
- **INF** = Inflation

3.1.1. Econometric Model

The specified relationship in the economic model is operationalized with the help of the following linear regression equation:

$$GDPC_t = \beta_1 + \beta_2 TEC_t + \beta_3 GFCF_t + \beta_4 LF_t + \beta_5 TO_t + \beta_6 INF_t + \mu_t$$

The primary econometric approach used is the Autoregressive Distributed Lag (ARDL) model, which is suitable for analyzing relationships between variables that are integrated of order zero, I(0), and order one, I(1), but not higher.

4. Results, Findings, and Discussion

Table 2 presents the descriptive statistics for all variables included in the study. It reports the mean, median, mode, standard deviation, and interquartile values, which provide a quantitative overview of the dataset. To complement the statistical findings, Figures 1 and 2 present the time-series bar charts of GDP and Internet Users, two of the most critical indicators for Pakistan's economic trajectory.

Table 2. Descriptive Statistics

	LNGDPPC	LNTEC	LNGFCF	LNLF	LNTO	LNINFL
Mean	6.692902	4.481924	23.78401	17.78498	20.60519	2.125873
Median	6.837118	4.543068	24.03466	17.80592	20.60726	2.190188
Maximum	7.358409	6.269096	24.72504	18.22133	21.01610	4.219661
Minimum	5.841965	2.772589	22.65793	17.28332	19.97128	-0.081033
Std. Dev.	0.515088	1.038721	0.664991	0.291752	0.238539	0.697747
Skewness	-0.271688	-0.050315	-0.203107	-0.208206	-0.361520	-0.143494
Kurtosis	1.536539	1.908287	1.518715	1.739473	2.803122	6.169507
Jarque-Bera	3.452379	1.702782	3.342223	2.496632	0.795525	14.34819
Probability	0.177961	0.426821	0.188038	0.286988	0.671822	0.000766
Sum	227.5587	152.3854	808.6562	604.6892	700.5764	72.27970
Sum Sq. Dev.	8.755430	35.60508	14.59303	2.808935	1.877732	16.06608
Obs	34	34	34	34	34	34

The descriptive statistics will give a representation of the variables used in the model. The average LNGDPPC (6.69) value depicts that there is a moderate rate of economic growth in the sample, and LNTEC (4.48) represents an average level of technological development. The average of LNGFCF (23.78) is an indicator of gross fixed capital formation and portrays that there is a regularity of investment. Likewise, LNLF (17.78) shows

that there is a stable rate of participation in the labor force, and LNTO (20.60) is relatively open to trade. On the contrary, LNINFL (2.12) exhibits a middle rate of inflation. The values of the standard deviation indicate that the variables of technology (1.03) and inflation (0.69) are more volatile than others. All variables have skew values that are negative suggesting that the variables are slightly skewed to the left skew, i.e. most of the data is above the means of the variables. Most variables have values of kurtosis that are below 3 which implies a flatter-than-normal distribution except inflation (6.17) where the value is leptokurtic with longer tails. Jarque-Bra test supports the fact that all variables are normally distributed except inflation, which is not normally distributed at the 1 percent significance level. On the whole, the data show a consistency in economic, investment, labor and trade indices, but technology and inflation have had a significant fluctuation throughout the sample period.

Table 3. Correlation Matrix

	LNGDPPC	**LNTEC**	**LNGFCF**	**LNLF**	**LTO**	**LNINFL**
LNGDPPC	1					
LNTEC	0.9346	1				
LNGFCF	0.9952	0.9334	1			
LNLF	0.9777	0.9633	0.9693	1		
LNTO	0.3013	-0.4405	-0.2589	-0.4481	1	
LNINFL	-0.1609	-0.1118	-0.1574	-0.1310	-0.0261	1

The correlation table illustrates the direction and strength of the relationship between the variables in the model. The findings indicate that the positive correlation between LNGDPPC and LNGFCF (0.9952) is very strong, which means that the greater the gross fixed capital formation is, the greater the per capita income. In an equally strong fashion, LNGDPPC and LNLF (0.9777) and LNGDPPC and LNTEC (0.9346) have positive results, indicating that the two labor force participation and technological development are both significant to the growth of an economy. The great intercorrelations of LNTEC, LNGFCF and LNLF (between 0.93 and 0.97) mean that there is a co-movement of these factors, which serves as a sign of the strong association between investment, technology and labor dynamics in economic development. But LNTO (trade openness) presents the negative or negative associations with most variables, especially with LNTEC (-0.44) and LNLF (-0.45), suggesting that the liberalization of trade did not necessarily result into the increased use of technology and involvement of labor throughout the study period. LNINFL (inflation) shows weak and negative correlations with all the other variables indicating that the inflation has minimal or rather a negative impact on the economic performance and the determinants. Generally, the matrix indicates that there was a high internal consistency of the variables of growth, investment, labor and technology, whereas trade openness and inflation seem to have less significant impact on the growth of the GDP per capita.

Table 4. Unit root test

Variables	ADF		Phillips Perron		
	Level	1st Difference	Level	1stdifference	Decision
LNGDPPC	0.5906	0.0001	0.5035	0.0000	I (1)
LNTEC	0.9017	0.0000	0.9877	0.0000	I (1)
LNGFCF	0.5906	0.0001	0.5035	0.0000	I (1)
LNLF	0.3188	0.0009	0.3597	0.0007	I (1)
LNTO	0.7970	0.0026	0.7827	0.0037	I (1)
LNINFL	0.0067	0.0000	0.0064	0.0000	I (0)

Source: Author's own calculations in E-Views

The outputs of the unit root test of both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests give information of the stationarity of the variables. The findings indicate that all the variables except LNINFL are non-stationary at level, but they turn into stationary after first differencing, which implies that LNGDPPC, LNTEC, LNGFCF, LNLF, and LNTO are all order 1, I(1). It is to imply that their mean and their variance move with time, but differentiating their series once again eliminates the trend and stabilizes them. On the contrary, ADF (0.0067) and PP (0.0064) tests of the null hypothesis (H0: LNINFL is stationary) have a p-value below 0.05 at level, which proves that LNINFL is an I(0) process. This means that inflation is a short-term variable, which does not have a unit root and is a mean-reverting variable. The similarity in the results of the ADF and PP test supports the reliability of the results. It is a combination of integration orders, and this may imply the possibility of suitable ARDL (Autoregressive Distributed Lag) modeling in terms of conducting further analysis. Given that the majority of variables are I(1), and one of them is I(0), this combination of integration orders may be assumed. In general, the results show that economic growth, technology, investment, labor force, and the openness to trade follow long-run trends and inflation is a stationary variable and it oscillates about a constant value on a short-run.

Table 5. ARDL Bound test

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	**Value**	**Signif.**	**I(0)**	**I(1)**
F-statistic	13.01526	10%	1.81	2.93
k	5	5%	2.14	3.34
		2.5%	2.44	3.71
		1%	2.82	4.21

The F-Bounds Test outcome of the Autoregressive Distributed Lag (ARDL) model is applied in the determination of the existence of a long-run cointegrating relationship among the variables. The value of the calculated F-statistic 13.01526 is far much greater than the upper critical bound (I) value of 4.21 at 1% level of significance. This is a clear indication that one can reject the null hypothesis of no long run relationship with a lot of force. That is, the relationship between the dependent variable (LNGDPPC -economic growth) and the explanatory variable (LNTEC, LNGFCF, LNLF, LNTO, and LNINFL) is stable and statistically significant over the long run. The large F-statistic indicates that a combination of technology, capital formation, labor force, trade openness and inflation explain the long run economic growth changes. As the F-statistic is greater than even the strictest critical value, the cointegration evidence is strong at all the significance levels (1%, 2.5%, 5%, and 10%). Thus, the model can go ahead and estimate the long-run coefficients, as well as short-run error correction terms, such that the dynamic relationships among variables have an important meaning. On the whole, the F-Bounds findings argue in favor of the long-run equilibrium relationship between economic growth and its most important determinants in the model.

Table 6. Long run results of ARDL model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNTEC	0.579082	0.079169	7.314504	0.0000
LNGFCF	0.463361	0.133874	3.461175	0.0019
LNLF	0.967314	0.362149	2.671042	0.0131
LNTO	0.374113	0.158585	2.359071	0.0286
LNINFL	-0.211935	0.088902	-2.383924	0.0272
C	-20.89384	4.825514	-4.329868	0.0002

The ARDL model estimation in the long-run will show that economic growth (LNGDPPC) is significantly related to its determinants, which can be technology, capital formation, labor force, trade openness, and inflation. The LNTEC coefficient (0.5791) is positive and significant at the 1% level which means that, a one percent increase in technology will result in about 0.58 percent increase in GDP per capita. This observation is in line with the Endogenous Growth Theory developed by Romer (1990) which focuses on the fact that advancements in technology increase productivity and long term economic growth through efficiency and innovations. Likewise, coefficient of LNGFCF (0.4634) shows that 1 percent of increases in gross fixed capital formation is equivalent to 0.46 percent increase in the economic growth which proves the Solow-Swan growth model where capital accumulation is a major factor in economic growth by increasing the capacity to achieve output.

Its labor force (LNLF) has a positive and significant coefficient (0.9673) implying that a 1 per cent increase in the labor participation will positively influence the economic growth by approximately 0.97. This goes in line with the Human Capital Theory (Becker, 1964) that postulates that effective and proactive workforce enhances

production and general productivity. The trade openness coefficient (LNTO = 0.3741) is significant and positive, which implies that a higher level of openness to international markets fosters growth by enabling countries to enjoy comparative advantage, technology spillovers, and larger export market, as Balassa (1978) and Grossman and Helpman (1991) found out.

On the other hand, the coefficient of inflation (LNINFL) is significant and negative (-0.2119) such that an increase in inflation by one percent decreases the GDP per capita by approximately 0.21. This finding is in line with Fischer (1993) and Barro (1995) who has argued that high inflation distorts the price signals, it deters investment and it derails growth. The negative constant (-20.8938) indicates inefficiency in the structure and other factors that are not observable that hold down economic growth. In general, all the findings affirm that long-run economic growth is positively contributed by technological advancement, investment, labor involvement, and trade openness, but inflation has a negative influence.

Table 7. Short run results of ARDL model

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LNTEC)	0.543605	0.233009	2.332975	0.0315
D(LNGFCF)	0.579082	0.053714	10.78083	0.0000
D(LNLF)	0.145400	0.058459	2.487203	0.0218
D(LNTO)	0.367621	0.156083	2.355290	0.0301
D(LNTO)	0.211935	0.058484	3.623832	0.0017
D(LNINFL)	0.145400	0.058459	2.487203	0.0218
CointEq(-1)*	-0.485870	0.087481	-5.554021	0.0000

According to the outcomes of the short-run estimation, the economic growth is affected significantly and instantly by changes in technology, investment, labor force, trade openness, and inflation. The coefficient of D(LNTEC) (0.5436) indicates that a 1 percent short term rise in technology raises the economy by approximately 0.54 in line with the argument by Romer (1990) which highlighted the fact that diffusion of technology can enhance productivity even on a short run basis. The D(LNGFCF) (0.5791) coefficient is not negligible as the short-run increases in the gross fixed capital formation lead to the stimulation of the growth by 0.58 and proves Solow (1956) who emphasized the role of investment in the output growth by increasing the capital. The D(LNLF) (0.1454) coefficient justifies the fact that an increase in the labor force has a positive effect on its growth in agreement with Mankiw, Romer, and Weil (1992), who emphasized on the importance of human resource involvement in the productive efficiency. Some previous scholars are aligned with our findings (Ali Gardezi & Samar Abbas, 2021; Rasheed et al., 2025)

In the same way, D(LNTO) (0.3676) demonstrates that the trade openness enhances the economic performance in the short-term through facilitating the market accessibility and earning of foreign exchange in accordance with Edwards (1998) who established that liberalized trade policies promoted output growth. Remarkably, D(LNINFL) (0.1454) presents a low positive short-run effect meaning that modest inflation can stimulate

production and expenditure, which agrees with Mallik and Chowdhury (2001). Cohen error correction (CointEq (-1)) = -0.4859) = -.4859 and is much less than zero, and significant and indicates the adjustment of long-run equilibrium and approximately 48.6% of the short-run disequilibrium has been corrected each year. This means that there is a stable approach to long-run growth equilibrium.

Table 8. Variance inflation factor

	Coefficient	Uncentered	Centered
Variable	**Variance**	**VIF**	**VIF**
LNTEC	0.006547	10.15252	4.837011
LNGFCF	0.059605	3.123177	1.790868
LNLF	0.004752	12.52802	4.880263
LNTO	1.15E-15	40.27421	1.971665
LNINFL	0.226239	2.155078	1.090898

The results of the Variance Inflation Factor (VIF) test are used to determine the presence of the multicollinearity of the explanatory variables used in the model. The centered VIFs, which are more agreeably interpreted, indicate that all the variables have a VIF less than the critical value of 10, which proves to be an acceptable degree of multicollinearity. Particularly, LNTEC (4.83) and LNLF (4.88) have moderately high values of multicollinearity, implying the close relationship between technology and labor force, which is theoretically correct because technological advancement tends to be complementary to labor productivity. LNGFCF (1.79) and LNTO (1.97) show low VIF values, which means that they have weak multicollinearity and independent variables on economic growth. LNINFL (1.09) has the least VIF, which proves that it has little relation with other regressors. The uncentered VIFs are greater because of the inclusion of the intercept term and cannot be applied to make diagnostic purposes. All in all, the findings provide no critical multicollinearity so the estimated coefficients are authentic and can be interpreted using statistical significance. Some previous researchers have similar findings (Nosheen et al., 2025; Shaheen et al., 2025; Zaib et al., 2023).

Table 9. Results of Diagnostic Tests

Diagnostic Tests	Coefficient of F- Statistics	p-value	Decisions
Heteroscedasticity (Breusch-Pagan-Godfrey)	1.570357	0.2008	There is no evidence of heteroscedasticity.
Heteroscedasticity (Harvey)	1.517854	0.2161	There is no evidence of heteroscedasticity.
Serial correlation (serial correlation LM test)	1.131100	0.3380	There is no evidence of serial correlation.
Ramsay Reset Test	0.003269	0.9548	There is no evidence of model misspecification.

Table 9 of the diagnostic test results showed the overall reliability and strength of the estimated ARDL model. Both the Breusch-Pagan-Godfrey and Harvey tests of heteroscedasticity have p-values of 0.2008 and 0.2161, respectively, significantly more than the 0.05 significance level, so no heteroscedasticity. This implies that error terms have constant variance and one of the major assumptions of classical linear regression model is met and results in efficient and unbiased estimates of coefficients. Serial Correlation LM test has an F-statistic of 1.1311 with a p-value of 0.3380 and this indicates that there is no autocorrelation between the error terms across time and thus the error terms of the model are independent. Lastly, Ramsey RESET test has p-value 0.9548, which reports no misspecification of the model or the bias of omitted variable. Altogether, diagnostic tests confirm that the model does not contain any heteroscedasticity, serial correlation, and specification errors, gathered in statistical validation that the regression results are robust and reliable and can be used to interpret the policies and conduct additional econometric survey.

Figure 1. Normality test

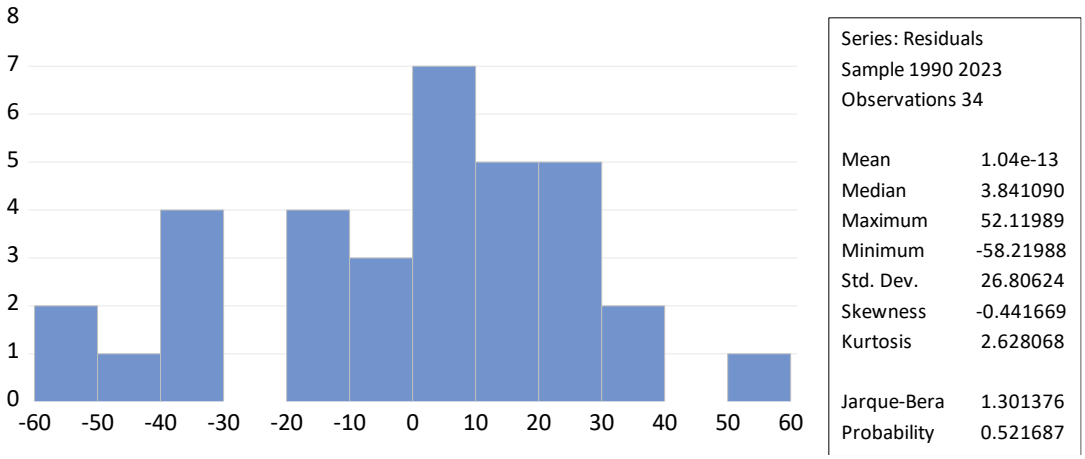
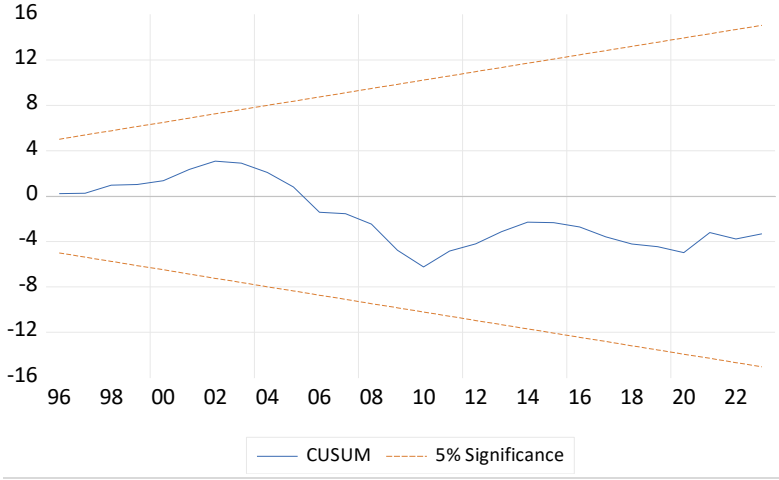
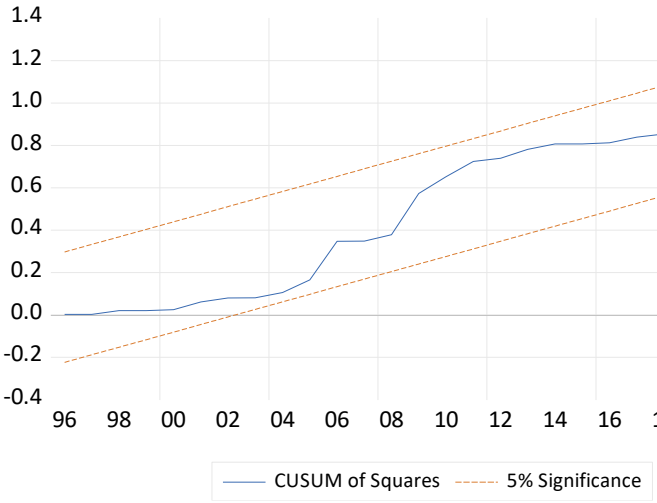


Figure 2. CUSUM test



According to the graph of CUSUM stability test, the blue line does not cross the 5-percent boundaries of significance values, which means that the model parameters are not changing during the sample period of 19902023. The cumulative number of recursive residuals does not exceed the critical values, which means that the structure is not too unstable, and the parameter does not change, which proves the reliability of the estimated ARDL model and its dynamically sound test during the period of analysis.

Figure 3. CUSUM of Square Test



CUSUM of Squares test graph indicates that the blue line is neither below nor above the 5% significance level during 1990-23, implying that the variance of reside is constant across time. The fact that the plot does not exceed the critical limits proves that there are no structural breaks or instability in the parameters of the model. Therefore, the regression model of the ARDL that has been estimated is both stable in structure and statistically sound.

5. Conclusion, Policy Recommendations and Future Research

This paper identified with an aim of analyzing the contribution of technology in enhancing economic growth in Pakistan during the years 1990-2023, which incorporated both the classical and modernized growth theories to offer a total perspective of the relationship between technology development and economic growth. The study implemented Autoregressive Distributed Lag (ARDL) model to examine the relationship between technology, gross fixed capital formation, participation in the labor market, trade openness, and inflation and their impact on the economic growth of Pakistan in the form of GDP per capita. Rigorous econometric tests such as unit root testing, cointegration analysis and diagnostic evaluations were also used in the study to ascertain the reliability and stability of the results. The results showed that technology is a major factor that dictates the amount as well as sustainability of economic growth in the short run and long run.

The empirical findings showed that technological advancements which are measured by patent applications, positively and significantly influence GDP per capita. This validates the fact that, technological innovation increases productivity, efficiency and competitiveness in the agricultural sector, manufacturing sector and the services sector. Likewise, the effects of gross fixed capital formation and labor force participation were also

extremely positive and in support of the fact that physical and human capital are required complements to technological growth. The openness to trade was also a positive factor, which implies that the globalization process and the international exchange lead to the transfer of technology and market growth. Nevertheless, inflation showed negative effect, which emphasized that macroeconomic instability can undermine gains of growth which are based on technology and investment. The stability tests and diagnostic tests provided that the model did not have serial correlations, heteroscedasticity of the test, or specification errors, which makes the model robust and credible of the findings.

Policymaking-wise, the results indicate that the economic development in Pakistan can be enhanced considerably through the focus on technological advancement and digitalization. Research and development (R&D) investments, advancement of ICT infrastructure, and the growth of digital education initiatives are very important in improving productivity and competitiveness. Structural issues that the government needs to tackle are the digital divide, poor intellectual property rights, and poor venture capital funding are some of the challenges that limit adoption of technology. A greater involvement in the public-private partnerships will facilitate innovations, foreign direct investments, and the incentive to become an entrepreneur through technology.

6. Future Research Directions

Though this study contributes greatly to understanding the connection between technology and development of the economy in Pakistani country, it also creates several opportunities in the future researches. First, future research would utilize industry-specific research to investigate the effect of technology on productivity in agriculture, manufacturing, education and services individually. This would guide the policymakers in making more focused and effective strategies of technology-driven development. Second, future studies can include more technologically based indicators, including ICT diffusion, broadband penetration, artificial intelligence adoption, and innovations indices to address the larger aspects of digital transformation. This would enable a wider perspective of the role of emerging technologies in the economic performance. Third, the further studies could incorporate the regional or provincial comparisons in Pakistan to examine the differences in the technological adoption and their effect on the local economic performance. This kind of analysis can be used in planning development in a region and in distributing resources fairly.

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