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Impact of Transport Infrastructure on Economic Growth of Pakistan

Chandi Gul*	M. Phil Scholar, Department of Economics, University of Science and Technology, Bannu chandigul3@gmail.com
Assad Ullah Khan	Assistant Professor, Department of Economics, University of Science and Technology, Bannu *asadwazir82@yahoo.com*
Muhammad Haroon Khan	*Lecturer Institute of Management Sciences University of Science and Technology Bannu haroon_barakzai1@yahoo.com*
Abdul Wahab Khan	M. Phil Scholar, Department of Economics, University of Science and Technology, Bannu ab.wahab.eco@gmail.com

Abstract: *Infrastructure is the fundamental factor of economic growth and enhancing a nation's quality of life. Among various infrastructure elements, road transportation stands out as a significant driver of economic progress due to its productive influence and dynamic characteristics. This study examines the transport infrastructure of Pakistan to understand its influence on economic growth and environmental quality. To this end, the study utilizes time series data covering from 1980 to 2021. To empirical evaluate the existence of long run relationship between transport infrastructure and economic growth, the analysis employs both Auto-Regressive Distributive Lag method (ARDL) and Non-Linear Auto-Regressive Distribution method (NARDL). The results from both models indicate a positive and significant long-run and short-run relationship between infrastructure and economic progress. However, the study reveals a negative impact of carbon emissions (environmental contamination) on economic growth in both models. Based on these findings, the study suggests that expanding transportation infrastructure can lead to economic advancements but at the cost of worsening environmental quality through increasing level of CO2 emissions. Consequently, the study recommends that the government should prioritize carbon reduction projects and direct investments towards cleaner energy resources in the region.*

Keywords: Transport infrastructure, International Energy Agency, CO2 emission, NARDL, Renewable Energy, Economic Growth

1. Introduction

In today's contemporary world, where economic possibilities knotted with the movement of information, products, and people, this sector becomes even more vital. The link between transport and economic growth is one of the most substantial topics in current economics research. The majority of empirical research shows that transport sector has a beneficial influence on economic progress and that transportation shows a dynamic part in production, either straight or as a supplement to other factors of production potentials (Ahmed, Abbas, & Ahmed, 2013). According to Marazzo et al. (2010) and Bagchi (2013), transportation has an auspicious influence on economic growth and accelerates national growth.

Despite its numerous benefits, transportation infrastructure has serious environmental effects as fossil fuel usage results in carbon dioxide emissions (CO2). Globally, fuel demand increases due to technological breakthroughs, rapid industrialization, urbanization, and human mobility. According to International Energy Agency (IEA), demand for fuel increased from approximately zero in the year 1990 to 33 gaga tons in 2015. This surge in fuel demand resulted in rising consumption of fuel by 68% during the period 1990–2015 is merely attributed to the transport sector. Many empirical studies like (Lorca and Jamasb, 2017, Achour et al, (2016); Liddle, 2009; Gao et al., (2015) have investigated the long-term relation amongst transport infrastructure, energy usage and economic progression. Additionally, past studies have also focused on highlighting the adverse effects of transport emissions on environmental quality. Further, it is concluded that despite its importance, transport sector is a highly energy-consuming and CO2-emitting industry. International Energy Agency reported in the year 2012 that transport industry accounts for 22% of total carbon emissions and 27% of world energy demand. It further estimates that international transport energy use and pollutant emissions will rise by 50% until 2030.

It is believe that the countries who seek to achieve high economic growth through deteriorate environmental condition through carbon dioxide and other poisonous gases emission. The country is experiencing a considerable rise in CO2 emissions and energy use, which have a detrimental influence on the environment of the country. Unfortunately, lack of rules and regulation to limit environmental degradation, is further devastating the environmental condition in the country. This is particularly concerning as Pakistan has been listed as one of the ten nation's most responsible to temperature variation (Abubakar, 2017). Floods and other extreme weather are already taking a heavy toll on Pakistan's economy by damaging the country's current transportation infrastructure. Although Pakistan has made investments in a number of public infrastructures throughout the year, poor control and a lack of liability have hurt the growth. The problems altogether is impeding economic progress by deteriorating transport and other communication resources in the country (Mohmand et al., 2017). The objectives of the study are to evaluate the strength and nature of the relationships among the variables in focus, analyze the impact of transport infrastructure on economic progress, and investigate the influence of transport emissions on economic growth.

Next sections of this study are structured as following: section 2 explains a brief overview of Pakistan current situation of transport sector; section3 reviews empirical studies relevant to the analysis of transport infrastructure and economic growth. Section 4 presents data and methodology of the empirical model used in the analysis. Section 5 shows empirical results and discussions relevant about findings. Lastly, section 6 concludes the study and gives recommendations based on result obtained in this study.

2. An Overview Transport Sector of Pakistan

Pakistan, situated in South Asia, holds the distinction of being the world's fifth-most populous and the 35th-largest nation. The country shares its northern border with China, its eastern border with India, its western border with Afghanistan, and also shares a border with Iran. The geographical positioning of Pakistan shows its potential as a favorable center for business activities. The truth, however, is the exact reverse. Observing the economy, the country has experienced a persistent trade imbalance over the past 35 years. Pakistan's ranking in the Logistics Performance Index (LPI) has dropped from 71 in 2012 to 122 in 2018. Pakistan, being a developing nation struggles with issues like inadequate investment, bad planning, and distributed infrastructure development. According National Transport Policy of Pakistan (NTP) 2018, Pakistan, a heavily populated and speedily urbanizing country, faces an increasing demand for transportation. The transportation sector contributes 22.3% to the GDP, and around 6% share of the total employment of the country (Ministry of Finance, 2017).

The majority of inter-urban transport occurs through roads (94% of passenger kilometers and 98% of freight tonne kilometers), with 80% utilizing the National Highway Network, while rail accounts for 5% of passenger kilometers and 2% of freight tons kilometers (Pakistan Economic Survey, 2017). According to the Rural Accessibility Index (2017) only 53% of the countryside population is located within 2 km of an all-weather road. The lack of connectivity hinders economic growth and development in rural areas. The present situation can be briefed as the development of Pakistan's transport sector has been unbalanced and inefficient legislation. Further investments are needed to address the growing needs of the transport sector.

Roads Infrastructure which is the main sector of concern in this research is regarded as the most vital transportation infrastructure in Pakistan. It is responsible for the majority of domestic delivery and passenger transport. The extent of the existing road network, measured in kilometers, serves as a representation of the country's road infrastructure. Although the national highway road network accounts for only 4% of the road network, it bears the burden of 80% of marketable transportation in Pakistan (Zameer, 2021, Government of Pakistan, 2011). Pakistan's road network can be categorized into two types: high-type roads and low-type roads. In 1980, the total road network spanned 93,960 km, a figure that grew to 269,835 km by 2018

In Pakistan, the total energy depletion is divided into six categories; agriculture, industrial, commercial, transport, domestic, and other government usage. Among these sectors, the industrial sector consumed the largest share of 37%. The transport sector, (including all means), is the second highest energy using industry with share of 34% in final. Furthermore, out of the total final energy the transport sectors consume more than 70%. So highlighting energy consumption management in these sectors is essential (Zameer, 2021). Futhermore, our country is experiencing a considerable rise in fuel consumption, which has a detrimental effect on the environments in form of CO_2 emission. This is concerning because Pakistan has been listed in the ten most effected nations of changes in meteorological conditions (Abubakar, 2017).

Serious attention is needed for the transport sector, as it currently accounts for approximately 25% of Pakistan's CO_2 emissions (Pakistan Transport policy 2018, World Health Organization, 2016). The rise in energy usage within Pakistan's transportation sector has led to a rise in environmental emissions, particularly CO_2 emissions. CO_2 emissions resulting from fuel combustion of the transport industry in Pakistan which indicates that the CO_2 releases of the transportation have experienced a steady increase, with 3.76% average growth rate annually. Furthermore, transport sector contribution to the overall CO_2 emissions has also grown, from 25% in 1990 to 29% in 2018. (Zameer, 2021).

3. **Review of Literature**

3.1. Transport Infrastructure and Economic Growth link

This section will cover different research studies; try to explore the relationship between transport infrastructure and economic growth. The majority of studies demonstrate positive relationship among them. Evidently (Pradhan et al, 2013) investigated association between transport (rail and roads) and economic growth in India, (Sayan et al, 2015) assessed road travel and Nigeria's economic expansion, (Yasir et al, 2016) analyzed a link between transportation and GDP, and they all showed a positive link between transport sector infrastructure and economic growth. The influence of transport sector on the Regional expansion was demonstrated by (Prus & Sikora,2021), the study concluded that development of transport infrastructure is not solely subject to market operations, but also a vital element of policies that support the country's development. (Tanveer and Natasha Manan, 2016) conducted an investigation into the influence of transportation infrastructure on the economic progress with reference of Pakistan. Similarly, (Fatima and Ayesha, 2021) examined the influence of road infrastructure and carbon emissions on economic growth. The both studies concluded that road infrastructure exhibited a positive correlation with economic growth.

Similarly, another study (Acheampong et al, 2022) explored the influence of transport infrastructure and technological advancement on economic progress, energy usage, and CO2 emissions. Empirical result showed that transport infrastructure has a positive association with GDP and CO2 but an adverse connection with EC. The study recommended highlighting technological innovation to boost energy efficiency in EU countries

Some other studies like by (Alam et al, 2021) checked the causality between Pakistan's transport sector and GDP. Using VECM model the paper resulted that there is a long run causative relation in relation to transportation infrastructure and economic growth. Long-term economic development is positively affected by transportation infrastructure. Similarly, (Maparu and Mazumder, 2017) conducted an analysis into the part of transportation infrastructure in facilitating economic progress for the case of India. Cointegration and GC tests were employed for estimation. The outcome revealed a long run correlation between transport sector infrastructure and economic progress, with a unidirectional causal relationship observed from economic development to transport infrastructure.

Many research studies demonstrated has a nonlinear effect of transport sector like (Deng, 2013) updated a review in this paper that focuses on how transportation infrastructure affects economic growth and productivity. In that paper he reviewed linear and nonlinear effects of transport sector. In the same way, (Chao Wang et al, 2020) analyzed linear and nonlinear models to observe the control of transportation infrastructure on economic progress. The outcomes revealed that transportation infrastructure shows an essential role in facilitating economic growth.

3.2 Linkage among Energy Use, Environmental Degradation (CO2 Emission) and Economic Growth

Focus of the second strand of research study was the linkage between transport related energy use, environmental degradation (CO2 emission) and economic growth. Majority of the empirical results demonstrated a negative relationship between energy emission (CO2) and economic growth. (Danish and Baloch, 2018) explored the association among economic progress, energy usage by road transport, and ecological quality in Pakistan. The study specified that road infrastructure supported economic progress but also contributed to sulfur dioxide (SO2) emissions, negatively impacting environmental quality. Similarly, (Apergis and Pyane, 2008) investigated the association in energy use and economic growth of six nations Central America between 1980 and 2004.

To examine the causal relationship, (ECM) and panel cointegration model is used. Empirical results showed that the cointegration is present between GDP, energy use, labour participation, and gross capital formation. In contrast, (Gosh, 2010) investigated the interconnection in CO2 emission and production growth of India. It is concluded in this study that no linkage exists among economic progress and CO2 release in the long term, but a short term one-sided causality exists between them. This study suggested that if in the short run there is any reduction in carbon emissions would reduce in the growth of production. Omri (2013) studied in this paper the connection among CO2 emissions, use of energy, and economic growth is inspected. The outcome demonstrated that, for the entire region, there is onesided causality exists in economic progression and pollution releases CO2. (Alshehry and Belloumi, 2014) in this paper examined the linkage among energy use, CO2 emission and economic activity taking the case study of Saudi Arabia. The Johansen multivariate cointegration method is used. The result shows a relationship among the variables. The result added further that the share of energy use in growth is smallest. The study concludes that energy price is more important than energy consumption. This paper suggested that any policy to control CO2 emissions may not reduce considerably economic growth of Saudi Arabia.

Another study by (Zang and Da, 2014) analyzed the carbon release strength in China. The result showed that economic progress is the major reason of carbon release in the last few years.

The use of clean energy consumption proves very affective in curbing emissions. An opposite result observed by (Salahuddin and Gow, 2014) investigating the association among GDP, energy use and CO2 emission. The outcomes revealed a positive link both in the short and long term between economic progress and energy usage. However no significant connection had created amid CO2 emission and GDP. Employing linear and non-linear models the paper (Rehermann and Romero, 2018) revealed an N-shaped curve for the association between GDP and transport energy consumption and resulted those economic structural changes positively influencing transport energy consumption.

In the contrary of the above another study by (Elisa and Musa, 2020) highlighted the complexity of the relationship, with varying outcomes across countries explored the connection among economic progress and carbon releases in Africa. The study utilized the ARDL model, the EKC hypothesis in 43 African. The study recommended policy actions such as deploying green energies, carbon tax policies, and emissions exchange schemes to limit carbon emissions. Similarly, a review paper was published by (Abbas Mardani et al, in 2019) investigated the association among CO2 emissions and economic progress. The study analyzed 175 articles published between 1995 and 2017, categorizing them based on various criteria. The study resulted one-sided causality between economic progress and CO2 releases, emphasizing the need for balanced policy decisions to address emissions without hindering growth. (Sousa et al, 2015) examined the association amongst road transport CO2 emissions and GDP, focusing on the Portuguese transport sector. Employing non-linear cointegration methodologies, the study revealed a unidirectional link between economic progress and CO2 releases.

It is concluded that implying various econometric approaches on varying datasets in different geographical countries, the empirical findings are ambiguous from past literature. Some empirical study found significant and positive association between transport infrastructure and growth some studies concluded a negative relation while studies have an inconclusive result. Moreover, another debate exists among the researcher is the nonlinearity of the relationship between the study variable. These arguments point out a literature gap to analyses the relationship among these variables with linear and nonlinear approach. The study will try to fill the gap in existing literature by observing "impact of transportation infrastructure and transport emission on economic growth" with linear and nonlinear approach with reference of Pakistan.

4. Theoretical Model Development

This study uses the quantitative method and time series data for investigation. Theoretical framework of the paper is the Cobb-Douglas production function. Various empirical studies like Shahbaz et al. (2015) (Magazzino, 2014), Sharma (2010); Azlina (2012); Magazzino (2014) identified that and transport energy usage and transport infrastructure is very effective in increasing activities in the economy, which boost domestic production and as well as economic growth. Another variable of our concern is transport emission (carbon emissions) that is related with economic growth (Lastuka, 2020; Zhang, 2020, Rojas, 2020) also added in this model. Therefore, including transportation infrastructure and energy consumption and emission due to transportation the production function will adopt the following form: run. By assuming that public infrastructure as transportation infrastructure, can have an impact on technological advancement. The same is used by Yasir Tariq Mohammad et al, and Samir Sadi et al. This indicates to identify A as follows:

$$Y = AK^{\alpha} L^{\beta} Emiss^{\rho} \varepsilon^{\upsilon} \quad (4.1)$$

Where, Y denotes economic growth; K shows the total capital stock of the economy. TE is total transport energy in use, TEmiss denotes the transport CO2 emission and L is labor force. A denotes technology and ε denotes and the error term. The production elasticity of variables is indicated with (α, λ, ρ, β). In this paper road transport energy is considered as total energy consumed, following the empirical literature (Azlina et al. (2014), Liddele and Lung (2013), and Achour and Belloumi (2016), Akhtar et al. (2018)) the energy consumed will be substituted by the road transport energy consumption. Replacing TE in Eq (4.1) with RTEC we have Eq. (4.2):

$$Y = AK^{\alpha} L^{\beta} RTEC^{\lambda} Emiss^{\rho} \varepsilon^{\mu} \quad (4.2)$$

By assuming that public infrastructure as transportation infrastructure and to identify A as follows:

$$A_t = \sigma TINF_t^{\gamma} \quad (4.3)$$

Where Tinfra is transport infrastructure, σ is a constant with respect to time. Replacing Eq. (4.3) into Eq. (4.2); we have:

$$Y = \sigma TINF^{\gamma} K^{\alpha} L^{\beta} RTEC^{\lambda} Emiss^{\rho} \varepsilon^{\mu} \quad (4.4)$$

4.1. Empirical Model

The log-linear empirical model for estimation can be written as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln TINF_t + \beta_2 CS_t + \beta_3 \ln L_t + \beta_4 \ln RTEC + \beta_5 \ln TEmiss_t + \varepsilon_t \quad (4.5)$$

Where; ln= Natural Log, Y= GDP Gross Domestic Product, Tinfra = Transport infrastructure, RTEC Road transport energy consumption, RTEmiss = Road Transport emission, L= labour force, K= capital stock, ε = error term, and β= coefficients of independent variables.

4.2. Data and Justification of the Variables

This study examines the association among the variables (transport infrastructure, CO2 emission and economic progress) using the reference of Pakistan. The period used is (1980–2021) and the form of analysis is time series data.

The discretion of variables is given in the Table 1 below:

Variable	Explanation	units	sources
GDP	GDP per capita	2010US$(contant)	WDI
RTEC	Road transport energy usage	Kg of oil equal	Pakistan Economic Survey
Tinfra	Road transport infrastructure	Kilometers of roads	Pakistan Economic Survey
RTEmiss	Co2 emission by road transport	CO2 emissions from liquid fuel consumption	WDI
L	Labour force	Total labor force	WDI
CS	Capital stock	Constant 2010US$	WDI

1.3. Methodology

This section will provide an explanation of the econometric approach used for estimation. In time series data, the issue of non-stationarity is common and it is necessary to assess variable stationarity afore employing any specific model. Among various unit-root tests available, two widely recognized tests are (ADF) test and Phillips Perron (PP) test, initially suggested by Dickey and Fuller (1979) and later by Phillips and Perron (1988). The ADF test is employed to verify stationarity. Once stationarity is checked next step is to estimate the ARDL method.

The ARDL bound testing technique is appropriate for variables that are stationary at level I(0) or first difference I(1), and beneficial when working with a small sample size. For this purpose, the optimum lag is to be selected because the cointegration result can be considerably changed if lag size is not correctly selected. Various methods exist in the literature for this purpose like Johansen and Juselius (1990), Granger (1987), Phillips and (1990) etc. But these methods are extremely unpredictable when the size of sample is less. As we have a small sample size of 43 observations so the ARDL bound testing approach will be employed to find the cointegration in the study variables.

The ARDL equation can be written as:

$$\Delta lnGDP_t = \beta_0 + \sum_{i=1}^{k} \beta_{1i}\Delta lnGDP_{t-1} + \sum_{i=0}^{k} \beta_{2i}\, \Delta lnTinfra_{t-i} + \sum_{i=0}^{k} \beta_{3i}\, \Delta lnTEC_{t-i} + \sum \beta_{4i}$$

$$\Delta lnTEmiss_{t-i} + \sum_{i=0} \beta_{5i}\, \Delta lnCS_{t-i} + \sum_{i=0}^{k} \beta_{6i}\, \Delta lnL_{t-i} + \sigma_1 lnGDP_{t-1} + \sigma_2 lnTinfra_{t-i} + \sigma_3 lnTEC_{t-i} +$$

$$\sigma 4lnTEmisst\text{-}i + \sigma 5lnCSt\text{-}i + \sigma 6lnLt\text{-}i + \varepsilon t \qquad (4.7)$$

Where: Δ GDPt is the first difference of the dependent variable GDP, ΔGDPt-i is the lagged level of GDPt, ΔTinfrat-i is the first difference of the independent variable Tinftat, ΔTECt-i is the lagged first difference of TEC up to a maximum lag values, α0 shows the constant term, β1 is the coefficient of the lagged level of GDP, the coefficients of the lagged first differences of dependent variables are βs , εt is the error term.

To analyze the long run relationship F bound test will perform. The procedure of this technique will be performed step by step in the following way: Step 1: Ho: δ1 = δ2 = δ3 = δ4 = 0 (there is no co-integration exists among the variables), will be tested alongside: *H1*: δ0 ≠ δ1 ≠ δ2 ≠ δ3 ≠ δ4 ≠ 0 (H1 reject the null hypothesis). Step 2: Computing F- Statistics and comparing by the upper and lower bound values. Step 3: If F- Statistics is larger than the lower and upper values at 0.05 level, H0 will be rejected, where H0 refers that no cointegration exists and if the value of F is less than the lower limit, H0 will not be rejected. Moreover, if F-value is in between the lower and upper bound, there is no certain conclusion of cointegration can be found**.**

ECM equation represents the association

among the dependent variable and explanatory variables, capturing the short-term dynamics and the long-term equilibrium. ECM reflects the adjustment mechanism bring the variables back to long-run equilibrium. ECM equation can be written as:

$$\Delta GDP = \beta_0 + \Sigma_{i=0}^{k} \beta_{1i} \Delta GDP_{t-1} + \Sigma_{t-1}^{k} \beta_{2i} \Delta T \inf ra_{t-i} + \Sigma_{t-1}^{k} \beta_{3i} \Delta TEC_{t-i} + \Sigma_{t-1}^{k} \Delta TEmiss_{t-i} + \Sigma_{i=0}^{k} \beta_{5i} \Delta \ln CS_{t-i}$$
$$+ \Sigma_{i=0}^{k} \beta_{5i} \Delta \ln CS_{t-i} + \Sigma_{i=0}^{k} \beta_{6i} \Delta \ln L_{t-i} + \eta_1 ECT_{t-1} + \varepsilon_t \ldots\ldots\ldots\ldots\ldots (4.8)$$

In this equation ΔGDP, *ΔTinfra*$_{t-I}$*, ΔTEC*$_{t-I}$ *and ΔTEmisst-i* represents the first difference of dependent variable with time t, capturing the short-term change. ΔGDP represents the lagged first difference of the dependent variable at time t-1, accounting for the lagged effect on the current period., ECM represents the error correction term, which captures the deviation from the long-run equilibrium, β_0 represents the intercept term, β_1 to β_6 represent the coefficients of lagged first difference of the dependent variable and the first difference of the independent variable(s), respectively, taking the short-term relationship between the variables. η represent coefficient of ECM, indicating the speed of adjustment towards the long-run equilibrium, εt represents the error term or residual at time

4.4 Non-Linear ARDL Model

However, Taotao Deng (2013), in his review paper mentioned that several studies have highlighted the nonlinear nature of the connection among transport infrastructure and GDP. Researchers like Age´nor (2010), De´murger (2001) and Banister (2012) have emphasized that the there is a nonlinear association between transportation infrastructure and economic progress. Age´nor (2010) proposed that the competence of infrastructure might be due to threshold properties, particularly because of transport infrastructure stock. Banister (2012) suggested that a well-developed transport network can significantly improve economic progress. However, once a specific threshold level of the transport system is surpassed, further investments, such as construction new links or improving existing ones may have diminishing impacts on a country's development. These opinions highlight a motivating economic phenomenon: the level of transportation infrastructure accumulation reaches specific 'threshold' levels beyond which efficiency decreases. Keeping the above references, we will also check positive and negative shocks of transport infrastructure and their impact on economic progress. For this purpose we will construct a non-linear ARDL equation. The same nonlinear transport infrastructure variable was analyzed by Sohail et al (2021).

$$\Delta \ln GDP_t = \alpha_0 + \sum_{i-1}^{k} \beta_{1i} \Delta \ln GDP_{t-1} + \sum_{i-0}^{k} \beta_{2i} \Delta \ln T \inf ra^{-}{}_{t-1} + \sum_{i-0}^{k} \beta_{3i} \Delta \ln TInfra^{+}{}_{t-i} + \sum_{i-0}^{k} \beta_{4i}$$
$$\Delta \ln GDPTEmiss_{t-i} + \sum_{i-0}^{k} \beta_{5i} \Delta \ln TEC_{t-I} + \sigma_I \ln GDP_{t-I} + \sigma_2 \ln T \inf ra^{-}{}_{t-I} + \sigma_3 \ln T \inf ra^{+}{}_{t-I} +$$
$$\sigma_4 \ln TEC_{t-I} + \sigma_5 \ln TEmiss_{t-I} + \varepsilon_t \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots\ldots\ldots\ (4.9)$$

Where, $\ln TInfra^{+}_{t-i}$ is the newly constructed variable of positive shock in transport infrastructure. Similarly, $\ln TInfra^{-}_{t-i}$ is variable of negative changes. The same work has done by Sohail et al (2021). These models were developed by shin et al. in 2014 as nonlinear ARDL models. They have demonstrated that linear and nonlinear ARDL methods can be estimated using ordinary least squares (OLS) methods and these methods yield similar diagnostic test results. The ECM equation for nonlinear ARDL model can be written as:

$$\Delta GDP_t = \beta_0 + \sum_{i-0}^{k} \beta_{1i} \Delta GDP_{t-I} + \sum_{i-0}^{k} \beta_2 \Delta \ln T \inf ra^{-}{}_{t-1} + \sum_{i-0}^{k} \beta_{3i} \Delta T \inf ra^{+}_{t-I} + \sum_{i-0}^{k} \beta_{4i} \Delta TEC_{t-1} + \sum_{i-0}^{k} \beta_{5i} \Delta TEmiss_{t-i} + \eta_1 ECT_{t-i} + \varepsilon_t \text{.............................} (4.10)$$

1. Empirical results

In this section, the study presents empirical findings and discuss its consistency with the economic theory and empirical results of other relevant studies. First, the study discusses descriptive statistics and stationary properties of data series. Descriptive statistics briefly summarize the important characteristics of the data (Sundaram et al., 2014; Altman and Bland, 1995). Below Table 2 provides descriptive statistics for six different variables of the model. The result indicates that mean value of LNGDP is approximately 25.73, LNTinra is around 12.26, and LNL is about 7.63, and so on. The median is the middle value of the data when arranged in ascending order. It represents the 50th percentile. For instance, the median value of LNGDP is approximately 25.73, LNTinfra is about 12.43, LNL is around 7.63, and so on. In this table, the standard deviation values are presented for each variable. Standard deviation of LNGDP is 0.529143, for LNTinfra it is 0.420226, for LNL 0.151130, and so on. Overall, the table provides a summary of the main statistical properties of the dataset for the above mentioned variables. It is concluded that all variables follow a normal distribution. Consequently, ARDL equation will be estimated for this study.

Table 2 Description of Statistics

	LNGDP	LNTinfra	LNL	LNCO2	LNRTEC	LNCS
Mean	25.72738	12.26343	7.628812	3.300459	15.79384	13.74272
Median	25.72767	12.43247	7.626267	3.321936	15.90124	13.77881
Maximum	26.55531	13.12521	7.867939	3.391168	16.67250	14.33072
Minimum	24.71445	11.45062	7.388279	3.147085	14.72677	12.97931
Std. Dev.	0.529143	0.420226	0.151130	0.054571	0.515024	0.401973
Probability	0.341692	0.825476	0.194989	0.102234	0.448599	0.278397

To determine the stationarity of the data series, we conducted ADF test. Table.3 presents the results of the test, which reveals that all variables, GDP, road length, capital stock, energy, and labour are non-stationary at level except CO2 which is stationary at level. However, taking the first difference, all of the series become stationary at I(1). No variable is integrated of higher level. The estimated result displays that there is mix order of integration of the series which confirms that the most suitable is the ARDL estimation method. This method of estimation was utilized by (Khilji et al. (2020); Akinlo and Akinlo (2019); Zaman et al. (2019).

Table 3 Unit Root Test (ADF)

Variables	At level (Intercept and Trend)		At First Difference (Intercept and trend)		Decision
	t-statistics	p-value	t-statistics	p-value	-
LNGDP	-3.324758	0.0780*	-4.812823	0.0020**	I (1)
LNTINFRA	-1.798085	0.6874	-6.314730	0.000**	I (1)
LNCO2	-4.325075	0.0084**	-6.752138	0.000**	I (0)
LNRTEC	-2.076915	0.5428	-4.959998	0.0014**	I (1)
LNCS	-1.036521	0.9271	-4.828680	0.0019**	I (1)

Next, the study selects optimal lags length. In time series analysis, the selection criteria play a vital role in determining the appropriate number of lags to include in an auto-regressive model. Five common lag selection criteria are used: AIC, SIC, BIC, HQC, and FPE. Among these criteria, SIC and AIC are frequently employed in many studies, especially when dealing with small sample sizes (< 60). This is supported by research conducted by Liew (2004), Asghar & Abdi (2007) and Akhter et al (2023). The selection of optimal lags is determined by estimating an unrestricted vector autoregressive model (VAR). Table 4 shows the results of lag length selection for Co- integration. Based on the AIC criteria lag 4 appears as the optimal choice and is suitable for the ARDL approach. After lag selection F bound co-integration will be conducted.

Table 4 Optimal Lag Criteria

Lag	LR	FPE	AIC	SC	HQ
0	NA	1.26e-14	-14.97939	-14.72083	-14.88740
1	460.7921	3.01e-20	-27.94892	-26.13895*	-27.30495

2	80.98092	9.08e-21	-29.29342	-25.93206	-28.09747
3	50.20350	6.54e-21	-30.04097	-25.12821	-28.29305
4	51.54496*	2.20e-21*	-32.11123*	-25.64707	-29.81133*

Table 5 The ARDL Bound testing (linear Approach)

Test Statistic	Value	Significance.	I(0)	I(1)
F-value	6.089822	10%	2.49	3.38
		5%	2.81	2.81
		1%	3.5	4.63

In Table 5, the F-statistic value (6.089822) significantly exceeds the critical values of lower and upper bound at all significance levels, 10%, 5% and 1%. Based on the results, null hypothesis is rejected and provides a strong evidence that long-run co-integration exists. Similar findings were reported in previous studies conducted by (Guo and He, 2018), (Chen et al., 2021), (Akarca and Long, 2018), and (Shahbaz et al., 2017).

Long Run ARDL Estimates

Long run results are presented in Table 6. The analysis shows that the coefficient of transport infrastructure (proxied as road length) demonstrates a positive and statistically significant effect on economic progress in Pakistan. It implies that 1% rise in transportation infrastructure investment increases GDP by 8% in the long run. This proposes that road transportation infrastructure boost GDP growth in Pakistan. Consistent result has been found by Maparu & Mazumder, Mohmand et al., 2017; 2017; Pradhan et al, (2013), Sayan et al, (2015) Meersman & Nazemzadeh, 2017; and Yasir et al, (2016)

Table 6 Long Run Coefficient

Variables	Co-eff	St. Er	t-value	Prob.
LNTINFRA	0.080978*	0.044024	1.839388	0.0778
LNTEC	0.053749	0.044458	1.209005	0.2380
LNCO2	-0.192412**	0.090405	-2.128342	0.0433
LNL	0.296275	0.664378	0.445943	0.6595
LNCS	0.384308***	0.105792	3.632685	0.0013

Table 7 Estimates of Error Correction Model

Variables	Coeff	St. Er	t-Stat	Prob value
D(Ln GDP(-1))	0.343957***	0.116853	2.943511	0.0069
D(LnTTEC)	0.035901	0.029328	1.224130	0.2323
D(LnCO2)	-0.120047**	0.047025	-2.552820	0.0172
D(LnTinfra(-1))	0.072702*	0.036342	2.000482	0.0564
D(LnL(-1))	-0.946369***	0.318469	-2.971618	0.0065
D(LnCS)	0.911027***	0.112677	8.085292	0.0000
C	13.428377***	1.924929	6.976037	0.0000
ECM(-1)	-0.811314***	0.116649	-6.955202	0.0000

The coefficient of CO2 is negative and statistically significant. More specifically, the estimated result shows that a 1% rise in CO2 emissions causes a 19% decrease in GDP. Particularly, the growing economic activity leads to increased energy intake and causes increasing level of CO2 emissions which in turn contaminate environment in Pakistan. Energy consumption by transport sector (lnTEC) has a positive influence on economic progress, however, it is statistically insignificant. It means that 1% increase in energy usage brings a 5.3% rise in economic growth in the long run. Consistent result has been obtained by Shahbaz et al (2014), showing that energy consumption in transport sector expedites economic development. Labor force and capital stock exhibit positively affect economic growth however they are statistically insignificant. These results support production theory and consistent with previous empirical studies conducted by Shahbaz et al. (2015), Magazzino (2014), Sharma (2010), Azlina (2012), and Magazzino (2014). The findings highlight the significance of transport industry in influencing GDP in Pakistan.

Table 7 presents (ECM) estimates for the variables related to economic growth. ECM measures the quickness of adjustment of the variables to the long-run equilibrium relationship. ECM value is negative and highly significant. The negative and significant ECM value provides evidence that a long-run relationship exists among the variables under study. With a negative value (-0.811314), suggests that almost 81% of the shocks from the preceding year are corrected back to the equilibrium in the long run. Short run results indicate that the change in all variables from the previous time period has a positive influence on economic growth while change in CO2 has a significant adverse influence on economic progress.

Table 8 Model Diagnostic Test

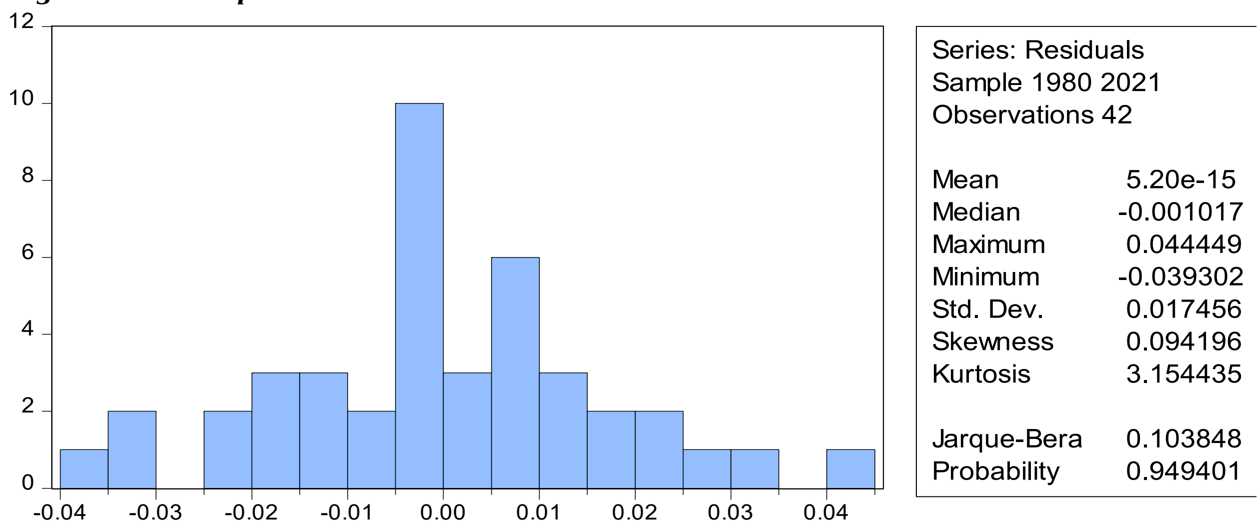
Heteroskedasticity Test			
F-stat	1.321426	P value of F(5,36)	0.2771
R-square	6.512980	P value of Chi-Square(5)	0.2595

LM Test			
F-stat	1.048685	Prob. F(2,34)	0.3615
R-squar	2.440330	Prob. Chi-Square(2)	0.2952

Breusch-Godfrey Serial Correlation LM Test is used to examine serial correlation in residuals and Breush-Pagan Godfrey Heteroscedasticity Test to check the normal distribution of errors is employed.The results in table 8 show that in both cases the null hypotheses will rejected which means there is no significant indication of heteroscedasticity, implying that the errors trems have constant variances throughout the dataset. The statistical analysis also demonstrates that the errors followa normal distribution, supporting the assumption of normally distributed errors in the model

Figure 1 shows normality test estimates by Jarque-Bera (JB) statistics. When P-value of the JB isgreater than 0.05, we accept the null hypothesis (H0), indicating that the model follows to the assumption of normality. In this specific figure, the obtained P-value is larger than 0.05 (P =0.949401), leading us to accept H0. In simpler terms, the results indicate that the model is normally distributed. Cumulative sum and cumulative sun of square tests are performed to check the model stability. ***Figure 2*** and ***figure 3*** the results indicate that parameters of the model are stable.

Figure 1 Jarque- Bera test



Model stability tests (CUSUM and CUSUM SUM OF SQUARE)

Figure 2 ***CUSUM of Squares***

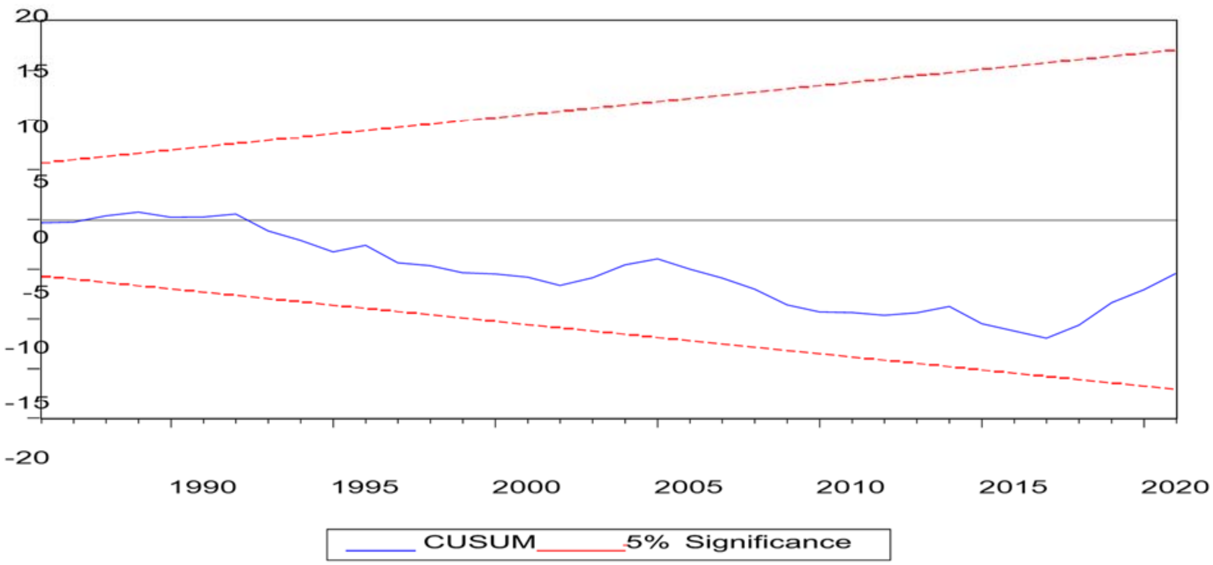
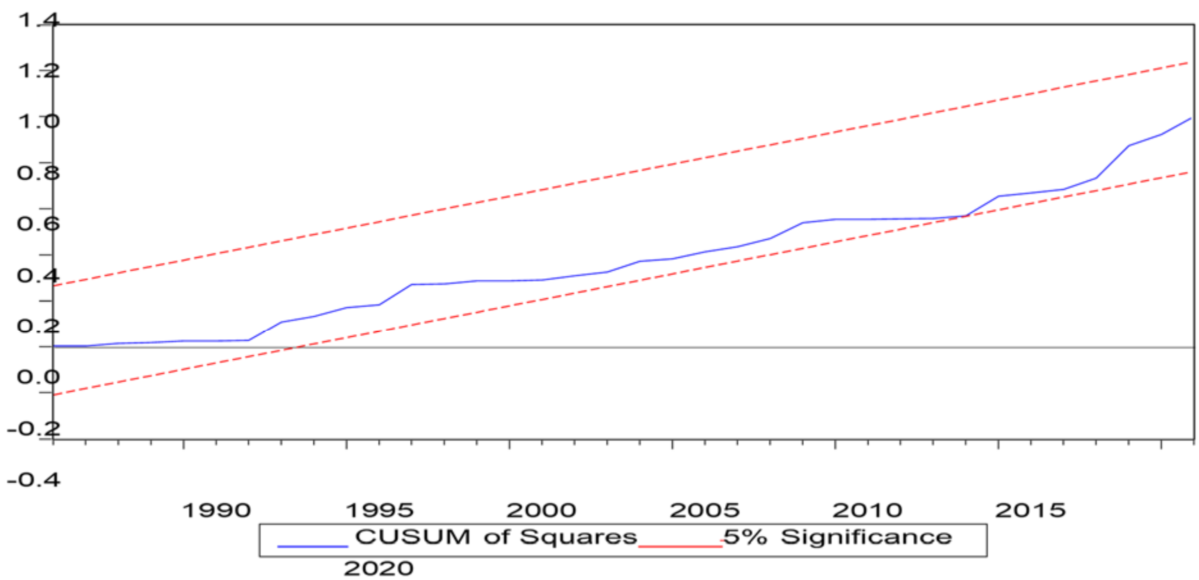


Figure 3 ***CUSUM sum OF Saquare***



Short Run and Long Run Results of Nonlinear ARDL Model

To examine nonlinear association between transport infrastructure and economic progress the study uses data on air transport. Because out of various transportation modes, the aviation sector stands out as another most significant supplier to emissions (Air Transport Action Group 2019). Emissions from air travel have the most severe environmental impact due to their distortion of the atmosphere at high altitudes and their degradation of surface-level environmental quality. Around half of these emissions are out near the Earth's surface, while the other half is released at altitudes 6000 m above (Balkanski et al. 2010); the study proxies transport infrastructure by Air Passenger Carried out. Similarly, Sohail et al, (2021) has also used Air Passenger to measure transport infrastructure. Results are shown in Table 9.

Table 9 Nonlinear F bound test

---	value	K
F-stat	4.394166	5
Signif	I0 Bound	I1 Bound
10%	2.08	3
5%	2.39	3.38
2.5%	2.7	3.73
1%	3.06	4.15

Table 9 demonstrates result of the long run F bound test. The result shows that F value is greater that lower and upper bound at all levels of significance. The result approves that long run nonlinear association occurs among the study variables. In the next step, the study examines the short run and long run association.

Nonlinear ARDL Estimates

Founded on the estimates provided in Table 10, the results of each variable as follows: In Panel A which represents long run results, AIR(POS) has a coefficient of 0.385567 which means that a positive shock in transport infrastructure bring 3.8% increase in GDP while negative shock bring 2% decrease in GDP. However both variables are not statistically significant. The coefficient of CO2 is -0.226710, indicating that transport emissions negatively influence economic progress of the country.

Panel B provides short run results of Non-linear ARDL. The result shows that Variables AIR (POS) and AIR (NEG) in the short run are statically significant. AIR (POS) has a coefficient of 0.078284, showing that a positive shock (negative shock) in air transport increases (decreases) economic growth. More specifically, a negative shock in transport infrastructure brings 7 % decrease in GDP. Similarly, all other independent variables (CO2, Energy and Capital Stock) significantly influence economic progress in the short run.

Panal C of the above table shows some diagnostic tests of the model. The result indicates that there is no indication of autocorrelation and there is no evidence of heteroskedasticity in the residuals. The results indicate that there is no proof of functional form misspecification and abnormality in the model. These statistics further confirm that our models do not experience issues such as autocorrelation, ensuring that they are appropriately specified and parametrically stable

Moreover, to illustrate the dynamic effects of transportation a dynamic multiplier graphs in Figure 8 has shown. These graphs provide asymmetric information of the nonlinear variable. To check the model stability CUSUM and CUSUM of squares graphs are shown in figure 4 and figure 5 respectively.

Table 10 Nonlinear Results

Panel A: Long Run results				
Variable	Coeff	St. Err	t-Stat	Prob
LNAIR(POS)	0.385567	0.288604	1.335975	0.2234
LNAIR(NEG)	0.028102	0.201405	0.139532	0.8930
LNCO2	-0.226710	0.122588	-1.849368	0.1069
LN ENERGY	0.208603	0.112024	1.862129	0.1049
LN CS	0.437474	0.410799	1.064935	0.3223
Panel B: Short run results				
Variables	Coeff	St. Err	t-Statistic	Prob.
Δ LNAIR(POS)	0.078284**	0.028994	2.699970	0.0306
Δ LNAIR(NEG)	0.063414***	0.014329	4.425708	0.0031
Δ LN CO2(-1))	-0.120876**	0.039107	-3.090876	0.0175
Δ LNENERGY	0.013309	0.021751	0.611870	0.5600
Δ LNCS	0.482903***	0.123101	3.922831	0.0057
ECT(-1)	-0.664797***	0.087959	-7.558053	0.0001
Panel C: Diagnostic Statistics				
LM Test:	F-stat**	0.352896	P f(2,5)	0.7188
Heteroskedasticity Test:	F-stat**	0.486122	P f(29,7)	0.9187
Ramsey RESET Test	t-statistic**	1.992305	6	0.0934
Jarque Bera test	1.480092 **		p value	0.477092

*, ** and *** denote 10% and 5% and 1% levels of significance, respectively.

Figure 4 ***Asymmetry Plot***

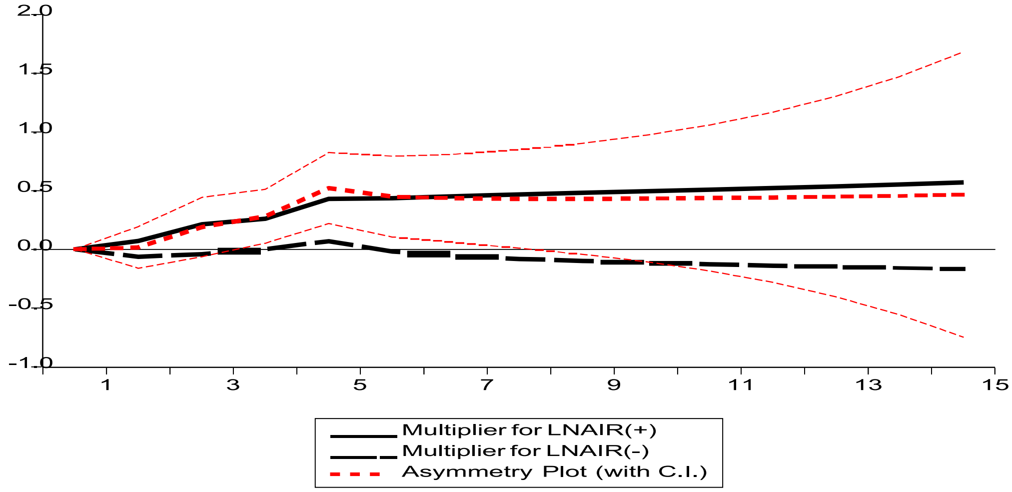


Figure 5 ***Nonlinear CUSUM***

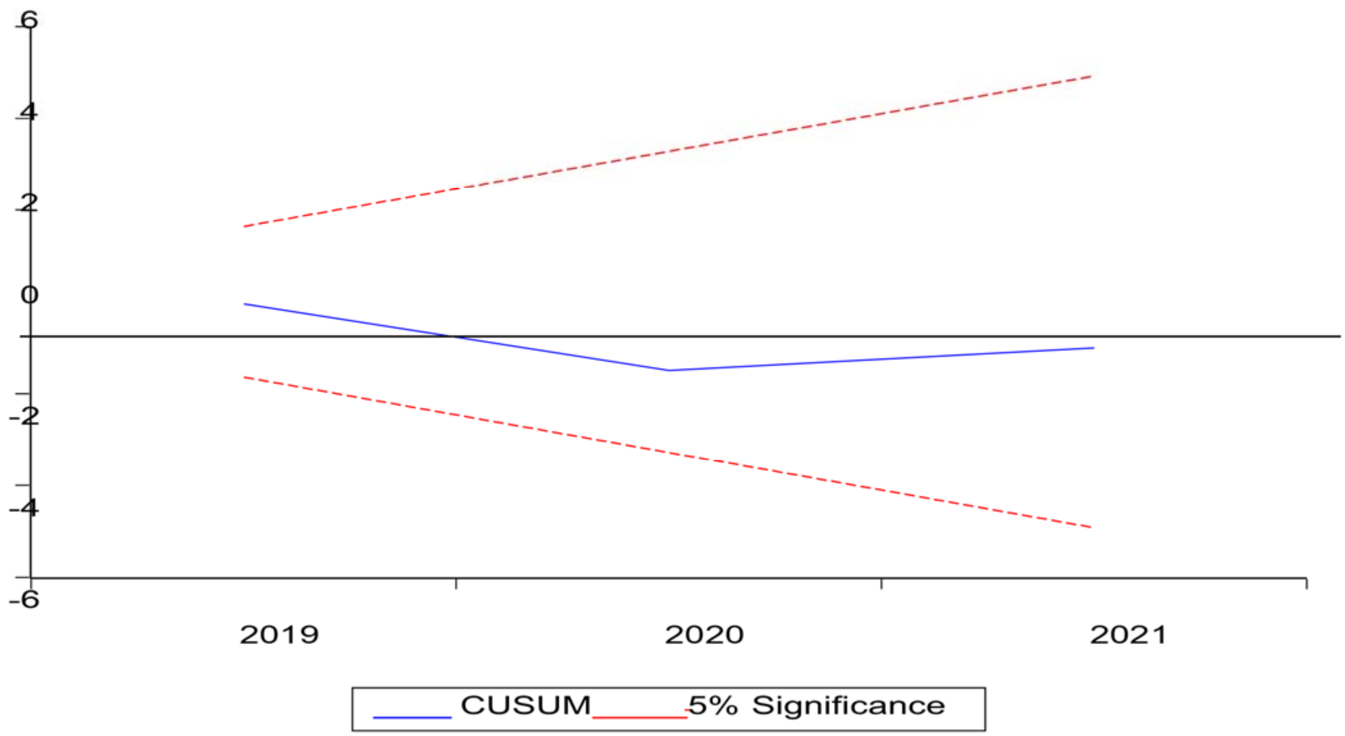
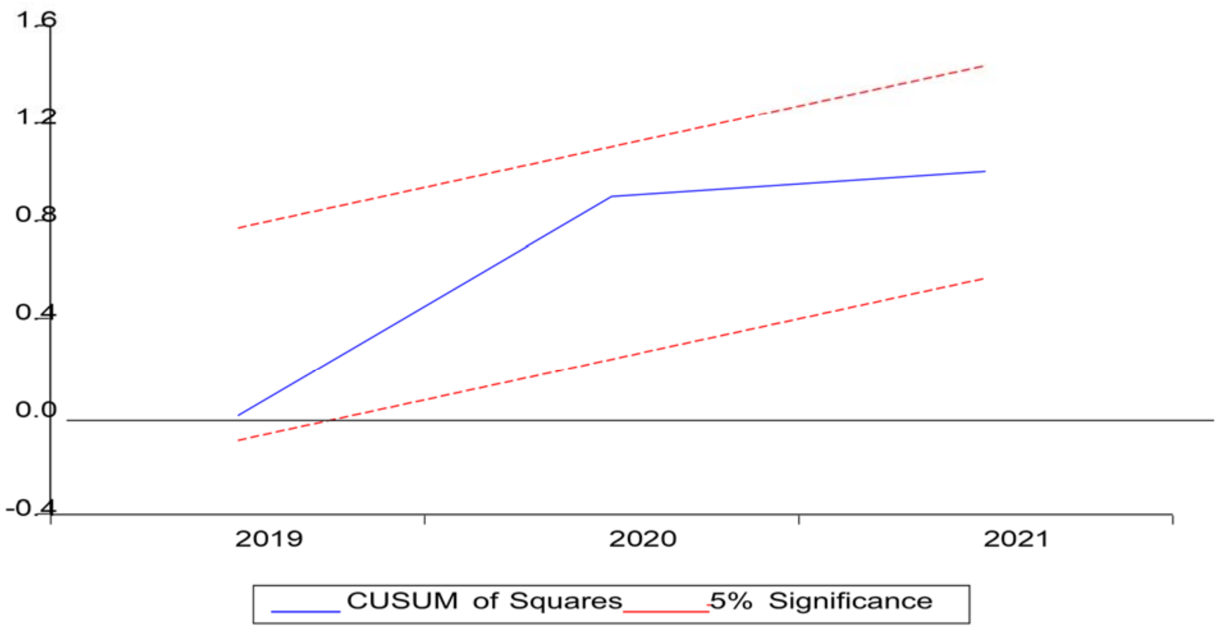


Figure 6 Nonlinear CUSUM OF SQUARE



CONCLUSION AND RECOMMENDATION

The study examined the relationship among transport infrastructure, GDP and transport emission (CO2) in Pakistan for the period 1980-2021. Two distinct models were employed to explore this relationship. Initially, the ARDL bound testing technique was utilized to establish the presence of this study examines the relationship among transport infrastructure, GDP and transport emission (CO2) in Pakistan for the period 1980-2021. Two distinct models were employed to explore this relationship. Initially, the ARDL bound testing technique was utilized to establish the presence of cointegration among transport infrastructure, CO2 emissions, and GDP. However, few studies argue that increase in transport infrastructure has non-linear influence on economic growth Sohail et al, (2022). Later, a nonlinear ARDL model applied to examine the fore mentioned association. The primary objective was to investigate asymmetric linkages between transportation, environmental impact (CO2 emissions), and economic growth using a latest NARDL approach. Symmetric effects were estimated using the linear ARDL methodology introduced by Pesaran et al. (2001), while the nonlinear ARDL methodology by Shin et al. (2014) was utilized to assess asymmetric effects.

The symmetric findings of this study indicate a positive and statistically significant impact of transport infrastructure on both long-run and short-run economic growth in Pakistan. However, CO2 emissions were found to have a negative effect on GDP due to their contribution to environmental degradation. As for asymmetric effects, positive shocks in both the long and short run were associated with positive impacts on GDP, while negative shocks in these scenarios had adverse effects on economic growth. These findings align with previous research that an increase in transport infrastructure can enhance economic growth over the long term in Pakistan. Additionally, the study reveals a negative association between GDP and carbon emissions in both symmetric and asymmetric models, emphasizing the need for sustainable environmental practices.

Based on these discernments, several policy implications emerge for Pakistan's economy. Firstly, there is a recommendation for environmentally friendly logistics practices, including the adoption of pollution-free vehicle engines in urban areas. Secondly, the adoption of efficient fuel substitution strategies is suggested. Furthermore, there is a call for government intervention to redefine the physical infrastructure of the transportation sector, promoting sustainable and environmentally friendly systems that align with long-term developmental goals.

The research's noteworthy contribution lies in its analysis of the impact of transport infrastructure on economic development in Pakistan, a connection that has been relatively unexplored in the existing literature. The findings firmly suggest a causal and long-term relationship between transport infrastructure and economic development. Specifically, road, rail, air, and port infrastructure were found to exert a positive influence on economic growth over the long term, underscoring the essential role of transport infrastructure in fostering economic development.

In conclusion, transport infrastructure emerges as a crucial promoter for economic development in Pakistan. The study recommends a comprehensive expansion and upgrading of transport infrastructure across various sectors, such as road, rail, air, and ports, to stimulate robust economic growth. The substantial positive outcomes highlighted in this research underscore the potential for even greater benefits with substantial improvements in transport infrastructure. As such, the enhancement and prioritization of transport infrastructure by the Government of Pakistan are essential steps toward fostering sustained economic growth and development.

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