economies

Article

Unraveling the Nexus between Road Transport Infrastructures and Economic Growth: Empirical Insights from Nepal's Case

Keshab Kumar Sharma [1], Netra Prakash Bhandary [2,*], Mandip Subedi [3,4] and Rojee Pradhananga [5]

[1] Ministry of Physical Infrastructure and Transport, Government of Nepal, Kathmandu 44600, Nepal; ksbsharma@gmail.com
[2] Department of Environmental Design, Faculty of Collaborative Regional Innovation, Ehime University, Matsuyama 790-8577, Ehime, Japan
[3] Geoinfra Research Institute, Kathmandu 44600, Nepal; mandip.subedi@gmail.com
[4] Universal Engineering and Science College, Lalitpur 44700, Nepal
[5] Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Lalitpur 44700, Nepal; rojee.pradhananga@pcampus.edu.np
* Correspondence: netra@ehime-u.ac.jp; Tel.: +81-89-927-8566

Abstract: Sustained efforts and investments in different sectors are essential for the overall development of a region. Various studies around the globe underscore the importance of investment in road transport infrastructure in many developing countries to achieve their development targets. The relationship between infrastructure investment and economic growth is often found to be inconsistent. This ambiguity leads to a lack of consensus on an appropriate scale of investment required among the policy makers. So, it is often necessary to depend on empirical evidence by developing causality direction, which significantly contributes to policy implications in developing countries. The objective of this analytical study is developing a relationship between the road transport infrastructure and economic growth of Nepal. For this, relevant data from 1998 to 2022 were used to perform a unit root test and determine the order of integration, followed by cointegration analysis to determine the long-run relationship between the variables. In addition, the vector error correction model (VECM) was employed to find the direction of causality. The findings indicate unidirectional long-run causality from gross capital formation, exports of goods and services, expenditure on road transport infrastructures, and road length to the GDP of Nepal. Furthermore, the expenditure on road transport infrastructures is observed to have a short-run impact on economic growth. This study recommends that a suitable transportation policy should be implemented to boost investment on road transport infrastructures to achieve sustainable economic growth in Nepal-like developing nations.

Keywords: transport infrastructures; economic growth; cointegration; causality analysis; VECM

Citation: Sharma, Keshab Kumar, Netra Prakash Bhandary, Mandip Subedi, and Rojee Pradhananga. 2024. Unraveling the Nexus between Road Transport Infrastructures and Economic Growth: Empirical Insights from Nepal's Case. *Economies* 12: 221. https://doi.org/10.3390/economies12080221

Academic Editor: Ralf Fendel

Received: 7 June 2024
Revised: 11 August 2024
Accepted: 14 August 2024
Published: 22 August 2024

1. Introduction

Economic growth and regional developments require sustained efforts and investment in different sectors. By investing in sustainable infrastructure solutions, developing countries can achieve a more balanced and sustainable development trajectory (The World Bank 2005). Road transport infrastructures, the primary mode of mobility, are the arteries of economic activities. They have a considerable influence on the sustainability and overall growth of a country, primarily by linking economic agents and markets, such as producers with consumers, workers with employers, and students with schools. In addition to improving the connectivity, road infrastructure expansion enhances trade and investment and steps up the access to goods and services, communication, and employment opportunities, as also highlighted by Tripathi and Gautam (2010).

Particularly in Nepal, the demand for new roads as well as upgrading of the existing roads has been exponentially increasing, which necessitates a huge investment in this sector. However, as a developing country with limited financial resources, Nepal is confronted with significant challenges in securing adequate funds for infrastructure projects (Estache 2010). Road transport infrastructures in many developing countries have not fully realized their socio-economic potential particularly due to insufficient investment, low traffic volume, and lack of comprehensive, coordinated, and integrated development priority programs (Starkey and Hine 2014). So, understanding the spatial distribution of investment in road transport infrastructures and assessing its economic impact are crucial in effective planning and policy implications in developing countries.

Some research works indicate that the relationship between transport infrastructures and economic growth varies significantly among countries. Banister et al. (2000) conducted a pioneering study addressing the question of whether transportation promotes economic growth or the vice versa. They conclude that transport infrastructure projects can enhance economic development, productivity, and regional competitiveness if the necessary market conditions are present and supported by appropriate policies. Banister and Berechman (2001) resolve the concern whether transport investments provide additional economic development benefits beyond the direct transport improvements, such as reduced travel time, requiring precise measurement to prevent double counting. Banister and Berechman (2017) also state that the long-term impacts of transport development are uncertain in their extent and influence. Therefore, transport development generally supports economic growth rather than directly contributing to the economy. Aschauer (1990) explores whether investment in highways drives economic growth by analyzing the link between highway capacity and per capita output growth and provides suggestions for future research. A study conducted in Iran by Bahrami (2012) revealed a unidirectional causality from transport infrastructures towards the GDP, and a study conducted by Mohmand et al. (2017) in Pakistan indicates that economic development influences transport infrastructures in the long run. Likewise, the findings of Pradhan and Bagchi (2013) show a bidirectional causality between the road transportation and economic growth in India. These inconsistent findings in the different regions can be attributed to their unique geographic features, travel patterns, and development stages. In the context of Nepal, there have been no studies so far that address the issue of how the investment in transportation sector has specifically affected economic growth. Without quantitatively understanding this relationship, policy making, targeted investments, and prioritization cannot be precise, which necessitates the relevancy of conducting such an analysis in Nepal.

Situated in between the economic giants, China and India, Nepal heavily depends on roads for the transport of freight and passengers. In the absence of railways and waterways and with limited air transportation, the roadways in Nepal serve as the main means of transportation and account for approximately 90% of all freight and passenger movements inside the nation (Asian Development Bank (ADB) (Asian Development Bank (ADB)) 2013). This situation does not seem to be changed for a few decades to come. While air travel stands out as the most efficient means of transportation within the country, it is limited by route availability and higher cost (Bhandari et al. 2012). So, the road transport in Nepal has been significantly contributing to the connectivity issue as well as the socio-economic growth of the nation. Both the government authorities and the public in Nepal have well acknowledged the pressing need for better road transport infrastructures in the country, understanding the fact that an improved road transport system could offer numerous benefits to the country and its people.

In this context and in an effort to promote trade, tourism, and market access for both industrial and agriculture products, the Government of Nepal has prioritized policy implementation for the road network expansion. Since the beginning of the 1956 development plan, Nepal has continued to accord a high priority in developing road transport infrastructures within its capacity and availability of resources as it is also crucial to develop an enabling atmosphere to achieve all development goals set by the nation (National Planning Commission (NPC) (National Planning Commission (NPC)) 2019). However, the expansion and improvement of the road network are still behind the national target as well as the target set in the Sustainable Development Goals (SDGs), which is primarily because of the financial constraints and the substantial budget demand in other sectors too. Therefore, it is important that there should be a rational policy for investment in road transport infrastructures, which could be an optimal solution for the country's overall development trajectory, fostering connectivity, economic growth, and social advancement.

To develop a viable policy for investing in road transport infrastructures and fostering regional development, it is essential to ascertain the causal relationship between economic growth and transportation (Zhang and Graham 2020). Relying solely on theory is inadequate to establish this relationship, so the use of empirical evidence specific to a region is necessary to discern the underlying causality between the parameters (Alam et al. 2021). Although the existing research findings provide insightful information about the connection between infrastructure and economic growth in various other countries, no specific study has so far been performed in Nepal to explore this relationship. So, in this paper, we examine the long-term relationship and causality between road transport infrastructures and the economic development in Nepal. Developing countries often have constrained budgets, which lead them to carefully prioritize spending on both infrastructures and social sectors. To achieve the best return from investments, it is essential to conduct a quantitative study to determine an optimal allocation of resources for the infrastructure development. So, in this study, we also explore the causal relationship between the investment in transport infrastructures and economic growth in Nepal. For this purpose, we utilize the time series data on the last 25 years and attempt to shed light on the above objectives.

2. A Review on Causal Relationship between Transport Infrastructures and Economic Growth

As also stated in the introduction section, the development of transport infrastructures is a crucial means of fostering the economic growth of a nation. Nonetheless, discussions revolve around the link between transportation and economic development, questioning whether one enhances the other, if it is the other way around, or if they mutually reinforce each other (Maparu and Mazumder 2017; Beyzatlar et al. 2014). Numerous studies have been conducted to determine the relationship between transportation and economic growth (Alam et al. 2021). An investigation by Njoku et al. (2015) shows that the economic development of Nigeria is positively influenced by the investment in transport sector. Herranz-Loncán (2007) examined the investment in railroads, urban transport, ports, telephone systems, roads, hydraulic works, and energy distribution, and demonstrated that these investments had a considerable influence on the economic growth of Spain from 1850 to 1935. Likewise, a study conducted by Pradhan and Bagchi (2013) on road and railway infrastructures in India suggests that advancement in these transportation systems would lead to substantial boost in the Indian economy.

Maparu and Mazumder (2017) also studied various sector transport infrastructures in India and revealed that there is a long-term association of transport infrastructures with the country's economic development. They mostly observed that the causality ran from development of economy to transport infrastructures. Pradhan et al. (2013) also discovered a long-run relationship between the transport infrastructures, foreign direct investment, and economic growth, indicating the existence of bidirectional causality between them, which highlights the importance of transportation development in stimulating economic growth and attracting the foreign direct investment. Moreover, a study conducted by Zhu et al. (2022) investigates the relationship of economic growth with road transport in 31 provinces and municipalities in China from 1980 to 2015, and reveals that the direction of causality differed from one region to other. Beyzatlar et al. (2014) investigated the relationship between income and transportation in 15 European countries, where they found that the economy and transportation influenced each other in most of the countries, but one-way or other, no causality was observed in the low-income countries.

Mohmand et al. (2017) use GDP and road length as proxy variables to represent economic growth and transport infrastructures, respectively and conclude that relying solely on infrastructure investment is inadequate to stimulate economic activities in underdeveloped regions of Pakistan. They also state that the development of transport infrastructures not only influences the economy of its immediate region but also has potential to affect other regions. Arbués et al. (2015) found in their analysis of 47 peninsular Spanish provinces that the road transportation has a positive influence on economic activity not only within the regions where the infrastructures are located but also in the neighboring provinces. However, they do not seem to have observed any significant impacts of other modes of transportation. In Table 1, we summarize and list out the literature we reviewed in relation with causal relationship between transport infrastructures and economic growth.

Table 1. A review of the literature from various countries in relation to the influence of transport infrastructure on economic growth.

Source	Country	Period	Methodological Framework	Main Findings
Fedderke et al. (2006)	South Africa	1875–2001	The unit root test using ADF. The cointegration test using the Johansen system. The VECM framework.	Investing in infrastructure leads to economic growth (both directly and indirectly). But economic growth has limited impact on infrastructure.
Herranz-Loncán (2007)	Spain	1850–1935	The unit root test using ADF and PP. Cointegration using the Engle–Granger and Johansen cointegration tests. The VECM.	Unlike large-scale nationwide networks, growth is positively impacted by investments in local-scale infrastructure.
Marazzo et al. (2010)	Brazil	1966–2006	The unit root test using ADF. The cointegration test using the Johansen. pair-wise Granger causality test.	Causality from GDP to Air transport demand in long run.
Bahrami (2012)	Iran	1963–2009	The unit root test performed using Dickey–Fuller. Causality using the Tuda and Yamamoto methods.	One-sided relationship from transportation section towards GDP
Sahoo et al. (2012)	China	1975–2007	The unit root test using ADF. Cointegration using ARDL and GMM. Ganger causality in the VECM and VAR framework.	Long-run unidirectional causality from infrastructure development to output growth.
Sahoo and Dash (2012)	Four South Asian Country	1980–2005	Panel unit roots, panel cointegrations and panel granger causality.	Infrastructure development in in South Asia has major positive impact on growth.
Kuştepeli et al. (2012)	Türkiye	1970–2005	The unit root test using ADF, PP, KPSS. The cointegration test using the bound test and the Johansen test. Granger causality.	Very weak short-run effect of the share of export in GNP on highway transportation expenditures.
Yu et al. (2012)	China provinces	1978–2008	The panel unit root test, the panel cointegration test, Granger causality in the ECM framework.	At the regional level, the causal link varies among sub-national areas, but unidirectional relationship between economic development and transport infrastructure at the national level.
Tong et al. (2014)	United States	1950–2006	The unit root test using ADF and PP. Granger causality using the LA-VAR procedure.	Bidirectional causality exits between economic output and transport infrastructure.

Table 1. *Cont.*

Source	Country	Period	Methodological Framework	Main Findings
Njoku et al. (2015)	Nigeria	1983–2012	The unit root test using ADF. Cointegration using the Johansen test. Granger causality.	Bidirectional causality between expenditure on transport and communication on GDP.
Achour and Belloumi (2016)	Tunisia	1971–2012	The unit root test using the ADF and PP tests. The cointegration test using the Johansen test. Ganger causality in the VECM framework.	Unidirectional causality exits between the various parameters used.
Maparu and Mazumder (2017)	India	1990–2011	The unit root test using ADF and DF-GLS. The cointegration test using the Engle–Granger and Johansen system. Granger Causality in both the VECM and the VAR framework.	Causality from economic development to transportation infrastructure except for airways-passenger where relationship reverse.
Subedi (2017)	Nepal	2014	Multiple regression and correlation.	The GDP per capita is influenced by the road density of bituminous and gravelled roads, as opposed to earthen roads.
Muvawala et al. (2021)	Uganda	1985–2015	The unit root rest using the augmented Dickey–Fuller test. The bound test for cointegration and the ARDL model.	Economic growth is influenced by road transport in both the short and long term.
Pandit (2023)	Nepal	1974–2019	The cointegration test.	Unidirectional causal relationship between change in gross domestic product transportation, capital expenditure and transportation recurrent expenditure.

3. Materials and Methods

To address the primary research question, the influence of road transport infrastructures on economic growth, it is crucial, firstly, to identify the variables and determine their stationarity, which, in turn, determines their order of integration. For the unit root tests, the augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) tests were employed. Once the order of integration was established, the long-term relationship between these variables was explored through a cointegration analysis. Cointegration suggests that the variables move simultaneously over the time, allowing short-term disruptions to be gradually resolved in the long run. In contrast, if cointegration is absent, it implies that the variables lack a lasting relationship over the time. To assess this, the Johansen (1988) cointegration test was applied. Moreover, the vector error correction model (VECM) was employed to find the direction of both short- and long-term causalities among the variables while the Jarque–Bera test, the serial correlation LM test, and the heteroscedasticity test were employed to verify the presence of normality, autocorrelation, and heteroscedasticity, respectively and in order to achieve a robust model analysis. Furthermore, the cumulative sum (CUSUM) and CUSUM of square tests were used to assess the stability of the model. Figure 1 shows the methodological framework, and the following subsections describe the methodological steps adopted in this study.

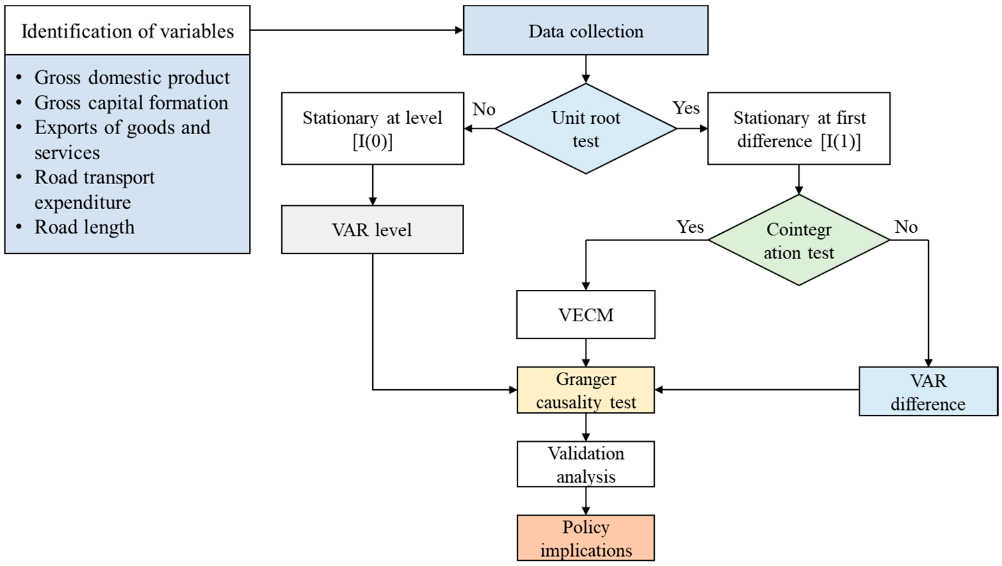

Figure 1. The methodological framework of this study to assess the relation between road transport and economic growth.

3.1. Variables and Data Collection

We used 25-year annual time series data of Nepal from 1998 to 2022 including the five key parameters of gross domestic product (GDP), gross capital formation (GCF), exports of goods and services (EGS), road transport expenditure (RTE), and road length (RL). Employing RTE and RL as the road infrastructure indicators, we have attempted to investigate the relationship between road transport infrastructures and the economic development. These two parameters were used because they include both monetary and physical indicators and provide a realistic picture of transport infrastructure endowment.

The road transport network of Nepal has been divided into two categories: the strategic road network (SRN) and the local road network (LRN). The SRN includes the designated national highways and major strategic road links under the authority of the federal government led by the Ministry of Physical Infrastructure and Transport (MoPIT). The LRN consists of all other roads (i.e., provincial, district, urban, and village roads) excluding those in the SRN, and are under the responsibility of the provincial and local governments. In this study, we have only considered the SRN in the road length data because it is the primary network for passenger and freight transportation with high traffic density and is the major contributor to the nation's economy.

Road length is taken as a proxy for road transport infrastructures to better capture investment trends in the transportation sector and prevent underestimation of transport infrastructures. The expenditure on road transport indicates the amount invested in the road infrastructures, so we have used it to assess its direct influence on the nation's development. It is crucial to emphasize that in this study, we examine used macroeconomic aggregates to find the relationship between road transport infrastructures and economic growth. Likewise, GDP is a dependent variable and is used to measure the economic development. Since many factors affect economic growth, it is essential to include a set of controlled variables to prevent leaving out the key factors. Controlled variables used are exports of goods and services (EGS) and gross capital formation (GCF). These data were collected from various sources: GDP, GCF, and EGS were obtained from the World Development Indicator (WDI) availed by the World Bank (https://data.worldbank.org/ (accessed on 12 October 2023)) while RTE and RL were primarily obtained from the Department of Roads, MoPIT annual report, i.e., Statistics of Strategic Road Network, SSRN 2023/24. The collected data were meticulously screened to ensure that there were no biases or missing values. Inflation adjustments were made using the national Consumer Price Index (CPI) published by Nepal Rastra Bank in 2023, and the data were expressed in constant 2015 prices, except for RL, which was measured in kilometers. In order to lower the data volatility and transform it into elastic analysis, all variables were taken into logarithmic form. Table 2 consists of descriptive statistics of the parameters (i.e., mean, std. dev., and source) employed in this study.

Table 2. Summarized statistics (mean, std. dev., and source) of the variables used in this study.

Variables	Observations	Mean	Std. Dev.	Data Source
lnGDP	25	28.229	0.403	World Bank
lnGCF	25	26.990	0.583	World Bank
lnEGS	25	26.062	0.123	World Bank
lnRTE	25	16.730	0.855	MOPIT
lnRL	25	9.992	0.031	MOPIT

Likewise, Table 3 presents the correlation matrix among the variables, developed to identify relationships among them. A positive correlation indicates that the factors move together while a negative correlation indicates that they move apart. The matrix shows that GCF, RTE, and RL have a strong positive correlation with the GDP of Nepal while EGS has negative correlation with it.

Table 3. Correlation matrix of the variables used in this study.

	lnGDP	lnGCF	lnEGS	lnRTE	lnRL
lnGDP	1.000000	0.980386	−0.111868	0.992275	0.877841
lnGCF	0.980386	1.000000	−0.116185	0.961926	0.881904
lnEGS	−0.111868	−0.116185	1.000000	−0.086514	−0.003715
lnRTE	0.877841	0.881904	−0.003715	1.000000	0.869396
lnRL	0.992275	0.961926	−0.086514	0.869396	1.000000

The trends of the above variables from the 1998 to 2022 are demonstrated in Figure 2. As seen in this figure, the trends of GDP, GCF, RTE, and RL are increase significantly from 1998 to 2022 with a few ups and downs with GCF and RTE while the trend of EGS is slightly decreasing with aggressive ups and downs. The trends of lnGDP, lnGCF, and lnRL show an upward trajectory from 1998 to 2022, indicating growth during this period. The InRTE demonstrates a decline around 2006 and 2015, but the overall trend shows an upward movement over the years. However, lnEGS shows fluctuations throughout the time period.

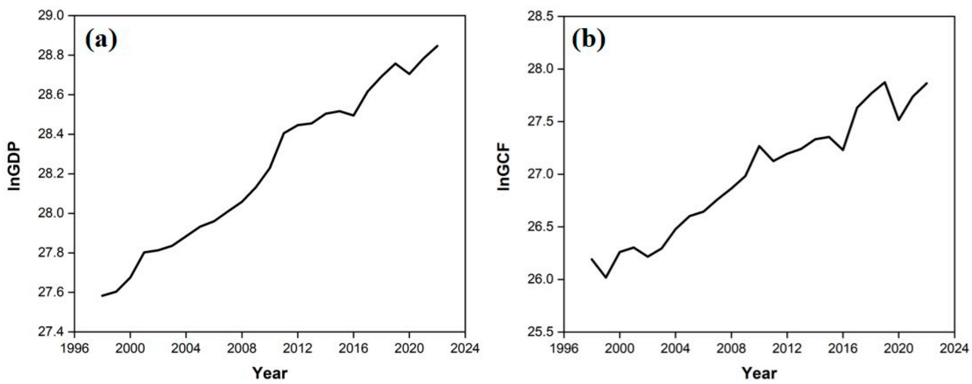

Figure 2. *Cont.*

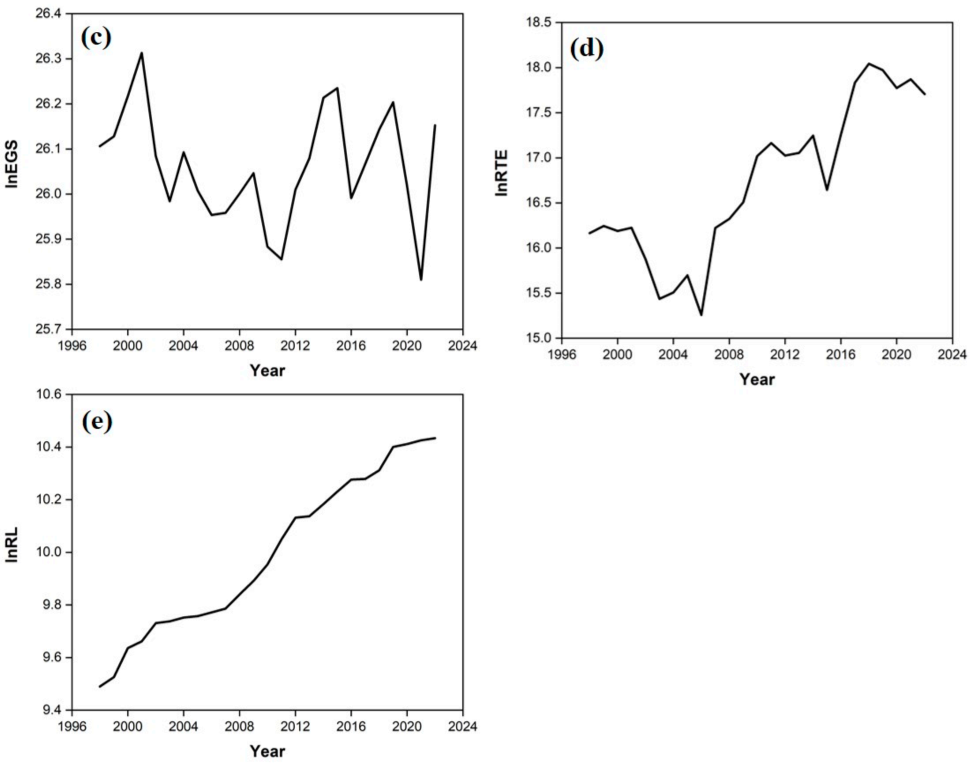

Figure 2. Trend analysis of (**a**) lnGDP, (**b**) lnGCF, (**c**) lnEGS, (**d**) lnRTE, and (**e**) lnRL from 1998 to 2022 in Nepal.

3.2. The Unit Root Test

Conducting the unit root tests prior to analyzing the long-run relationship (i.e., cointegration) is crucial to avoid non-stationary data because such data can lead to spurious results with no meaningful interpretations trends (Pradhan and Bagchi 2013; Dritsaki and Dritsaki-Bargiota 2005; Elliott et al. 1992). The unit root tests are generally employed in macroeconomic time series data to determine the appropriate order of integration (Maparu and Mazumder 2017). The order of integration is denoted as I (0) when a variable is identified as stationary at the level.

The augmented Dickey–Fuller (ADF) test is a widely used unit test method for evaluating the order of integration of variables (Dickey and Fuller 1979, 1981). It examines the following equation (Equation (1)).

$$\Delta y_t = x_t b + \delta y_{t-1} + \sum_{i=1}^{m} a_i \Delta y_{t-i} + \varepsilon_t \quad (1)$$

where y is a time series variable, y_t are the time series values of y that correspond to period t, and x_t are optional exogenous regressors that include constant and trend. ε_t are terms of error that are described as white noise. Δ, a, and b are the parameters to be assessed. The difference operator is represented by Δ, and the utmost latency length is denoted by m.

We contrast the null hypothesis, H0: $\delta = 0$, with the alternative hypothesis, Ha: $\delta < 0$. If the null hypothesis is rejected, the series is stationary, which implies that there is no unit root. Conversely, the presence of a unit root is implied by the null hypothesis, rendering the series non-stationary.

The Phillips–Perron (PP) unit root test is another method to determine the order of integration, which shares a similar null hypothesis to the ADF test. However, the PP test incorporates a non-parametric adjustment to the ADF test, enabling it to account for potential dependence and heterogeneity in the residuals. The statistical expression of the PP test is comparatively more intricate (Zuo 2019).

We have adopted the ADF and PP tests in this study for their resilience in identifying the existence of a unit root, which signifies the non-stationarity of a time series. By including lagged difference of the series into the regression, the ADF test incorporates higher order correlation. This approach helps to compensate for autocorrelation and yields more precise outcomes. The PP test is a valuable addition to the ADF test as it addresses issues of autocorrelation and heteroscedasticity without the need for lag extensions in the model. This makes it a reliable method to verify the findings of the ADF test. These tests are crucial for verifying the assumptions necessary for later cointegration analysis, guaranteeing that all series have the same level of integration.

3.3. Lag Length Selection

For the efficiency of the method, determining the optimal lag length is necessary before performing both the cointegration test and the VECM. It is possible to omit pertinent variable by choosing fewer lags, potentially resulting in grave consequences. To determine ideal lag length, a statistical test was conducted.

3.4. The Johansen Cointegration Test

The concept of cointegration was initially presented by Granger (1988) with the objective of identifying the long-term relationship between parameters. This concept was further explored and expanded upon by (Johansen 1988; Engle and Granger 1987; Engle and Yoo 1987; Johansen 1991, 1995; Phillips 1986, 1987; Phillips and Ouliaris 1990; Stock and Watson 1988). The underlying idea behind cointegration is that although the variables may have correct short-term disruption, they have a long-term relationship among them (Alam et al. 2021). The absence of cointegration means there is no long-term equilibrium link between these variables and that they might diverge arbitrarily from one another.

The Johansen (1988) test for multivariant cointegration is utilized to determine the number of cointegration vectors in equations. The test yields two likelihood statistics: the trace statistics and maximum eigenvalue as depicted in Equations (2) and (3) (Enders and Chumrusphonlert 2004).

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} Log\ (1 - \lambda_i) \tag{2}$$

$$\lambda_{max} = -T\ Log(1 - \lambda_{r+1}) \tag{3}$$

where T is the number of observations and $\lambda_{r+1}, \ldots\ldots \lambda_n$ represents $(n-)$ the smallest estimated eigenvalues. The test compares the alternative hypothesis of $r+1$ cointegrating vectors with the null hypothesis of r cointegrating vectors.

We adopted this test because it is well suited for models with numerous equations and has capability to identify various cointegrating relationships among the variables, a common occurrence in macroeconomic studies. The advantage of this test over single-equation methods, such the Engle–Granger approach, is that it allows for a system-wide analysis and can identify many cointegration vectors. This offers a full understanding of the long-term interactions between the variables. The test employs both the trace statistic and the maximum eigenvalue statistic, which offer a reliable assessment of the number of cointegrating links.

3.5. The Vector Error Correction Model (VECM)

The VECM is used to determine the long-run and short-run causality between the dependent and independent variables (Imbens and Wooldridge 2009; Wooldridge 2002). It evaluates the co-integration in an entire system of equations in a single step by eliminating the need to normalize a specific variable in order. This eliminates the need for transferring the errors from the first step into next, as in the method of Engle and Granger. Additionally, the VECM has a benefit of not requiring endogeneity and exogeneity assumptions in advance.

We have chosen the VECM because of its capacity to handle cointegrated variables and concurrently capture both short-term dynamics and long-term relationships. The VECM includes an error correction term, which helps to measure how quickly variables return to their equilibrium state following a shock. By doing so, the VECM provides valuable insights into the dynamics of adjustment and the causal relationship between variables. This model is essential for our investigation as it uncovers equilibrium linkages and the temporal interactions among major economic variables.

3.6. The Granger Causality Test

This test (Granger 1969) is employed in investigating the causal relationship direction between transport and economic development. Engle and Granger (1987) suggest that the existence of a cointegration connection between two series variables necessitates either unidirectional or bidirectional causality between them. In the Granger causality test (Granger 1969), variable x is considered to have Granger causality with variable y if the lagged value of x can enhance the predictability of y, provided that all other relevant information is present. It is crucial to recognize that Granger causality evaluates predictability and precedence rather than illustrating a conventional cause-and-effect relationship (Kirchgässner et al. 2013).

To the accompanying hypothesis, this test is conducted for the following two variables:

H_0: Y_t does not cause X_t;

H_t: Y_t does cause X_t.

The Granger causality test employs Equations (4) and (5) to determine whether the hypothesis is valid:

$$X_t = \alpha_1 + \sum_{i=1}^{p} \beta i Y_{t-i} + \sum_{j=1}^{q} \gamma_i X_{t-j} + \mu_{1t} \tag{4}$$

$$Y_t = \alpha_2 + \sum_{i=1}^{p} \delta i X_{t-i} + \sum_{j=1}^{q} \theta_i Y_{t-j} + \mu_{2t} \tag{5}$$

where α_1 and α_2 are constants, μ_{1t} and μ_{2t} are the error terms of white noise, t represents the period, and p and q represent the delays number for X and Y, respectively.

3.7. The Diagnostic Test

Diagnostic tests are essential for assessing the adequacy and reliability of VECMs. These tests help researchers evaluate whether the model adequately captures the underlying dynamics and relationship among the variables. The diagnostic test for VECMs includes various tests, such as normality test, serial correlation test, and heteroscedasticity test to examine the presence of normality of residuals, autocorrelation, and heteroscedasticity, respectively. Furthermore, CUSUM and CUSUM of square tests are used to detect the structural changes in the parameters of the model, ensuring its stability over the time. From these aforementioned tests, the reliability of the results can be verified, and informed decisions can be made based on the findings.

Normality tests evaluate whether the residual of the model follow a normal distribution. We used the Jarque–Bera normality test in this study to examine the normality of the dataset. The hypothesis for this test was:

Null Hypothesis (H0): Data are normally distributed.

Alternative Hypothesis (H1): Data are not normally distributed.

To analyze the relationship between the same variables across different points in time, the serial correlation test is used on the lagged residuals. We used the Breusch–Godfrey serial correlation LM test to evaluate the serial correlation, with the following hypothesis.

Null Hypothesis (H0): no serial correlation.

Alternative Hypothesis (H1): serial correlation.

In addition, to evaluate the residuals' variance in the model, heteroscedasticity test is used. It is imperative to identify heteroscedasticity in order to obtain dependable results, so we used the Breusch–Godfrey test to assess the heteroscedasticity. The following hypothesis was made in the test.

Null Hypothesis (H0): no heteroscedasticity.

Alternative Hypothesis (H1): heteroscedasticity.

Furthermore, to assess the long-run relationships among the variables over the time and to ensure that these relationships remain constant, stability tests are used. Two common methods for assessing the stability are CUSUM and CUSUM of square tests. We used these tests to monitor the stability of the model and identify any shifts with the time series. The plotted lines in these tests should remain within the boundaries of 5% significance so as to confirm the model stability.

4. Results

4.1. The Unit Root Test

The unit root test results are presented in Table 4. The test results demonstrate that the variables are non-stationary at levels but are stationarity at the first order difference. It indicates that the time series data are not stationary in their original form due to trends or seasonality. Taking the first order difference removes the trends or other non-stationary element from the data, making it stationary. The variables are integrated of the first order, denoted as I (1).

Table 4. Unit root test results at the level and first order difference, as determined by the ADF and PP tests.

Variables	ADF		PP		Remarks
	Intercept	Intercept Trend	Intercept	Intercept Trend	
At level					
lnGDP	−0.5014	−2.2939	−0.4952	−2.4383	Non-stationary
lnRTE	−0.7832	−2.3732	−0.7832	−2.3732	Non-stationary
lnRL	−0.9145	−1.9857	−0.8967	−1.9299	Non-stationary
lnNGCF	−0.4696	−3.9526 **	0.1062	−3.9843 **	Non-stationary
lnEGNS	−3.1104 **	−3.0247	0.0522 *	0.1839	Non-stationary
At 1st difference					
lnGDP	−4.5335 ***	−4.4678 ***	−4.5506 ***	−4.4799 ***	Stationary-I (1)
lnRTE	−4.9986 ***	−4.9306 ***	−4.9986 ***	−4.9309 ***	Stationary-I (1)
lnRL	−4.0014 ***	−3.9969 ***	−4.0028 ***	−4.0087 **	Stationary-I (1)
lnGCF	−4.8203 ***	−4.6959 ***	−13.8088 ***	−17.4013 ***	Stationary-I (1)
lnEGNS	−5.7784 ***	−5.6213 ***	−6.1920 ***	−6.3528 ***	Stationary-I (1)

***: statistically significance at the 1% level; **: statistically significance at the 5% level; *: statistically significance at the 10% level.

To examine the presence of structural break, regression analysis was performed using all the data and the Chow test was conducted. Table 5 presents the results of this test. The value of the P was 0.2069, which is statistically insignificant even at the 5 percent level. Therefore, the null hypothesis of no structural break cannot be rejected, implying that the series does not contain a structural break.

Table 5. Structural break analysis using the Chow test.

Parameter	Value	Probability Parameter	Value
F-statistic	1.651501	Prob. F(5,15)	0.2069
Log likelihood ratio	10.96444	Prob. Chi-Square(5)	0.0521
Wald Statistic	8.257507	Prob. Chi-Square(5)	0.1426

4.2. Lag Length Selection

The likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz criterion (SC), and Hannan–Quinn (HQ) statistics in Table 6 were used to determine the optimal lag length of the model. The choice of an appropriate lag length is a very crucial determinant that significantly affects the predictive accuracy and efficiency of the model. In this study, minimum values of AIC, SC, and HQ always suggested that a lag length of 1 is optimal. This means that the presence of one lag in the model is the most optimal in balancing between capturing essential temporal dependencies and parsimony. Therefore, a lag length of 1 was considered most appropriate to ensure robust and reliable forecasts without over fitting the model.

Table 6. Results of LR, FPE, AIC, SC, and HQ tests for selection of lag length.

Lag	LogL	FPE	SC	HQ	LR	AIC
0	61.59074	6.16×10^{-9}	−4.470467	−4.650783	NA	−4.715895
1	152.5600	2.66×10^{-11} *	−8.740763 *	−9.822657 *	136.4538 *	−10.21333 *

* best optimal lag length based on the respective statistical criteria, NA—not applicable

4.3. The Johansen Cointegration Test

The subsequent step is to ascertain the quantity of cointegrating equations after verifying that all variables are stationary at the initial difference level I (1). The maximal eigenvalue and trace statistics of the Johansen cointegration test are presented in Table 7. The presence of a single cointegrating equation is indicated by the rejection of only one hypothesis within eigenvalue and trace statistics at a 5% significance level. It suggests that there is a long-term relationship among the time series variables.

Table 7. Results of the Johansen cointegration test (trace, maximum eigenvalue) for different hypotheses.

Unrestricted Cointegration Rank Test (Trace)				
Hypothesis	**Eigenvalue**	**Trace Statistic**	**5% Critical Value**	**Prob. ****
None *	0.826231	87.52152	69.81889	0.0010
At most 1	0.679280	47.27090	47.85613	0.0567
At most 2	0.400209	21.11558	29.79707	0.3505
At most 3	0.303842	9.358586	15.49471	0.3333
At most 4	0.043731	1.028462	3.841466	0.3105
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesis	**Eigenvalue**	**Max-Eigen Statistic**	**5% Critical Value**	**Prob. ****
None *	0.826231	40.25062	33.87687	0.0076
At most 1	0.679280	26.15532	27.58434	0.0753
At most 2	0.400209	11.75700	21.13162	0.5718
At most 3	0.303842	8.330124	14.26460	0.3461
At most 4	0.043731	1.028462	3.841466	0.3105

(*) shows null hypothesis is rejected at the 5% significance level, signifying the presence of a cointegrating relationship. (**) shows *p*-values that are critical for determining statistical significance.

The result seems coherent with the findings of Achour and Belloumi (2016) and Alam et al. (2021), who also use one cointegrating equation between the variables while the study conducted by Kuştepeli et al. (2012) in Türkiye showed no long-run relationship between the variables.

4.4. The Vector Error Correction Model (VECM)

To assess the direction of long-term and short-term relationships among the variables, as also evidenced by the cointegration test findings, the VECM results are presented in Table 8. When GDP is the dependent variable, the error correction model (ECT) is significant and negative at 5%. This finding implies that there is a long-term causal relationship between the variables and GDP. In contrast, the error correction terms for other variables are not negative and significant. This illustrates the existence of long-term, unidirectional causality without feedback from other variables to GDP. The short-run causality from RTE to GDP and GCF is demonstrated by the Wald test. Furthermore, short-run unidirectional relationship exists from GCF to RL.

Table 8. VECM model results showing GDP, GCF, EGS, RL, RTE and ECT.

Variables	GDP	GCF	EGS	RTE	RL	ECT
GDP	-	1.081044 (0.2985)	1.231608 (0.2671)	3.99759 (0.0456)	0.589929 (0.4424)	−0.991461 (0.0134)
GCF	0.005822 (0.9392)	-	2.519279 (0.1125)	4.63718 (0.0313)	1.642027 (0.2)	−0.027322 (0.8497)
EGS	1.646139 (0.1995)	0.389741 (0.5324)	-	1.775274 (0.1827	0.003667 (0.9517)	−1.098447 (0.0083)
RTE	0.702402 (0.4020)	0.362249 (0.5473)	0.133378 (0.7150)	-	0.029733 (0.8631)	−0.730462 (0.5682)
RL	1.895392 (0.1686)	4.611436 (0.0318)	2.672019 (0.1021)	1.043288 (0.3071)	-	0.254867 (0.0007)

4.5. The Granger Causality Test

The pair-wise Granger causality test results are presented in Table 9. These data indicate that road transport expenditure (RTE) is a driving force behind the economic development in Nepal, as evidenced by a unidirectional causality between GDP and RTE at a 5% significance level. The results also indicate unidirectional causal relationships of EGS with GDP, RTE with both GCF and RL, and GDP with RL. The pair-wise Granger causality test indicates that the investment in road transport improves infrastructure, enhances connectivity, facilitates trade, and stimulates the economic growth of the country. These results well align with the VECM findings, demonstrating the robustness of this study.

Table 9. Pair-wise Ganger causality test results.

Null Hypothesis	Obs	F-Statistic	Prob.
lnGCF no Granger Cause lnGDP lnGDP no Granger Cause lnNGCF	24	1.86014 3.96032	0.1870 0.0598
lnEGS no Granger Cause lnNGDP lnNGDP no Granger Cause lnEGS	24	5.15598 0.01013	0.0338 0.9208
lnRTE no Granger Cause lnGDP lnGDP no Granger Cause lnRTE	24	1.43649 3.08355	0.0244 0.0937
lnRL no Granger Cause lnGDP lnGDP no Granger Cause lnRL	24	0.23831 10.8164	0.0630 0.0035
lnEGS no Granger Cause lnGCF lnGCF no Granger Cause lnEGS	24	3.69575 0.03948	0.0682 0.8444
lnRTE no Granger Cause lnGCF lnGCF no Granger Cause lnRTE	24	0.00535 4.99305	0.0424 0.0364
lnRL no Granger Cause lnGCF lnGCF no Granger Cause lnRL	24	4.08239 6.83407	0.0563 0.0162
lnRTE no Granger Cause lnEGS lnEGS no Granger Cause lnRTE	24	0.48969 1.03314	0.4917 0.3210
lnRL no Granger Cause lnNEGS lnEGS no Granger Cause lnRL	24	0.01319 0.09501	0.9097 0.7609
lnRL no Granger Cause lnRTE lnRTE no Granger Cause lnRL	24	3.17956 10.8841	0.0890 0.0034

4.6. The Diagnostic Test

The Jarque–Bera Normality test indicates that the Jarque–Bera statistic is 0.663943, with a probability value of 0.717508, as illustrated in Figure 3. It is assumed that the residuals are typically distributed due to the fact that the p-value is greater than 5%.

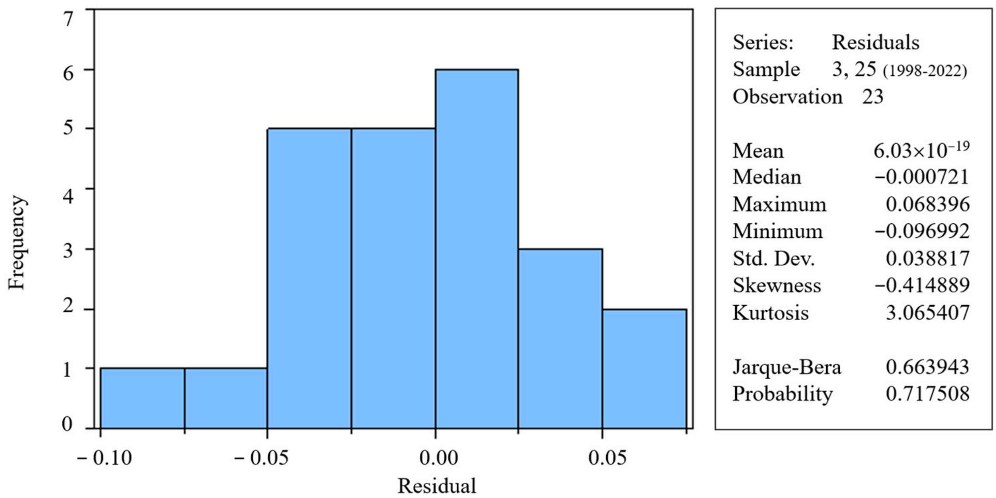

Figure 3. Histogram of the normality test of the residuals of different samples in the VECM.

The observed R-squared value is 1.286286, with a probability Chi-square value of 0.2567, as shown in Table 10. Due to the fact that the probability value exceeds 5%, the null hypothesis cannot be rejected. Therefore, the model is devoid of autocorrelation.

Table 10. Results of the Breusch–Godfrey serial correlation LM test.

Breusch–Godfrey Serial Correlation LM Test			
F-statistic	0.888576	Prob. F (1,15)	0.3608
Obs×R-squared	1.286286	Prob. Chi-Square (1)	0.2567

The results of the heteroscedasticity test are represented in Table 11. The probability value of the Chi-square statistic is greater than 5%. Therefore, the model is free from heteroscedasticity.

Table 11. Results of the Breusch–Godfrey heteroscedasticity test.

Parameter	**Value**	**Probability Parameter**	**Value**
F-statistic	1.626039	Prob. F (10,12)	0.2103
Obs× -squared	13.23368	Prob. Chi-Square (10)	0.2109
Scaled explained SS	6.613639	Prob. Chi-Square (10)	0.7613

Figure 4 demonstrates the CUSUM statistic plot (irregular curve) and stays within the critical bounds at a 5 percent significance level, represented by regular upward and downward sloping lines. Because the curve remains within these bounds, this indicates that the model is stable.

Similarly, the cumulative sum of squares (CUSUMQ) diagram (Figure 5) also supports the stability of the model at the 5% significance level, where the plot stays within the critical red lines.

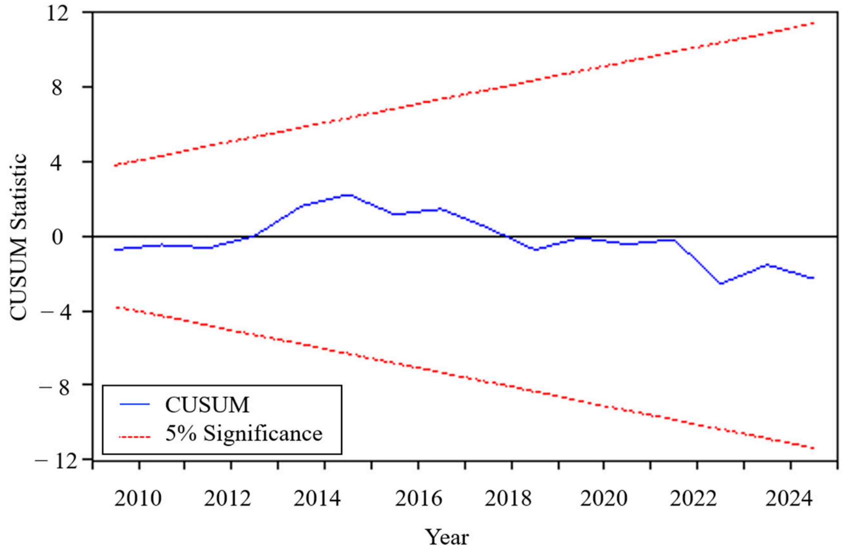

Figure 4. Plot of the cumulative sum (CUSUM) statistic along with 5% significance from 2009 to 2025.

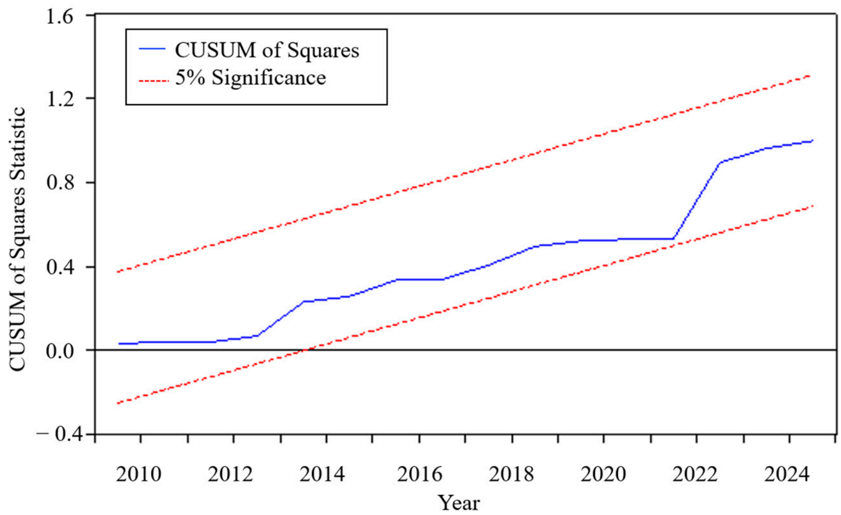

Figure 5. The cumulative sum of squares (CUSUMQ) statistic plotted with a 5% significance level from 2009 to 2025.

5. Discussion

The findings of the diagnostic test (refer to Sections 3.7 and 4.6) clearly indicate a long-run causal relationship of the road transport infrastructure parameters to economic growth. On the other hand, the findings also reveal a short-run relationship of road transport expenditure to GDP within the context of Nepal. Table 12 summarizes the previous studies of causal relationships between GDP and transport infrastructure in various developed and developing countries. The direction of causality varies between the utilized variables in these studies. In developed countries (e.g., America and Spain) the causality is from economic growth to transport infrastructure, except for Türkiye, where no long-run relationship was observed between the variables. However, the trend observed in developing countries is highly inconsistent. In Tunisia, the causality runs from infrastructure investment to transportation growth, whereas the relationship for India and Pakistan varies across different studies. In Pakistan, the causality is from economic growth to transportation according to a study by Mohmand et al. (2017) based on data from 1982 to 2010. Conversely, another study by Alam et al. (2021) found that the causality runs from transportation infrastructure to economic growth, considering data from 1971 to 2017.

Similarly in India, the causal relationships between GDP and transport infrastructure are interpreted differently in various studies. According to Pradhan and Bagchi (2013), the relationship is bidirectional based on data from 1970 to 2010, but Maparu and Mazumder (2017) found the relationship to be unidirectional, with causality running from economic growth to transportation, based on data from 1990 to 2011.

Table 12. Comparison of relationships between road transport and economic growth in different countries in various study periods.

Country	Study Period	Result	GDP	Status
America	1970–2008	Economic Growth → Transport Infrastructure Formation Capital Formation → Economic Growth Both Transport and Non-Transport → Exports	14,769.86 billion USD (2008) 1073.30 billion USD (1970)	Developed
India	1970–2010	Road Transport ⇔ Economic Development Road Transport ⇔ Formation of Capital Capital Formation ⇔Economic Development Rail Transport → Economic Growth Rail Transport → Capital Formation	1675.6 billion USD (2010) 62.42 billion USD (1970)	Developing Country
India	1990–2011	Economic Growth → Transport Infrastructure	1823.05 billion USD (2011) 320.98 billion USD (1990)	Developing Country
Nepal	1998–2022	Road Transport Infrastructure → Economic Growth	40.83 billion USD (2022) 4.86 billion USD (1998)	Least Developed Country
Pakistan	1982–2010	Economic Growth → Transport Infrastructure Investment At the province level, In rich and much developed provinces Transport Infrastructure ⇔ Economic Growth In underdeveloped provinces Transport Infrastructure → Economic Growth	177.17 billion USD (2010) 30.73 billion USD (1982)	Developing country
Pakistan	1971–2017	Transport Infrastructure → Economic Growth	339.21 billion USD (2017) 10.67 billion USD (1971)	Developing Country
Spain	1850–1935	Infrastructure Investment → Economic Growth	12.07 billion USD (1960)	Developed
Türkiye	1970–2005	No long-run relationship between highway expenditure, economic growth, international trade	506.31 billion USD (2005) 17.35 billion USD (1970)	Developed
Tunisia	1971–2012	Infrastructure Investment → Economic Growth	47.31 billion USD (2012) 1.69 billion USD (1971)	Developing Country
Uganda	1983–2009	Road Transportation → Economic Growth	25.13 billion USD (2009) 2.24 billion USD (1983)	Least Developed Country

The result for Nepal aligns with those of Uganda, which is also a least developed country. The GDP values of both countries were quite comparable during the study period. The direction of causality in these two least developed countries is from economic growth to road transport infrastructure. This relationship contrast with that of developed or developing countries, which suggest the influence of contextual factors and the size of economy on this relationship. Additionally, this indicates that transportation infrastructure aids the GDP until it reaches saturation. After that point, it can no longer aid GDP growth; instead, GDP growth will drive further development of the transportation infrastructure.

Furthermore, Nepal's road transport system has substantial obstacles as a result of natural calamities such as landslides and earthquakes (Subedi et al. 2024; Bhandary et al. 2013; KC et al. 2024a). Landslides, especially during the monsoon season, may interrupt road networks, resulting in significant economic damages and hindering connection (KC et al. 2024a; KC et al. 2024b). Earthquakes are an additional significant danger, as also demonstrated by the 2015 Gorkha earthquake, which exposed the extreme susceptibility of Nepal's transport infrastructures to earthquakes. It is essential to tackle these problems in order to guarantee the durability and long-term viability of road transport infrastructures, which is key for fostering economic development (McAdoo et al. 2018). Subsequent investigations should delve into the effects of these natural calamities on infrastructure and economic advancement, as well as formulate tactics to alleviate these hazards.

6. Conclusions

This study has explored the effect of road transport expenditure, road length, gross capital formation and exports of goods and services on the economic growth of Nepal from 1998 to 2022. The results of the econometric tests, including the unit root test, the cointegration test, and the VECM demonstrate a clear relationship between road transport infrastructure and economic growth both in the long run and short run. In the long run, road transport infrastructure had a significant and positive effect on the economic growth of the country. When GDP is considered as a dependent variable, the coefficient of the long-run cointegration equation is -0.991, which is statistically significant at the 5% level. The negative coefficient implies a convergence speed of the short-run disturbance to the long-run equilibrium, indicating that the rate of adjustment is high. Similarly, in the short run, road transport expenditure has a positive impact on the GDP and GCF. This suggests that the investment in road transport infrastructure is positive for the country's economic growth and is not excessively costly to show the negative effect immediately.

The results of this study highlight the importance of developing road transport infrastructures for regional development. Expanding the road network alone without considering its sustainability and operational reliability is not sufficient for achieving the desired economic development of the region. For less-developed countries like Nepal, expanding and maintaining the road network to cover entire regions of the country are always challenging, with many constraints like funding, technology, and human resources. Increased funding for road transport infrastructure can help the nation promote long-term economic prosperity by enhancing connectivity and facilitating more efficient movement of goods and people. However, while chasing the long-term benefit, the government should not overspend, which can result in a short-term decline in overall output. As road transport is still in the stage of basic connectivity in various parts of the country and not as commercially viable for private sector investment so far, the government is the only financing authority in Nepal. Since the investment demand in all sectors including the social and infrastructure sectors is always higher and budgetary resources are always a major constraint in less-developed countries like Nepal, there is a confusion in prioritization of investment for achieving the targeted economic growth. Similarly, providing basic transportation facilities and regional balance in the infrastructures are also major concerns of the government. To meet the objectives of regional economic development, well-balanced investment in road transport infrastructures is essential.

However, as this study is predicated on secondary data sources that might have contained inaccuracies as well as data points that might have been estimated, we do expect that the obtained results are potentially biased. Nevertheless, the focus of this analytical study is exclusively on the infrastructures related to road transport, without considering any other modes of transport. Additionally, the analysis has relied on the national-level data, which might have resulted in oversights in terms of the regional differences. The VECM assumes linear relationships and does not consider exogenous influences such as political instability and natural disasters. Subsequent investigations should encompass all transport modes to conduct a thorough analysis and assess the initial level of accessibility and connection. Conducting a regional analysis in Nepal could reveal inequalities while utilizing non-linear models and machine learning approaches could offer more profound insights. Evaluating the long-term viability and adaptability of infrastructure investments in the face of climate change, as well as analyzing the effectiveness of regulatory frameworks and collaborations between the public and private sectors, could provide valuable insights for the development of sustainable infrastructures. Future research should concentrate on the influence of baseline accessibility and connectivity on the relationship between road infrastructures and economic development, as well as the investigation of regional disparities to capture the heterogeneous impacts across different areas. Furthermore, it is imperative to evaluate the sustainability and resilience of infrastructure investments in the context of climate change and natural disasters to guarantee the long-term benefits.

Author Contributions: Conceptualization, K.K.S. and N.P.B.; methodology, K.K.S.; software, K.K.S.; validation, N.P.B., M.S. and R.P.; formal analysis, K.K.S. and M.S.; resources, K.K.S.; writing—original draft preparation, K.K.S. and M.S.; writing—review and editing, N.P.B. and R.P.; visualization, K.K.S.; supervision, N.P.B. and R.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The authors will provide the data used in this study upon request.

Acknowledgments: We extend our gratitude to the Ministry of Physical Infrastructure and Transport (MOPIT), Nepal for generously providing the necessary data for this study. Our sincere thanks to Rajan KC and Richa Pokhrel from the Geoinfra Research Institute for their assistance during data collection and analysis.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

CPI	Consumer Price Index
CUSUM	Cumulative Sum of Recursive Residuals
CUSUMSQ	Cumulative Sum of Squares of Recursive Residuals
ECM	Error Correction Model
EGS	Exports of Goods and Services
GDP	Gross Domestic Product
GCF	Gross Capital Formation
LNGDP	Log of Gross Domestic Product
LNGCF	Log of Gross Capital Formation
LNEGS	Log of Exports of Goods and Services
LNRTE	Log of Road Transportation Expenditure
LNRL	Log of Road length
LRN	Local Road Network
MoPIT	Ministry of Physical Infrastructure and Transport
RTE	Road Transportation Expenditure
RL	Road Length
SDG	Sustainable Development Goal
SRN	Strategic Road Network
VECM	Vector Error Correction Model

References

Achour, Houda, and Mounir Belloumi. 2016. Investigating the causal relationship between transport infrastructure, transport energy con-sumption and economic growth in Tunisia. *Renewable and Sustainable Energy Reviews* 56: 988–98. [CrossRef]

Alam, Khalid Mehmood, Xuemei Li, Saranjam Baig, Osman Ghanem, and Salman Hanif. 2021. Causality between Transportation Infrastructure and Economic Devel-opment in Pakistan: An ARDL Analysis. *Research in Transportation Economics* 88: 100974. [CrossRef]

Arbués, Pelayo, José F. Baños, and Matías Mayor. 2015. The Spatial Productivity of Transportation Infrastructure. *Transportation Research Part A: Policy and Practice* 75: 166–77. [CrossRef]

Aschauer, David A. 1990. Highway capacity and economic growth. *Economic Perspectives* 14: 4–24. Available online: https://econpapers.repec.org/scripts/redir.pf?u=http://www.chicagofed.org/digital_assets/publications/economic_perspectives/1990/ep_sep_oct1990_part2_aschauer.pdf;h=repec:fip:fedhep:y:1990:i:sep:p:14-24:n:v.14no.5 (accessed on 10 October 2023).

Asian Development Bank (ADB). 2013. Nepal: Country Partnership Strategy, 2013–2017. Asian Development Bank. Available online: https://www.adb.org/documents/nepal-country-partnership-strategy-2013-2017 (accessed on 5 October 2023).

Bahrami, Hamid. 2012. Investment in Transportation and Examining Its Influence on the Economical Growth of Iran. Available online: https://www.researchgate.net/publication/288772840_Investment_in_transportation_and_examining_its_influence_on_the_economical_Growth_of_Iran (accessed on 15 November 2023).

Banister, David, and Yossi Berechman. 2001. Transport investment and the promotion of economic growth. *Journal of Transport Geography* 9: 209–18. [CrossRef]

Banister, David, and Yossi Berechman. 2017. The economic development effects of transport investments. In *Transport Projects, Programmes and Policies*. London: Routledge, pp. 107–23. [CrossRef]

Banister, David, Dominic Stead, Peter Steen, Jonas Akerman, Karl Dreborg, Peter Nijkamp, and Ruggero Schleicher-Tappeser. 2000. *European Transport Policy and Sustainable Mobility*, 1st ed. Book Series: Transport, Development and Sustainability; London: Routledge, Taylor and Francis Group. ISBN 9780415234092. Available online: https://www.routledge.com/European-Transport-Policy-and-Sustainable-Mobility/Akerman-Banister-Dreborg-Nijkamp-Schleicher-Tappeser-Stead-Steen/p/book/9780415234092 (accessed on 22 July 2024).

Beyzatlar, Mehmet Aldonat, Müge Karacal, and Hakan Yetkiner. 2014. Granger-Causality between Transportation and GDP: A Panel Data Approach. *Transportation Research Part A: Policy and Practice* 63: 43–55. [CrossRef]

Bhandari, Sahadev Bahadur, Padma Bahadur Shahi, and Rabindra Nath Shrestha. 2012. Overview of Rural Transportation Infrastructures in Nepal. *Eurasia Journal of Earth Science & Civil Engineering* 1: 1–14. [CrossRef]

Bhandary, Netra Prakash, Ryuichi Yatabe, Ranjan Kumar Dahal, Shuichi Hasegawa, and Hideki Inagaki. 2013. Areal distribution of large-scale landslides along highway corridors in central Nepal. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 7: 1–20. [CrossRef]

Dickey, David A., and Wayne A. Fuller. 1979. Distribution of the Estimators for Autoregressive Time Series with a Unit Root. *Journal of the American Statistical Association* 74: 427–31. [CrossRef]

Dickey, David A., and Wayne A. Fuller. 1981. Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root. *Econometrica* 49: 1057–72. [CrossRef]

Dritsaki, Chaido, and Melina Dritsaki-Bargiota. 2005. The Causal Relationship between Stock, Credit Market, and Economic Development: An Empirical Evidence for Greece. *Economic Change and Restructuring* 38: 113–27. [CrossRef]

Elliott, Graham, Thomas Rothenberg, and James Stock. 1992. *Efficient Tests for an Autoregressive Unit Root*. NBER Technical Working Papers No. 130. Cambridge, MA: National Bureau of Economic Research. [CrossRef]

Enders, Walter, and Kamol Chumrusphonlert. 2004. Threshold Cointegration and Purchasing Power Parity in the Pacific Nations. *Applied Economics* 36: 889–96. [CrossRef]

Engle, Robert F., and Byung Sam Yoo. 1987. Forecasting and Testing in Co-Integrated Systems. *Journal of Econometrics* 35: 143–59. [CrossRef]

Engle, Robert F., and C. W. J. Granger. 1987. Co-Integration and Error Correction: Representation, Estimation, and Testing. *Econometrica* 55: 251–76. [CrossRef]

Estache, Antonio. 2010. Infrastructure Finance in Developing Countries: An Overview. *EIB Papers* 15: 60–88. Available online: http://hdl.handle.net/10419/45371 (accessed on 17 November 2023).

Fedderke, Johannes W., Peter Perkins, and John Manuel Luiz. 2006. Infrastructural Investment in Long-Run Economic Growth: South Africa 1875–2001. *World Development* 34: 1037–59. [CrossRef]

Granger, C. W. J. 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* 37: 424–38. [CrossRef]

Granger, Clive W. J. 1988. Some Recent Development in a Concept of Causality. *Journal of Econometrics* 39: 199–211. [CrossRef]

Herranz-Loncán, Alfonso. 2007. Infrastructure Investment and Spanish Economic Growth, 1850–1935. *Explorations in Economic History* 44: 452–68. [CrossRef]

Imbens, Guido W., and Jeffrey M. Wooldridge. 2009. Recent Developments in the Econometrics of Program Evaluation. *Journal of Economic Literature* 47: 5–86. [CrossRef]

Johansen, Søren. 1988. Statistical Analysis of Cointegration Vectors. *Journal of Economic Dynamics and Control* 12: 231–54. [CrossRef]

Johansen, Søren. 1991. Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica* 59: 1551–80. [CrossRef]

Johansen, Søren. 1995. Identifying Restrictions of Linear Equations with Applications to Simultaneous Equations and Cointegration. *Journal of Econometrics* 69: 111–32. [CrossRef]

KC, Rajan, Keshab Sharma, Bhim Kumar Dahal, Milan Aryal, and Mandip Subedi. 2024a. Study of the spatial distribution and the temporal trend of landslide disasters that occurred in the Nepal Himalayas from 2011 to 2020. *Environmental Earth Sciences* 83: 42. [CrossRef]

KC, Rajan, Milan Aryal, Keshab Sharma, Netra Prakash Bhandary, Richa Pokhrel, and Indra Prasad Acharya. 2024b. Development of a framework for the prediction of slope stability using machine learning paradigms. *Natural Hazards* 1–25. [CrossRef]

Kirchgässner, Gebhard, Jurgen Wolters, and Uwe Hassler. 2013. *Granger Causality, Introduction to Modern Time Series Analysis*. Berlin and Heidelberg: Springer, pp. 95–125. [CrossRef]

Kuştepeli, Yeşim, Yaprak Gülcan, and Sedef Akgüngör. 2012. Transportation Infrastructure Investment, Growth and International Trade in Turkey. *Applied Economics* 44: 2619–29. [CrossRef]

Maparu, Tuhin Subhra, and Tarak Nath Mazumder. 2017. Transport Infrastructure, Economic Development and Urbanization in India (1990–2011): Is There Any Causal Relationship? *Transportation Research Part A: Policy and Practice* 100: 319–36. [CrossRef]

Marazzo, Marcial, Rafael Scherre, and Elton Fernandes. 2010. Air Transport Demand and Economic Growth in Brazil: A Time Series Analysis. *Transportation Research. Part E, Logistics and Transportation Review* 46: 261–69. [CrossRef]

McAdoo, Brian G., Michelle Quak, Kaushal R. Gnyawali, Basanta R. Adhikari, Sanjaya Devkota, Purna Lal Rajbhandari, and Karen Sudmeier-Rieux. 2018. Roads and landslides in Nepal: How development affects environmental risk. *Natural Hazards and Earth System Sciences* 18: 3203–10. [CrossRef]

Mohmand, Yasir Tariq, Aihu Wang, and Abubakr Saeed. 2017. The Impact of Transportation Infrastructure on Economic Growth: Empirical Evidence from Pakistan. *Transportation Letters* 9: 63–69. [CrossRef]

Muvawala, Joseph, Hennery Sebukeera, and Kurayish Ssebulime. 2021. Socio-economic Impacts of Transport Infrastructure Investment in Uganda: In-sight from Frontloading Expenditure on Uganda's Urban Roads and Highways. *Research in Transportation Economics* 88: 100971. [CrossRef]

National Planning Commission (NPC). 2019. The Fifteenth Plan, Fiscal Year 2019/20. National Planning Commission (Nepal). p. 759. Available online: https://npc.gov.np/images/category/15th_plan_English_Version.pdf (accessed on 20 October 2023).

Njoku, Charles Odinakachi, Emmanuel Ezeji Chigbu, and A. B. C. Akujuobi. 2015. Public Expenditure and Economic Growth in Nigeria (A Granger Causality Approach) 1983-2012. *Management Studies and Economic Systems* 1: 147–60. [CrossRef]

Pandit, B. 2023. Public Expenditure on Transportation and its Contribution on Economic Growth in Nepal. Doctoral dissertation, Department of Economics, Tribhuvan University, Kathmandu, Nepal. Available online: https://elibrary.tucl.edu.np/handle/123456789/18827 (accessed on 10 December 2023).

Phillips, P. C. B. 1986. Understanding Spurious Regressions in Econometrics. *Journal of Econometrics* 33: 311–40. [CrossRef]

Phillips, P. C. B. 1987. Time Series Regression with a Unit Root. *Econometrica* 55: 277–301. [CrossRef]

Phillips, P. C. B., and S. Ouliaris. 1990. Asymptotic Properties of Residual Based Tests for Cointegration. *Econometrica* 58: 165–93. [CrossRef]

Pradhan, Rudra P., and Tapan P. Bagchi. 2013. Effect of Transportation Infrastructure on Economic Growth in India: The VECM Approach. *Research in Transportation Economics* 38: 139–48. [CrossRef]

Pradhan, Rudra P., Neville R. Norman, Yuosre Badir, and Bele Samadhan. 2013. Transport Infrastructure, Foreign Direct Investment and Economic Growth Interactions in India: The ARDL Bounds Testing Approach. *Procedia - Social and Behavioral Sciences* 104: 914–21. [CrossRef]

Sahoo, Pravakar, and Ranjan Kumar Dash. 2012. Economic Growth in South Asia: Role of Infrastructure. *The Journal of International Trade & Economic Development* 21: 217–52. [CrossRef]

Sahoo, Pravakar, Geethanjali Nataraj, and Ranjan Kumar Dash. 2012. China's Growth Story: The Role of Physical and Social Infrastructure. *Journal of Economic Development* 37: 53–75. [CrossRef]

Starkey, Paul, and John Hine. 2014. Poverty and Sustainable Transport: How Transport Affects Poor People with Policy Implications for Poverty Reduction. A Literature Review. UN Habitat. Available online: https://sustainabledevelopment.un.org/index.php?page=view&type=400&nr=1767&menu=35 (accessed on 22 July 2024).

Stock, James H., and Mark W. Watson. 1988. Testing for Common Trends. *Journal of the American Statistical Association* 83: 1097–107. [CrossRef]

Subedi, H. P. 2017. A Study on Impacts of Road Infrastructures on Regional Economy of Developing Nation: A Case Study of Nepal. Doctoral dissertation, Institute of Engineering, Tribhuvan University, Kathmandu, Nepal. Available online: https://elibrary.tucl.edu.np/handle/123456789/7369 (accessed on 20 November 2023).

Subedi, Mandip, Rajan Kc, Keshab Sharma, Jibendra Misra, and Apil Kc. 2024. Reconnaissance of the Effects of the MW5.7 (ML6.4) Jajarkot Nepal Earthquake of 3 November 2023, Post-Earthquake Responses, and Associated Lessons to Be Learned. *Geosciences* 14: 20. [CrossRef]

The World Bank. 2005. *A Framework for the Economic Evaluation of Transport Projects*. The Transport Note No. TRN-5. Washington DC: World Bank. 25p.

Tong, Tingting, T. Edward Yu, and Roland K. Roberts. 2014. Dynamics of Transport Infrastructure, Exports and Economic Growth in the United States. *Journal of the Transportation Research Forum* 53: 65–81. [CrossRef]

Tripathi, Shruti, and Vikash Gautam. 2010. Road Transport Infrastructure and Economic Growth in India. *Journal of Infrastructure Development* 2: 135–51. [CrossRef]

Wooldridge, Jeffrey H. 2002. *Econometric Analysis of Cross Section and Panel Data*. Cambridge, MA and London: The MIT Press.

Yu, Annan, Martin De Jong, Servaas Storm, and Jianing Mi. 2012. Transport Infrastructure, Spatial Clusters and Regional Economic Growth in China. *Transport Reviews* 32: 3–28. [CrossRef]

Zhang, Fangni, and Daniel J. Graham. 2020. Air Transport and Economic Growth: A Review of the Impact Mechanism and Causal Relationships. *Transport Reviews* 40: 506–28. [CrossRef]

Zhu, Feng, Xu Wu, and Wei Peng. 2022. Road Transportation and Economic Growth in China: Granger Causality Analysis Based on Pro-vincial Panel Data. *Transportation Letters* 14: 710–20. [CrossRef]

Zuo, Xiuxia. 2019. Several Important Unit Root Tests. Paper presented at the 2019 IEEE 2nd International Conference on Information Communication and Signal Processing (ICICSP), Weihai, China, September 28–30; pp. 10–14. [CrossRef]