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Nexus between infrastructural development and economic growth: Evidence from Bangladesh through auto-regressive distributive lag and nonlinear auto regressive distributive lag analysis

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Abstract

This study aims to scrutinize the influence of infrastructure on the economic growth of Bangladesh, employing an extensive time series analysis spanning from 1973 to 2020. Utilizing Principle Component Analysis, two distinct indices were constructed to gauge the dimensions of economic and social infrastructure. Subsequently, Auto-Regressive Distributive Lag (ARDL) and Nonlinear Auto Regressive Distributive Lag (NARDL) bound tests were employed to assess the existence of long-run relationships among the variables under examination. The findings indicate a significant and positive contribution of economic infrastructure to both long and short-term production expansion. Upon further disaggregation into negative and positive shocks, consistent results emerge. An increase (decrease) in the economic infrastructure (EI) index by one unit corresponds to an upsurge (subside) of 0.16% (0.17%) in economic growth. In contrast, social infrastructure (SI) exhibits no significant long-run association with GDP growth. The discerned pattern suggests that EI play a pivotal role in driving aggregate output, while SI display a lag. Despite this, it is imperative to underscore the importance of SI for human development. Consequently, adopting a comprehensive and strategic approach, encompassing vision, ensuring quality inclusivity, and anti-corruption measures, is imperative for Bangladesh to fully realize the transformative potential of its infrastructure investments and foster sustained economic growth.

Keywords

Economic growth, infrastructural development, PCA, ARDL, NARDL

JEL Classification: B23, C22, H54, O47

Introduction

Infrastructural development can be defined as the improvement of fundamental equipment that accelerates the economy and enhances the livelihood quality of a region (Palei, 2015). The word infrastructure comprises elements such as transportation, energy production, telecommunication status, pure water access and sanitation, health and education facilities, and other technical necessities. Globally, scholars consider it as one of the core inputs in a country's development mechanism. It has often been viewed as a means to boost productivity, reduce transport and production costs, and facilitate market accessibility, thereby attracting business activities (Égert et al., 2009). Additionally, it acts as a draw for foreign investment (Sahoo, 2000). Studies (e.g., Sanchez-Robles, 1998) suggest that allocating funds to infrastructural development enables governments to generate short-term employment opportunities.

The multifaceted impact of infrastructure on the economy has increased the interest of researchers worldwide. According to Zahra et al. (2008), infrastructure, such as telecommunications, can have both direct and indirect impacts on an economy. In direct impact, the expansion of telecommunication generates demand for skilled labour, creates employment opportunities, paves the way for foreign investments, and enhances communication at a reduced cost. On the other hand, indirect impact involves the expansion of the accessory markets, such as cell phone franchises, and the participation of telecommunication

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service providers in stock markets. Binswanger et al. (1993) explained that agrarian regions with good infrastructures attract more investment due to the cost-effective accessibility for financial institutions. Conversely, well-developed transportation systems contribute to urbanization by expanding city areas or fostering the emergence of new cities (World Bank, 2009). In Kumo's (2012) view, infrastructure is the only investment to create more job opportunities, directly and indirectly. The significance of induced employment depends on the multiplier effect of the investment. Furthermore, efficient channeling of natural resources can be impeded by inadequate infrastructure. For example, despite Nigeria's oil wealth, the country struggles with persistent poverty and slow growth due to a lack of abundant transport facilities (Adelowokan et al., 2019).

Economic growth remains vital for a country's sustainable goals as it makes resources available to tackle development challenges, diminish poverty, advance infrastructure, promote renewable energy, and invest in dynamic services (Sanchez-Robles, 1998). When managed effectively, economic growth starts contributing to the wellbeing of the population, especially in developing countries like Bangladesh, helping to achieve long-term sustainable objectives. It is evident that to establish a sustainable economic situation, keeping the pace of continuous economic growth and emphasizing core engines like infrastructures is essential. Therefore, the examination of infrastructural development trends and their contribution to the economy is crucial for policymakers in formulating strategies to expedite the gross economic output.

Today, Bangladesh is recognized as one the world's emerging economic powerhouses. Recent economic performances astonish almost every nation and force them to rethink their geo-political relationship with her. Despite economic fragility at its inception, concerted policy efforts led to a remarkable rise in GDP by 124.51% in 1980, accompanied by a reduction in inflation to 17.56% from 61.41% (in 1973). With liberalization and privatization, there has been significant growth in every sector of the economy except FDI (WDI, 2022). Since the beginning of the twenty-first century, Bangladesh has experienced exponential growth, with GDP exceeding 460.2 billion in 2022, reflecting stability in inflation rates (WDI, 2022). The substantial increase in exports and imports, along with a notable reduction in poverty from 71.3% in 1973 to 31.5% in 2010, underscores the positive trajectory (Hossain, 2014). Notably, per capita income surged from 119.56 US dollars in 1973 to 2688.30 in 2022 (WDI, 2022).

It cannot be ignored that the experiences of most of the developed countries' infrastructure-led economic growth set examples for developing countries to follow (Sahin et al., 2014). Despite occasional political challenges, Bangladesh's economy has flourished in the last decade, which is evident in its growth rates. Along with all other macroeconomic variables, infrastructure is an important one. Therefore, to keep the pace of growth, the country's infrastructure must be in a better position. With around 92.2% of the population having access to electricity, and major projects like the Padma Bridge, Karnaphuli Tunnel, Metro-rail, Rooppur Nuclear Power Plant, and the launch of the country's first-ever satellite shaping a robust infrastructure landscape (WDI, 2019), Bangladesh is addressing the issue. However, such developments necessitate taking a closer examination of the impact of infrastructural development on the economy, evaluating its current status and charting a more efficient course for improvement.

Improved infrastructure paves ways to produce more output. In the case of developed countries, it has been proven often. However, for developing countries, the degree of this influence has been a subject of debate. Notably, the existing body of work on Bangladesh has predominantly focused on limited dimensions of infrastructure sectors. Specifically, much attention has been directed toward examining the impact of individual infrastructure components. To address this gap, the present study introduces a comprehensive analysis encompassing a diverse array of infrastructure elements. Through this approach, the research aims to shed light on the collective influence of various infrastructural components on economic growth.

In this study, a comprehensive exploration of various infrastructure sectors has been undertaken, categorizing infrastructures into economic and social. EI involves those things that directly help production and the economy (Singh et al., 2007 and Kumari and Sharma, 2017b). While SI includes things that facilitate society's development and people's wellbeing (Grimsey and Lewis, 2002). A detailed description of the indicators that are considered as factors for both infrastructures in this study is discussed in the methodology section. Indices for economic and social infrastructure have been constructed using various indicators from 1973 to 2020, examining their long-run relations with economic growth. Additionally, an asymmetric analysis has been conducted, shedding light on the impact of positive and negative shocks from both infrastructure indices on economic growth—an innovative addition to the literature. To the best of the authors' knowledge, no scholarly works have thus far examined the asymmetric relationships among these mentioned variables. Besides, no other literature has scrutinized the impact of EI and SI on Bangladesh's economic growth simultaneously.

This study consists of five sections. Firstly, in the Introduction, the background of the study, justification of the study, and research gap are explored. Secondly, the review of literature highlights the views and findings of different scholars. Thirdly, the methodology section discusses the approaches followed to meet the study's objective. Fourthly, the findings and discussion section provides the estimated results and discuss possible reasons behind them. Finally, the concluding remarks provide an overview of the study and policy recommendations.

Review of literature

Context of other countries

The subject of infrastructure has been up for debate for the past couple of decades. Notably, Aschauer is often credited as a torch bearer in this domain, having initiated scholarly exploration into the positive underpinnings of the infrastructure-growth relationship. In the USA, the lack of public infrastructure investment and productivity growth slowed down (Aschauer, 1989a). In his seminal studies, Aschauer delved into the aftermaths of insufficient public infrastructure investment on productivity growth in the USA (Aschauer, 1989a). Furthermore, his comprehensive analysis extended to G7 countries, revealing a robust positive correlation between public non-military investment and labour productivity growth (Aschauer, 1989b).

This intricate relationship between public expenditure and productivity involves both direct and indirect effects. Public expenditure serves as a complement to private capital, augmenting the marginal productivity of labour and capital within the private production function, albeit in a diminishing manner (Aschauer, 1989c). Simultaneously, it exerts a crowding-out effect on private investment. This implies that increased spending on public capital leads to improved services, subsequently reducing costs for private capital. The surplus funds, thus liberated, find their way into the production process, resulting in heightened productivity in the private sector output. Consequently, this augments private investment returns, underscoring the multifaceted impact of public infrastructure expenditure on economic dynamics.

Researchers worldwide have disputes over the efficacy of public investment on economic output. Nowadays, attention has been strategically honed towards scrutinizing the infrastructural dimension, particularly those initiatives financed directly by the government. For example, Banerjee et al. (2012) delved into the historical transportation system of China, revealing a moderately positive role in achieving higher GDP per capita. However, it did not exert a significant contribution to GDP per capita growth, failing to have a substantial impact on economic growth during China's period of heightened economic expansion. Banerjee identified a lack of factor mobilization as the underlying reason. This resulted in relatively impoverished areas being deprived of the benefits of rapid economic growth, despite possessing a robust communication system.

Baltagi and Pinnoi (1995) scrutinized data from 48 Canadian states between 1970 and 1986, introducing measurement error into the analysis. They noted a noteworthy shift in the significance of public infrastructure capital in the private production model, where it transitioned from being highly significant and positive to insignificant. Disaggregating public infrastructure capital into different components, they discovered varied impacts for different infrastructures, with only water and sewer capital inducing private production.

Examining 44 African countries from 1990 to 2010, Batuo (2015) employed the Generalized Method of Moments (GMM) to assess the impact of telecommunication investment. The findings indicated increasing growth returns, with Batuo asserting that telecommunication enhances the working environment, conditions, and overall quality of work. The provision of clearer communication pathways ensures transparency of information. E-based services and administrative goods effectively narrow the distance between providers and receivers, enabling citizens to enjoy rapid feedback through e-governance. Moreover, e-learning facilitates knowledge acquisition, offering students comprehensive answers to their inquiries through engagement with international educational platforms.

Some other key contributions to the literature are summarized in Table 1, highlighting the impact of infrastructure in the case of different countries in different periods.

Context of Bangladesh

Alam et al. (2004) conducted a comprehensive assessment of the efficiency of transportation accessibilities across 20 regions, employing the Data Envelopment Analysis (DEA) framework. The findings indicated that regions with deficient accessibility suffered from inadequate infrastructure, emphasizing the need for improved intra-city transportation systems to integrate the agriculture and industry sectors.

Raihan (2011) employed three techniques to investigate the link between infrastructure, growth, and poverty. Utilizing a district-wise infrastructure development index constructed through PCA, he revealed that regions with higher index values exhibited lower headcount poverty ratios. Expanding the study, Raihan incorporated Social Accounting Matrix (SAM) multipliers and Computable General Equilibrium (CGE) models, revealing that a 20% increase in infrastructure investment could lead to an 8.07% rise in GDP. Additionally, a reduction in transport margins could elevate real GDP by 0.57%. The models, based on 2007 data, underscore the potential economic impact of strategic infrastructure investments.

The Bangabandhu Bridge, formerly known as the Jamuna Multipurpose Bridge, emerged as a landmark infrastructure project in Bangladesh upon its inauguration in 1998. Analyzing the pre and post-implementation scenarios, Ghosh et al. (2010) observed a substantial improvement in living standards of people of surrounding areas. The bridge's impact was evident in increased literacy rates (by approximately 19%), heightened health awareness, enhanced birth control measures, improved sanitation practices, and increased school enrollments. The development of communication systems facilitated better medical

Table 1. Literature Review.

Author	Country/area and time span	Method	Findings
Sahin et al. (2014)	European Union (1980–2010)	GMM	Telecommunication investment exerts a positive influence on the growth in each estimation group, outperforming other variables that exhibit significant effects across diversified groups.
Sahoo (2000)	India (1970–71 to 2000–01)	Vector Auto Regressive model (VAR)	The communication system exhibits the most significant impact on GDP, while the energy supply shows negative elasticity. The researcher's assumption is that this negative elasticity is attributed to distribution loss.
Sahoo et al. (2012)	China (1975–2007)	ARDL, GMM	The focus should be given to physical infrastructure rather than human capital, as it contributes much to growth.
Égert et al. (2009)	OECD countries (1960–2005)	DOLS	The contribution of infrastructure to output will depend on the level of investment made by individual countries.
Ismail and Mahyideen (2015)	10 Asian Country (1971 to 2013)	Pooled mean group estimation (Panel ARDL)	The construction of new infrastructure and the maintenance of its quality have significantly contributed to the GDP growth of these countries. A 10% increase in paved roads, air freight, internet use, and electricity consumption lead to growth increments of 5.4%, 3.7%, 2.1%, and 7.4%, respectively. Notably, the impact of quality measures appears to have a more substantial influence compared to quantity measures.
Kumo (2012)	South Africa (1960–2009)	VAR, Granger causality Tests, ARDL	Though there had been two-way causal relationships between infrastructure investment and growth, the study found a smaller elasticity. It also found bidirectional causality between infrastructure and public sector employment. However, for private-sector employment, it was insignificant.
Roller and Waverman (2001)	21 OECD countries (1970–1990)	GMM	Having the existence of externality in telecommunication infrastructure means increasing returns on growth, which could be one of the reasons for higher growth rates in OECD countries than in non-OECD countries.
Urrunaga and Aparicio (2012)	24 regions of Peru (1980–2009)	GMM	The disparities in per capita output among different regions depend on the level of their existing infrastructure gap and its quality.
Keho and Echui (2011()	Côte d'Ivoire (1970–2002)	Johansen cointegration, Granger Causality, ARDL bound test	The result of this study supports Wagner's law, where causality runs from GDP to transport investment. It means higher economic growth will introduce better infrastructure for a communication system.
Chakamera and Alagidede (2018)	Sub-Saharan Africa (2000–2004)	PCA, GMM	The impact of aggregate infrastructure quality appears to be weaker than that of the Aggregate Infrastructure index.
Awan and Anum (2014)	Pakistan (1971–2013)	PCA, ARDL	Larger infrastructure assets may contribute to accelerating the economy at a slower pace in the short run, but their impact may be higher in the long run. Infrastructure development is recognized as one of the principal components influencing both growth and poverty alleviation.
Enimola (2010)	Nigeria (1980–2006)	VECM	Despite having a relation for both infrastructure variables, in the long run, impulse response function and variance decomposition explore their decaying nature. Investment cuts, lower maintenance, lack of expansion, and poor quality in the public infrastructure sector might be the ramifications of this.
Song and Mi (2016)	China (1999–2009)	Error Correction Model (ECM), Granger Causality Test.	This study found the presence of bi-directional causality between the two subject variables in the short run and unidirectional causality in the long run, which ran from port investment to GDP.

(continued)

Table 1. Continued.

Author	Country/area and time span	Method	Findings
Tsaurai and Ndou (2019)	Transitional Economy (2000–2014)	GMM	While the individual impacts of infrastructure and human capital appeared insignificant, their interaction yielded a positive effect. The study implies that fostering human capital improvement is essential to enhance the capability of infrastructure to influence economic growth.
Sojoodi et al. (2012)	Iran (1985–2008)	ARDL	Except for electricity, the other four infrastructures possess a positive long-run impact on output. The reason behind holding an insignificant relationship of electrification is its inefficient uses.
Herranz-Loncán (2007)	Spain (1850–1935)	Johansen co-integration test, VECM	During that period, state-owned infrastructure underperformed due to inefficient allocation, influenced by subjective political interests in decision-making. In contrast, infrastructure managed by local governments provided better services with a focus on revenue generation. However, when examining the aggregate impact on overall output, the contribution appeared marginal, with an elasticity of 0.008.
Kuştepeli et al. (2012)	Turkey (1970–2005)	Johansen cointegration, Granger Causality, ARDL bound test	None of the assumed causal relations, namely infrastructure and growth, and infrastructure and trade, exhibit significance in the long run. The attributed reasons for this lack of significance are inefficient funding mechanisms and suboptimal utilization of the allocated funds.

services, while government rehabilitation programs and NGO expansions contributed to economic prosperity. Furthermore, Mahmud and Sawada (2018) noted a significant decrease in household unemployment rates, attributing it to the bridge's role in creating new business opportunities. Moniruzzaman (2008) explored the impact of the Jamuna Bridge project on household income, finding a notable 7–10% increase in income in the treatment area.

Rahman (2011) examined the causal relationships between education and health expenditures with economic growth in Bangladesh. Granger causality tests revealed a unidirectional causality from health spending to economic growth, while a bidirectional causality existed between education spending and output. Building on this foundation, Muktdair-Al-Mukit (2012) highlighted the positive long-term impact of increased public expenditure on education, leading to a 0.34% rise in economic growth.

In examining the case of Bangladesh, researchers have selectively employed specific infrastructures to explain the overall landscape. Within the existing body of literature, a discernible gap persists—namely, the mechanisms through which infrastructure accelerates economic growth over time within the Bangladeshi context. To address this aspect, this study incorporates various pivotal infrastructures, aiming to yield robust findings. Consequently, the research endeavours to provide a thorough examination of the infrastructural contributions that underpin the pursuit of a sustainable economy from a national standpoint.

Methodology

Since the major objective of this study is to check the infrastructure-growth relations, a production function needs to be introduced here where infrastructure plays a role of input alongside others. In compliance with some previous empirical works, this study embraces infrastructure as an input in a Cobb–Douglas production function where the other two factors are labour and capital. Unlike most, infrastructure variables will be disaggregated into economic and social infrastructure to get a more concrete scenario of repercussions. Based on the augmented Cobb–Douglas production function framework infrastructure-output relation can be written as,

$$Y = AL^{\alpha}K^{\beta}E^{\gamma}S^{\delta} \tag{1}$$

Here Y is output, L denotes labour, K indicates capital, and A represents technological innovation. E and S symbolize EI and SI, respectively. α, β, γ and δ are elasticities for their associated variables.

This study investigates the impact of infrastructural development on GDP growth in Bangladesh for the period 1973–2020. For this, the structural form of our previously discussed growth model needs to be generalized to

Table 2. Description of Data.

Variable name	Description	Sources
Economic growth(Y)	Gross Domestic Product (GDP) in current US$	(WDI, 2020)
Labour (L)	Number of persons engaged (in millions)	PWT
Capital (K)	Gross capital formation in current US$	WDI (2020)
Economic Infrastructure (E)	Economic infrastructure Index	Authors' estimation based on data from 6 variables collected from BBS
Social Infrastructure (S)	Social infrastructure Index	Authors' estimation based on data from 6 variables collected from BBS
Trade (To)	The exports and imports of goods and services are measured as a share of the gross domestic product.	WDI (2020)
Inflation (Ifl)	Measured by the annual growth rate of the GDP implicit deflator shows the rate of price change in the economy as a whole.	WDI (2020)

Note: WDI = World Development Indicators, BBS = Bangladesh Bureau of Statistics, PWT = Penn World Table (Feenstra et al., 2015).

construct a simple econometric model:

$$lnY_t = \phi + \alpha lnL_t + \beta lnK_t + \gamma E_t + \delta S_t + u_t \qquad (2)$$

Inflation is regarded as one of the key macroeconomic stability indicators. Both directions of it have a crucial effect on an economy. The modest level of it attracts more investment and results in higher economic growth. On the other hand, high inflation worsens the business environment and discourages international integration (Mohanty and Bhanumurthy, 2019). Furthermore, openness is a broadly recognized growth-enhancing factor. Cross-border integration creates many opportunities like productivity enhancement, the introduction of advanced technology, more employment prospects, and so on (Sahoo and Dash, 2012). So, with its inclusion in the growth model, how economic growth reacts to infrastructure development is a matter of concern.

Since indicators of both indices are standardized through the linear scaling technique and inflation has some negative values, data will be badly manipulated if they are transformed into the natural logarithm. Hence, the possibility of gaining significant estimated results will be lessened.

After including control variables,

$$lnY_t = \phi + \alpha lnL_t + \beta lnK_t + \gamma E_t + \delta S_t + \theta lnTo_t + \xi Ifl_t + u_t \qquad (3)$$

where To and Ifl symbolize trade openness and inflation. A description of the respective variables and their sources are provided in Table 2. All the data that have been used in this work are time series.

Construction of infrastructure indices

Infrastructure is a multidimensional concept encompassing various domains such as transportation, health facilities, education, water supply, sewerage systems, and more. Researchers defined infrastructures in different ways while exploring the infrastructure-growth nexus. For example, few studies considered the total length of the road as a variable to portray the whole concept of infrastructure. However, such an approach may lead to biased estimations by omitting other important infrastructural variables (Calderon, 2009). To overcome this problem, PCA can help to create an infrastructure index by taking major infrastructure variables. One of its key advantages is that it considers the multicollinearity among the variables (Sanchez-Robles, 1998). Underscoring its efficacy in this context, researchers including Calderón et al. (2014), Vidyarthi and Sharma (2014), Munir et al. (2018), and Mohanty et al. (2016) also utilized PCA for constructing the infrastructure index.

Taking recommendations from previous studies (Bakar and Mat, 2017; Awan and Anum, 2014; Dash and Sahoo, 2010; Jan et al., 2012; Chakamera and Alagidede, 2018) and based on availability, infrastructure indicators have been selected for this study. Data for all these indicators are collected from statistical yearbooks (BBS, various issues), which the Bangladesh Bureau of Statistics published in various years. The chosen infrastructure indicators are given in Figure 1.

In Figure 2, the sequential way of generating an index is represented graphically in a descending manner. The description of this process of generating indices is given in the supplementary file.

Auto-regressive distributive lag (ARDL)

Auto-Regressive Distributive Lag (ARDL) approaches were developed by Pesaran et al. (2001). This dynamic modelling system has several advantages over the cointegration procedures. Firstly, unlike other cointegration

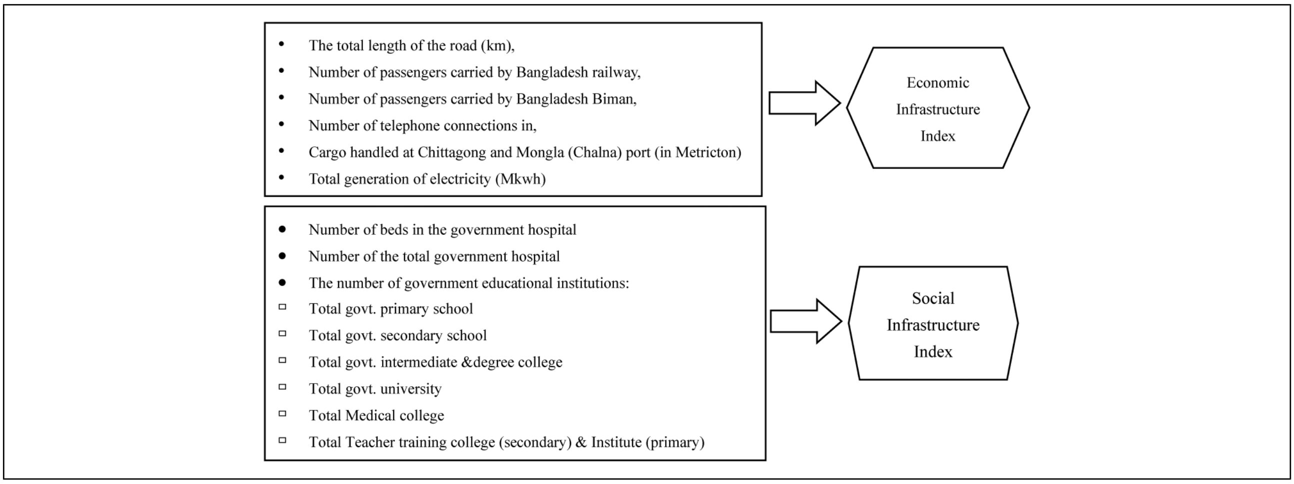

Figure 1. Construction of Economic infrastructure index and Social infrastructure index. Source: Authors' compilation.

tests, this can be used regardless of the integration order of the variables. It is flexible to the combinations, either they are pure I(0) or I(1) or a mixture of both I(0) and I(1).[1] Nevertheless, it gives a biased estimation in the case of I(2). Secondly, a small sample (30 to 80 observations) does not hinder its calculation. Thirdly, problems like omitted variables and autocorrelation are abolished, and endogeneity in regressors is corrected during this dynamic process. Fourthly, both long-run and short-run coefficients are estimated simultaneously. ARDL dynamic framework for equation (3) is as follows:

$$\begin{aligned}\Delta lnY &= \beta_0 + \sum_{i=1}^{p}\beta_{1i}\Delta lnY_{t-i} + \sum_{i=0}^{p}\beta_{2i}\Delta lnL_{t-i}\\ &\quad + \sum_{i=0}^{p}\beta_{3i}\Delta lnK_{t-i} + \sum_{i=0}^{p}\beta_{4i}\Delta E_{t-i}\\ &\quad + \sum_{i=0}^{p}\beta_{5i}\Delta S_{t-i} + \sum_{i=0}^{p}\beta_{6i}\Delta lnTo_{t-i}\\ &\quad + \sum_{i=0}^{p}\beta_{7i}\Delta Ifl_{t-i} + \gamma_1 lnY_{t-1} + \gamma_2 lnL_{t-1}\\ &\quad + \gamma_3 lnK_{t-1} + \gamma_4 E_{t-1} + \gamma_5 S_{t-1} + \gamma_6 lnTo_{t-1}\\ &\quad + \gamma_7 Ifl_{t-1} + \delta D_t + \mu_t \end{aligned} \tag{4}$$

where β_0 is an intercept, β_1 to β_7 indicate short-run coefficients, and γs' are long-run coefficients. $D_t$indicates dummy variables included in the model to foresee the impact of a structural break. $\mu_t$represents the error term that is required to be white noise.[2] Estimating long-run relations by using the ARDL approach requires two steps. In the first stair, cointegration must be confirmed by the value of F statistics after estimating equation (14) by Ordinary Least Square (OLS) procedure. The long-run and short-run coefficients are estimated in the final stair. Computation of F statistics value and comparing it against the critical values (Upper bound and Lower bound), provided by Pesaran et al. (2001), give the decision about cointegration.

The null and alternative hypotheses of the ARDL bound test are;

$$Null\, Hypothesis,\; H_0: \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = \gamma_5 = \gamma_6 = \gamma_7 = 0$$

$$Alternative\, hypothesis, H_1: \gamma_1 \neq \gamma_2 \neq \gamma_3 \neq \gamma_4 \neq \gamma_5 \neq \gamma_6 \neq \gamma_7 \neq 0$$

If the value of F statistics surpasses the critical value of the upper bound at the 5% level, the null hypothesis will be rejected. Hence, there is a long-run relationship among the study variables. On the contrary, the alternative hypothesis will be accepted if the F statistics value is beneath the lower bound critical value, resulting in no long-run relation. However, the inference of outcome will only be conclusive if the F statistics value falls between two bounds.

Nonlinear auto regressive distributive lag (NARDL)

Cointegration tests assume symmetricity to determine the long-run influence of regressors over the regressand. However, the effect of the explanatory variable could go in either direction, positive or negative. When the variable's positive and negative movements are considered during the relationship investigation, it is regarded as an asymmetric relationship (Qamruzzaman and Jianguo, 2018). For this purpose, Shin et al. (2014) proposed a new mechanism, named NARDL, which can inspect asymmetricity while examining the short-run and long-run relations. Researchers from diverse fields (Akber et al., 2020; Ahmad et al., 2018; Mujtaba and Jena, 2021; Neog and Yadava, 2020; Ha and Ngoc, 2020) have applied it and appraised its superiority.

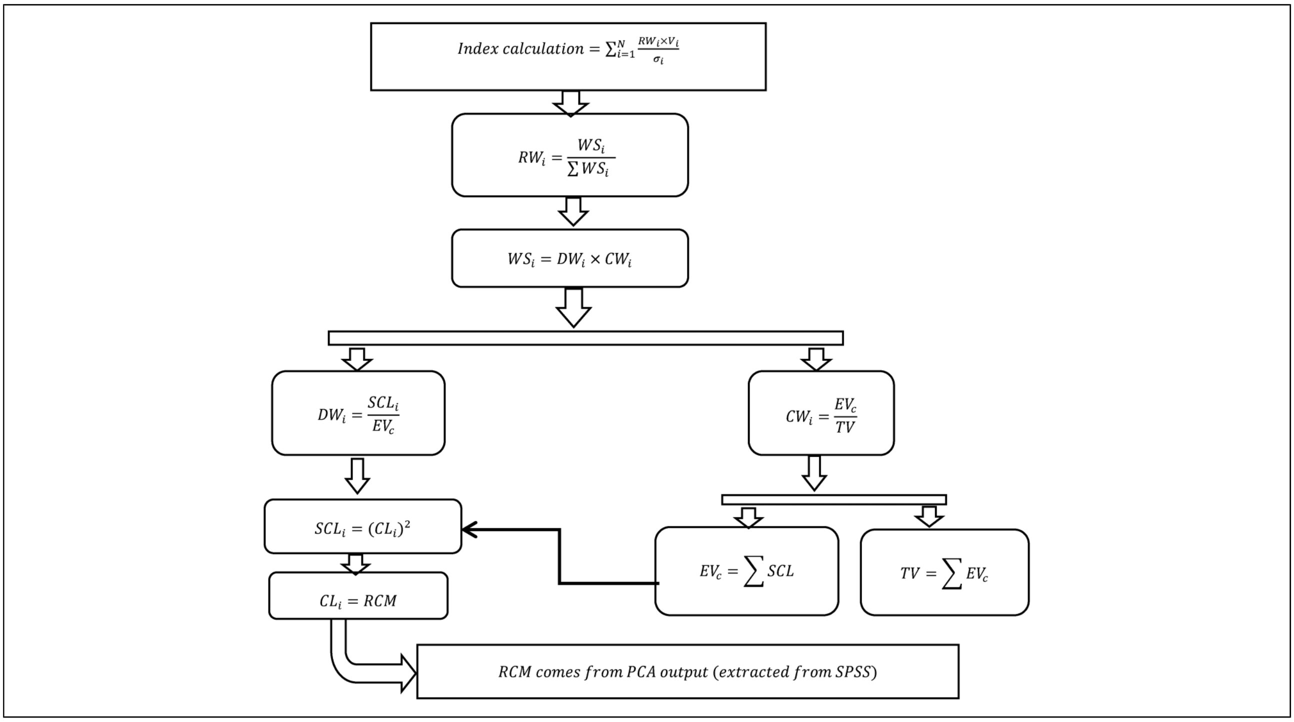

Figure 2. Dissection of Index generating process in a descending manner.

Note: RW_i = resulting weight for ith variable; V_i = ith variable; σ_i = standard deviation of ith variable; WS_i = weight score of ith variable; DW_i = domain weight for ith variable; CW_i = component weight ith variable; SCL_i = squared component loadings for ith variable; EV_c = explained variance for ith component; TV = total variance; CL_i = component loadings for ith variable; RCM = Rotated Component Matrix; PCA = Principle Component Analysis.
Source: Author's compilations based on Goel M and Garg (2018).

NARDL is nothing but an extended version of ARDL. The exception is there, and it takes account of the impact of both positive and negative movement of explanatory variables on the dependent variable in both the short-run and long-run.

To achieve this objective, equation (3) is reformed as follows:

$$lnY_t = \phi_0 + \phi_1 lnL_t + \phi_2 lnK_t + \phi_3 E_t^+ + \phi_4 E_t^- + \phi_5 S_t^+ + \phi_6 S_t^- + \phi_7 lnTo_t + \phi_8 Inf_t + u_t \tag{6}$$

here E_t^+ and E_t^- represent positive and negative components of the economic infrastructure index. While S_t^+ and S_t^- also designate the identical for social infrastructure index. Equations (7) and (8) explain how the economic infrastructure index and social infrastructure index are decomposed into their positive and negative shocks.

$$E_t = E_0 + E_t^+ + E_t^- \tag{7}$$

$$S_t = S_0 + S_t^+ + E_t^- \tag{8}$$

E_0 and S_0 are the initial values. These positive and negative components can now be defined as the partial sum process as follows:

$$E_t^+ = \sum_{j=1}^{t} \Delta E_j^+ = \sum_{j=1}^{t} max(\Delta E_j, 0) \tag{9}$$

$$E_t^- = \sum_{j=1}^{t} \Delta E_j^- = \sum_{j=1}^{t} min(\Delta E_j, 0) \tag{10}$$

$$S_t^+ = \sum_{j=1}^{t} \Delta S_j^+ = \sum_{j=1}^{t} max(\Delta S_j, 0) \tag{11}$$

$$S_t^- = \sum_{j=1}^{t} \Delta S_j^- = \sum_{j=1}^{t} min(\Delta S_j, 0) \tag{12}$$

Here the steps for assessing cointegration and long-run relations in NARDL are the same as the ARDL methods previously discussed. The requirements are also identical, such as no variable should be integrated at the second difference, I(2). A dynamic equation is adopted based on Shin et al. (2014) to move forward to the cointegration test and explore the asymmetric long-run relations.

NARDL representation of equation (16) is as:

$$\begin{aligned}\Delta lnY_t = \alpha_0 &+ \sum_{k=1}^{q}\alpha_{1i}\Delta lnY_{t-k} + \sum_{k=0}^{q}\alpha_{2i}\Delta lnL_{t-k} + \sum_{k=0}^{q}\alpha_{3i}\Delta lnK_{t-k}\\ &+ \sum_{k=0}^{q}\alpha_{4i}\Delta E^{+}_{t-k} + \sum_{k=0}^{q}\alpha_{5i}\Delta E^{-}_{t-k} + \sum_{k=0}^{q}\alpha_{6i}\Delta S^{+}_{t-k} + \sum_{k=0}^{q}\alpha_{7i}\Delta S^{-}_{t-k}\\ &+ \sum_{k=0}^{q}\alpha_{8i}\Delta lnTo_{t-k} + \sum_{k=0}^{q}\alpha_{9i}\Delta Ifl_{t-k} + \lambda_1 lnY_{t-1} + \lambda_2 lnL_{t-1}\\ &+ \lambda_3 lnK_{t-1} + \lambda_4 E^{+}_{t-1} + \lambda_5 E^{-}_{t-1} + \lambda_6 S^{+}_{t-1} + \lambda_7 S^{-}_{t-1} + \lambda_8 lnTo_{t-1}\\ &+ \lambda_9 Ifl_{t-1} + \delta D_t + \mu_t\end{aligned} \tag{13}$$

where α s' are short-run coefficients, λ s' are long-run coefficients, q s' are lag orders, and μ_t depicts the white noise error term. D_t stands for dummy variable to portray the structural break. OLS procedures would run this above-mentioned dynamic equation. Then a cointegration test will be operated by a bound test given by Pesaran et al. (2001) to calculate F statistics. F statistics value will be confronted with the critical values of lower and upper bounds given by Pesaran et al. (2001).

Null hypothesis, H_0: $\lambda_4 (+) = \lambda_5 (-) = \lambda_6 (+) = \lambda_7 (-) = 0$

Alternative hypothesis, H_1: $\lambda_4 (+) \neq \lambda_5 (-) \neq \lambda_6 (+) \neq \lambda_7 (-) \neq 0$

If the value of F statistics is greater than the upper bounds' critical value at the 5% level, the null hypothesis will be rejected. The null hypothesis stipulates that there is no cointegration.

Findings and discussion

Results of unit root tests

Prior to delving into time series analysis, it is imperative to assess the integration or stationarity level of the variables. Failure to account for non-stationarity can introduce bias into the estimation process. Hence, the Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979) is employed to scrutinize the stationarity levels of the study variables, as presented in Table 3. Among the variables, only K and E exhibit integration at the first difference, denoted as I(1). This implies that these variables are non-stationary at the level but achieve stationarity after the first difference is applied to their observations. Conversely, the remaining variables do not exhibit a unit root problem in their raw values and are integrated at their level, denoted as I(0). Therefore, a mixed level of integration exists among the variables and a pattern corroborated by the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) unit root tests (Kwiatkowski et al., 1992), whose values are detailed in the supplementary file.

To further assess the unit root problem and articulate variables with distinct stationarity levels, the Zivot–Andrews unit-root test (Zivot and Andrews, 1992) is conducted, as detailed in Table 4. This test not only determines the stationarity level but also identifies breakpoints associated with it. Notably, each variable is associated with its stationarity level and corresponding breakpoints. Variables Y, L, K, To, Ifl, E, and S are linked to breakpoints in the years 2008, 2010, 2010, 2008, 1993, 2008, and 2008, respectively. The inclusion of the 2008 breakpoint in cointegration is pivotal as both economic and social infrastructure

Table 3. Augmented Dickey-Fuller (ADF) Tests.

	Level		At first difference		
Variables	Intercept	Trend and intercept	Intercept	Trend and intercept	Level of Integration
ln Y	2.5551	−3.1886*	−7.0210***	−7.0480***	I(0)
ln L	−1.9039	−1.1944	−4.5553***	−4.9107***	I(0)
ln K	0.1781	−1.18547	−5.5207***	−5.9432***	I(1)
ln To	−1.3631	−4.3105***	−2.9135*	−2.5859	I(0)
Ifl	−5.7351***	−5.9883***	−3.9530***	−4.2535***	I(0)
E	3.8904	2.6127	1.5913	−5.1391***	I(1)
S	0.1764	−3.8664**	−6.3520***	−6.3542***	I(0)

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

Table 4. Zivot–Andrews Unit-Root Test.

Variable	Level		At first difference		Level of integration
	t-statistics	Break year	*t*-statistics	Break year	
ln Y	−5.2064***	2008	−6.2033***	2003	I(0)
ln L	−3.7356	1997	−4.9955***	2010	I(1)
ln K	−4.6712**	2010	−5.1602***	1987	I(0)
ln To	−3.6677	1987	−8.1515**	2008	I(1)
Ifl	−3.3481***	1993	−10.2060	2009	I(0)
E	−1.2278	2008	−6.6430***	2008	I(1)
S	−4.3829***	2011	−6.8810***	2008	I(0)

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

variables exhibit stationarity. Given that the primary objective is to comprehend their impact on economic growth, the year 2008, coinciding with Bangladesh's infrastructure development upturn after the 2008 election, serves as a pertinent turning point. This aligns with the broader context of socioeconomic progress intertwined with infrastructure advancements during the last decade.

Table 5. Bound Test Result for ARDL.

F-statistics: 5.975041 K: 6	Sig.	I(0)	I(1)
	10%	2.12	3.23
	5%	2.45	3.61
	1%	3.15	4.43

Source: Author's estimations.

Results of the ARDL test and discussion

The ARDL bound test has been systematically employed to discern potential cointegration among the variables, essentially exploring the existence of a long-run relationship. As delineated in Table 5, the F-statistics value stands at 5.975041, surpassing the upper bound values at both the 5% and 1% significance levels. Consequently, the null hypothesis positing no cointegration is firmly rejected. This unequivocally signifies the presence of a long-run relationship between the regressand and the regressors.

Turning to the long-run relationship, both labour and capital significantly impact economic growth (Table 6). The impact of labour is almost five times higher than capital, with values of 1.45 and 0.30, respectively. This aligns with the case of the developing country's theory. labour-intensive economy like Bangladesh emphasizes the pivotal role of the labour force in driving economic growth. It is also supported by Sarker et al. (2019) and Hye and Islam (2012).

While EI demonstrates a substantial connection with economic growth, the contribution of SI appears limited in the long run. Specifically, a one-unit increase in the EI corresponds to a 0.15% or 15-unit increase in economic growth, given the semi-log relationship in the regression equation. This finding is consistent with the research by Jan et al. (2012) and Kumari and Sharma (2017a). EI development is acknowledged to enhance a nation's production processes, contributing to a conducive business environment that attracts international engagement and foreign investment, thereby fostering capital inclusion in the economy (Awan and Anum, 2014; Youssaf and Erum, 2018).

Table 6. Long-run Estimations of ARDL.

Dependent variable: *ln* Y

Variable	Coefficient	Std. error	*t*-statistics
ln L	1.454248***	0.346638	4.195289
ln K	0.301960***	0.096747	3.121117
E	0.152836***	0.054465	2.806115
S	−0.004412	0.057364	−0.076911
ln To	−0.241340**	0.103513	−2.331491
Ifl	0.003403	0.002411	1.41131

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

In contrast, SI exhibits no significant relationship with economic growth over the long term. This outcome contradicts the findings of Kularatne (2006) and Kumari and Sharma (2017a). Typically, SI exerts a lesser direct impact on gross domestic product but plays a crucial role by channelling indirect impacts through the development of skilled and healthier human capital. This human capital, in turn, fosters the generation of new ideas, innovation, and enhanced efficiency in the economy (Tsaurai and Ndou, 2019).

Among the control variables, trade openness emerges as a detrimental factor for growth. A 1% increase in trade openness results in a 0.24% contraction in economic growth. This finding aligns with the perspectives of

Table 7. Short-run Estimations of ARDL.

ARDL (2, 2, 1, 0, 1, 0, 1) based on Akaike information criterion
Dependent variable: $\Delta ln\, Y$

Variable	Coefficient	Std. error	*t*-statistics
ect_{-1}	−0.444093***	0.62506	−7.104843
$\Delta ln\, L$	0.179630	0.632742	0.283892
$\Delta ln\, K$	0.534132***	0.067500	7.764866
ΔE	0.067873***	0.024873	2.728749
ΔS	−0.037381**	0.016720	−2.235777
$\Delta ln\, To$	0.107177***	0.038892	−2.744762
ΔIfl	0.004967***	0.000537	9.241262
$dummy_{2008}$	0.099479***	0.28163	3.532267
Constant	−3.223539***	0.452642	−7.121605
R-squared	0.999391	F-statistic	3400.035
Adjusted *R*-squared	0.999097	Probability (F-stat)	0.000000
Durbin–Watson Stat	2.182517		

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

Table 8. Bound Test Result for NARDL.

F-statistics: 69.53945 K : 8	Sig.	I(0)	I(1)
	10%	1.95	3.06
	5%	2.22	3.39
	1%	2.79	4.1

Source: Author's estimations.

Table 9. Long-run Estimations of NARDL.

Dependent variable: $ln\, Y$

Variable	Coefficient	Std. error	*t*-statistics
$ln\, L$	0.486703**	0.187618	2.594110
$ln\, K$	0.427549***	0.067308	6.352091
E^{+}	0.158867***	0.034159	4.650783
E^{-}	−0.166260**	0.067950	−2.446781
S^{+}	0.043532	0.040722	1.069016
S^{-}	0.037944	0.054792	0.692507
$ln\, To$	−0.142250***	0.048550	−2.929970
Ifl	0.006641***	0.001178	5.638077

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

Shimul et al. (2009), Rahman et al. (2020), and Adhikary (2010), the latter attributing the effect to a large volume of imports compared to exports and a high depreciation rate. Despite recent initiatives aimed at export diversification, the negative balance in the trade balance persists. Conversely, inflation exhibits no significant impact on economic growth, a result congruent with the findings of Ahmed (2010).

A distinctive feature of ARDL is its simultaneous consideration of both short-run and long-run dynamics. The short-run relationships between independent and dependent variables are represented in Table 7. Notably, EI significantly impacts economic output in the short run, with a 1-unit increase resulting in a positive 0.07% response in economic growth. This can be attributed to the multiplier effect during the initial establishment period of EI.

Conversely, a 1-unit increase in SI yields a negative 0.03% impact on economic growth in the short run. This suggests that inferior quality SI may contribute to an inadequate labour market and an unfit workforce, placing a burden on the economy. The inclusion of the dummy variable proves significant, indicating a substantial turnover in the break year. The negative and statistically significant coefficient of the error correction term reveals that short-run shocks will be adjusted to the long-run equilibrium at a speed of 44%.

Results of the NARDL test and discussion

The cointegration test for Nonlinear Autoregressive Distributed Lag (NARDL) is also conducted through bound test procedures just like ARDL. As indicated in Table 8, the F-statistics value serves as an indicator that a long-run relationship is present. The null hypothesis is rejected as the value of F statistics exceeds the upper bound values at the 5% level.

In this analysis, the influence of both EI and SI indices is disaggregated into their positive and negative components. A one-unit increase (decrease) in EI corresponds to a notable rise (reduction) of 0.16 (0.17) in economic growth, and this effect proves statistically significant in the long run, as elucidated in Table 9. The significance of this impact is underscored by the notion that an expanded EI opens doors to a myriad of economic possibilities and opportunities. Conversely, a deceleration in the growth of EI hampers the overall prospects for development.

In contrast, SI repeats its lack of significance for both positive and negative components in this context.

All other variables maintain consistent relationships, as with the previous analysis. However, inflation exhibits significance, with a surprising outcome: a 1% increase in inflation leads to a 0.007% rise in economic growth. This unexpected result aligns with similar findings by Majumder'Majumder (2016). For developing countries aspiring to achieve higher growth rates, maintaining a stable inflation rate, rather than an excessively low one, is crucial during their initial high-growth phase (Mallik and Chowdhury, 2001). It is essential to recognize the existence of a threshold in this relationship; if inflation surpasses this limit, it can yield undesirable consequences (Sumon and Miyan, 2017).

The error correction mechanism's value is both negative and significant (see Table 10) indicating that short-run shocks will be corrected to long-run paths at a speed of 75%. Concurrently, the short-run positive and negative components mirror the signs of their long-run counterparts. Economic growth experiences an increase (decrease) of 0.12% (0.13%) with a unit increase (decrease) in EI. While the positive component of SI lacks significance, its negative component exerts a detrimental impact on growth. A unit reduction in SI results in a 0.7% decline in growth in the short run, emphasizing the indispensable role of human development in a nation's prosperity. Human capital serves as the engine of the economy, and any compromise in its quality can induce sluggishness across all sectors.

Table 10. Short-run Estimations of NARDL.

ARDL (2, 2, 1, 0, 0, 1, 1, 0, 0) based on Akaike information criterion
Dependent variable: $\Delta ln\, Y$

Variable	Coefficient	Std. error	t-statistics
ect_{t-1}	−0.756676***	0.026566	−28.48322
ΔlnY_{t-1}	0.125451***	0.022303	5.624914
$\Delta ln\, L$	−0.744259	0.596731	−1.247226
$\Delta ln\, K$	0.570926***	0.060150	9.491649
ΔE^{+}	0.120210***	0.028206	4.261898
ΔE^{-}	−0.125805**	0.050466	−2.492868
ΔS^{+}	0.009446	0.030217	0.31608
ΔS^{-}	−0.070223***	0.021099	−3.328246
$\Delta ln\, To$	−0.107637***	0.034458	−3.123690
ΔIfl	0.005025***	0.000543	9.253997
$dummy_{2008}$	0.142374***	0.008546	16.66034
Constant	4.733980***	0.167732	28.22346
R-squared	0.999580	F-statistic	4014.714
Adjusted R-squared	0.999331	Probability (F-stat)	0.000000
Durbin–Watson Stat	2.027642		

***, ** and * indicates significant at 1%, 5% and 10% respectively.
Source: Author's estimations.

The dynamic multiplier graphs for NARDL, as illustrated in Figure 3, investigate the adjustment of asymmetry in the long run stemming from positive and negative shocks in EI and SI. The asymmetry, represented by the green-colored line, highlights the disparity between the effects of positive and negative shocks. Notably, in the case of EI, the negative shock exerts a more substantial impact than the positive shock. Conversely, for SI, the positive shock prevails over the negative one. Furthermore, the asymmetry plots for both infrastructures consistently fall within the 5% critical red lines, affirming their asymmetric relationships with economic growth.

Results of diagnostic tests

Diagnostic tests, including the Jarque-Bera, Breusch-Godfrey Lagrange Multiplier (LM), Breusch-Pagan-Godfrey, and Ramsey Reset tests, have been applied to both the ARDL and NARDL models. As depicted in Table 11, all probability values exceed 5%, leading to the rejection of all null hypotheses. This implies that the residuals in both models exhibit normal distribution, lack correlation, and demonstrate homoscedasticity. Consequently, both models are deemed free from misspecification problems.

The CUSUM test and CUSUM square test have been applied to assess the stability of the coefficients in the regression model. To determine stability, the blue line must fall between the two red critical lines. As observed in Figures 4 and 5, all the blue lines are positioned within the 5% critical lines. Consequently, the stability of coefficients in both the ARDL and NARDL models is affirmed.

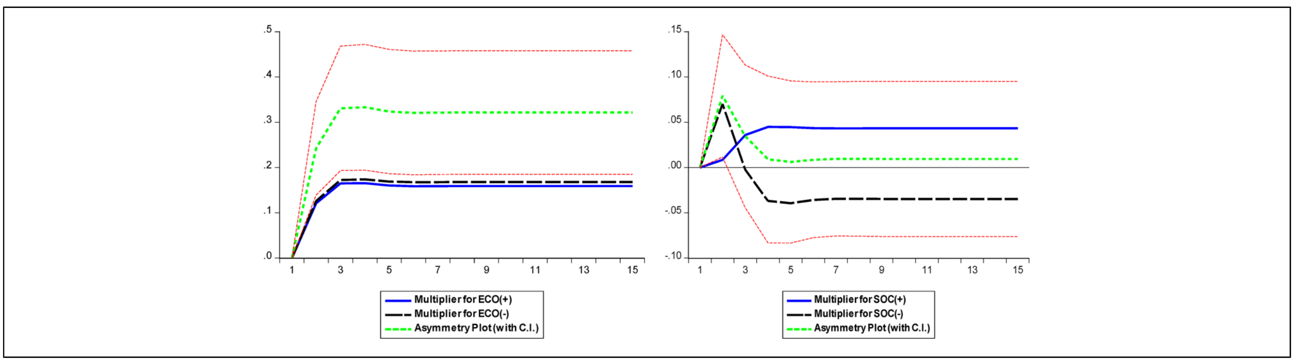

Figure 3. NARDL dynamic multiplier graph. Source: Author's estimations.

Table 11. Diagnostic Tests for ARDL and NARDL.

ARDL	Normality Test: Jarque-Bera	
	J-B value: 0.236087	Probability: 0.888658
	Serial correlation test: Breush-Godfrey Lagrange Multiplier (LM) test	
	F-statistic: 0.226682	Prob. F(2, 27): 0.7987
	Obs * *R*-squared: 0.726614	Prob. Chi-square (2): 0.6954
	Heteroskedasticity test: Breush-Pegan-Godfrey	
	F-statistic: 1.468158	Prob. F(14, 29): 0.1856
	Obs * *R*-squared: 18.25042	Prob. Chi-square (14): 0.1956
	Specification error test: Ramsey Reset test	
	F-statistic: 0.611700	Prob. F (1, 28): 0.4407
NARDL	Normality Test: Jarque-Bera	
	J-B value: 0.244958	Probability: 0.884725
	Serial correlation test: Breush-Godfrey LM test	
	F-statistic: 0.045553	Prob. F(2, 25): 0.9555
	Obs * *R*-squared: 0.159766	Prob. Chi-square (2): 0.9232
	Heteroskedasticity test: Breush-Pegan-Godfrey	
	F-statistic: 1.572402	Prob. F(16, 27): 0.1455
	Obs * *R*-squared: 21.22324	Prob. Chi-square (16): 0.1701
	Specification error test: Ramsey Reset test	
	F-statistic: 0.063875	Prob. F (1, 26): 0.8025

Source: Author's estimations.

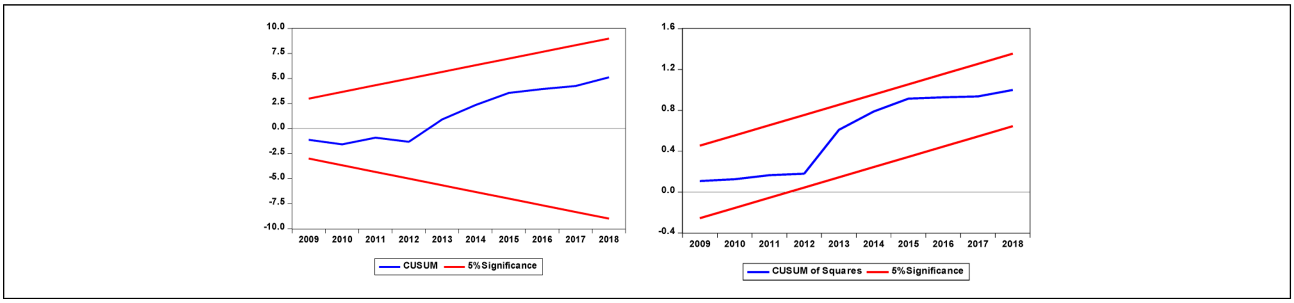

Figure 4. ARDL CUSUM and CUSUM square graphs. Source: Author's estimations.

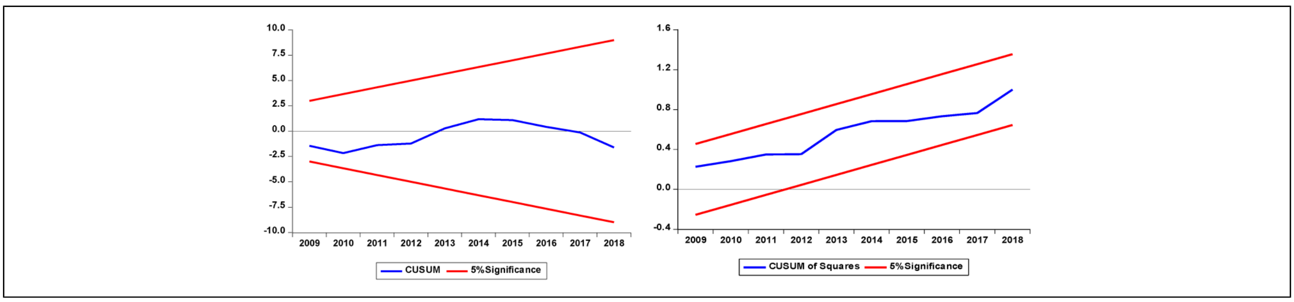

Figure 5. NARDL CUSUM and CUSUSM square graphs. Source: Author's estimations.

Concluding remarks

This study explores the intricate relationship between infrastructure development and economic growth over the period from 1973 to 2020 for Bangladesh. Infrastructure is conceptualized in terms of two components, EI and SI, giving rise to two composite indices that compress the various indicators associated with these critical elements. Employing the ARDL bound test to scrutinize long-run relations reveals a noteworthy finding: economic growth experiences a surge of 0.15% with a unit increase in the EI index. Conversely, the SI index exhibits no significant relationship with output growth. Delving into the asymmetry of long-run impacts by dissecting regressors into positive and negative shocks, both components of the EI index demonstrate a noteworthy association with growth. Specifically, a unit increase (decrease) in EI corresponds to a rise (fall) in economic growth by 0.16% (0.17%). However, the contribution of SI to growth is deemed insignificant for both positive and negative shocks. Despite the short-run results mirroring the long-run dynamics, the negative component of SI exerts a detrimental impact on economic output in the short term.

These findings underscore the pivotal role of recent developments in EI in fostering economic prosperity in Bangladesh. Consequently, the progression and enhancement of EI should be unhindered to sustain economic growth. Prioritizing SI is imperative to cultivate a more productive and efficient human capital system that can significantly contribute to overall economic development. In essence, this study reinforces the conclusion that if infrastructure cannot serve as the engine of an economy, it should be regarded as the oil that lubricates economy's intricate machinery.

Based on the comprehensive analysis presented in this study, several recommendations can be proposed to optimize the impact of infrastructure development on economic growth in Bangladesh. Firstly, a meticulous and visionary planning approach from policy makers is essential before commencing infrastructure projects. The feasibility of these development projects relies on maintaining equilibrium between supply and demand. Hence, foreseeing future demands and incorporating them into infrastructure planning is imperative to prevent future projects from becoming burdensome. Secondly, to broaden the scope of infrastructural development and enhance the nation's GDP, there should be a strategic shift from focusing exclusively on urban sides to channeling efforts into rural areas, where a significant portion of the population resides. This inclusive approach ensures a broader and sustainable economic impact. Thirdly, the issue of corruption in the construction sector demands immediate attention. Ensuring transparency, accountability, and ethical practices at all stages of infrastructure development, from planning to execution, is crucial. This would prevent the misuse of funds, substandard construction practices, and the resulting short lifespan of infrastructure. Lastly, the major recommendation emerging from this study emphasizes the need for governmental authorities and policymakers to transition their focus from traditional infrastructures to transformative infrastructures. Transformative infrastructures, distinguished by their longevity and value creation, provide a flexible design to address future needs, promote resource efficiency, facilitate technological upgradation, and enhance adaptability during crises. Importantly, the adoption of transformative infrastructures contributes to environmental sustainability, characterized by lower pollution, reduced carbon emissions, and efficient energy utilization.

Considering Bangladesh's goal to establish itself as a middle-income country by 2031, integrating the concept of transformative infrastructures into relevant frameworks becomes paramount. Key strategic plans such as the National Adaptation Plan, Delta Plan, Perspective Plan of Bangladesh 2021–2041, and Five-Year Plan should incorporate these transformative principles. This integration is essential not only for fostering sustainable economic growth but also for ensuring social equality and the overall well-being of the population.

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Availability of data

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Supplemental material

Supplemental material for this article is available online.

Notes

1. I(0) and I(1) refer to integrated at the level and integrated at the first difference, respectively.
2. An error term will be called white noise when its mean and covariance are zero and variance are constant (Gujarati et al., 2012).

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