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Abstract

The purpose of this study is to examine the nexus between infrastructure and economic growth in India over the period 1991 – 2016. More specifically, this study tries to find out whether infrastructure development in the post-reform period is cointegrated with economic growth. For the said purpose, a composite infrastructure index is constructed using Principal Component Analysis (PCA) based on eight infrastructural indicator variables in the areas of physical, and social. and financial infrastructure. The methodological approaches used to analyze the nexus between infrastructure index and economic growth mainly consist of time series estimation techniques. The cointegrating nature between the infrastructure index and economic growth is checked using the Engle and Granger method of cointegration. The study further applies VAR based Granger causality test to assess the direction of causality between infrastructure and economic growth. The results reveal that infrastructure and economic growth are cointegrated and hold a long-run equilibrium relationship. However, in the short run, the results of the study find no instantaneous effect of change in infrastructure on economic growth. Finally, the results of the Granger causality test confirm the unidirectional causality from infrastructure to economic growth. Therefore, the study concludes that infrastructural development can be an effective tool for achieving sustainable economic growth.

Key words: Infrastructure, economic growth, PCA, Engle and Granger cointegration, VAR, Granger causality, sustainable economic growth.

JEL Classification Number: C22, O18

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1. Introduction

India is a rapidly developing Asian economy next to China in the first decade of the 21st century (Sahoo and Dash, 2009). However, according to the World Bank, India's growth rate is set to surpass China in 2015. Truly, India emerges as the fastest growing economy in the World[1]. Economic researchers and business analytics search for logical reasons for it. It might be the outcome of several factors, particularly, initiation and adoption of infrastructural policy regarding massive investment in the golden quadrilateral mega highway project[2] in India since early of the 21st century. This shifting of public investment policy was an attempt to overcome infrastructure bottlenecks in India. In this context, the relevant question arises whether structural change in infrastructural development might shift economic growth in India recently. This paper attempts to investigate it and examines the long-run relationship between them.

Generally, the economic performance of a country depends on its available infrastructure facilities. An emerging economy like India definitely needs certain well-established infrastructure to maintain high economic growth. Infrastructure is a crucial factor for self-sustained growth (Rostow1960; Aschauer, 1989; Munnell, 1993; Canning, 1999). It provides access to productive resources and increases the scale of economic activities which may reduce the cost of production and/or transaction through creating some externalities that leads to developing several economic opportunities.

Infrastructure is just like another input in the production function and determines total factor productivity (TFP). In a Romer-style framework, infrastructure raises output growth. Truly,

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[1] See the article "India's growth rate set to surpass China this year: World Bank" in *The Economic Times* (2015, June 11); and also see remarks of Kausik Basu, the Chief Economist of the World Bank (see Dinda 2016).

[2] The Golden Quadrilateral Highway project was launched in India in 1999 by AtalBihari Vajpayee, Prime Minister of India and it gains momentum and visible since 2002-2003.

infrastructure is an ‘unpaid factor’ with spillover effects on the productivity of other inputs[3] (Hulten and Schwab 2000). Several economic theories[4] highlight the contribution of infrastructure on economic growth and development. Some economic theories[5] justify the role of infrastructure in the economic progress of a country. The availability of infrastructural facilities is the essential preconditions for economic development (Hirschman 1958; Barro 1990; Barro and Sala-I-Martin 1992, 1995), while Wagner (1958) opposes the view of Hirschman (1958) and argues that infrastructural demand follows only development. This debate still continues. Since, the early 1990s, economists and policymakers mainly focus on the relationship between infrastructure and economic growth.

Several studies (Dadibhavi, 1991; Gramlich, 1994; Ghosh and De, 1998, & 2005; Lall, 1999; Zhang and Fan, 2004; Calderon and Serven, 2004; Dasgupta and Koji, 2006; Ghosh, 2011; Kumari and Sharma, 2017, etc.) have shown certain evidence of the contribution of infrastructure in economic growth across the world. The World Development Report (1994) shows that a 1% increase in the stock of infrastructure is associated with 1% increase in GDP across all countries. Aschauer (1989) finds out that the output elasticity of core infrastructure with respect to GDP is 0.24 in the US economy. Economic theorists (Hirschman, 1958; Rostow, 1960; Barro, 1990; Romer, 1990; Aschauer, 1990, etc.), on the other hand, believe that like other factors (i.e., innovation, specialization, agglomeration, new knowledge, etc.) investment in infrastructure (or public capital) might be a determinant of economic growth in the long run. Concerned with the problem of infrastructural constraints in developing economies like India, researchers and

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[3] For example, Bougheas et al. (2000) and Agenor (2013) argue that transport and telecommunications services facilitate innovation and technological upgrading by reducing the fixed cost of producing new varieties of intermediate inputs.

[4] See Nurkse (1953), Hirschman (1958), Rostow (1960), Hansen (1965), Arrow and Kurz (1970), Romer (1986, 1990), Lucus (1988) and Barro (1990), Futagami et al. (1993)

[5] See, Hirschman (1958) and Wagner (1958), etc

policymakers examine the nature of the relationship between infrastructure and level of income or (economic activity).

The initial empirical work on the macroeconomic impact of infrastructural investment was started in the early 1990s when Aschauer (1989) attributed the productivity slowdown in the US economy to the lack of investment in public capital. Since then, the importance of infrastructure (or public capital), its role in economic progress, and its provisioning had been subjected to empirical testing along with a number of routes. Munnell (1990), Gramlich (1990), Groote et al. (1999), etc. have presented the evidence in line with Aschauer's work and agreed that public capital investment plays an important role in determining the productivity and growth of an economy. However, Duffy-Deno et al. (1991), Shah (1992), Prudhomme (1993), Baffes and Shah (1993), etc. balanced the scale with the findings of the non-significant role of infrastructural investment in economic development. Thus, the role of infrastructure in economic growth is no longer a settled issue rather debatable.

Researchers have identified various reasons behind this debate such as the use of infrastructure's investment as an explanatory variable instead of stock of infrastructure, lack of appropriate econometric techniques i.e., issues like stationary nature of the data (or the common trends of the variables), reverse causality (or the feedback effect), etc were ignored in many of these studies (Bajar and Rajeev, 2016). Considering these perspectives in mind, an effort is made to add a contribution to the literature by examining the linkages between infrastructure and economic growth, and especially in the context of India the mega infrastructural policy impact on economic growth.

Growth and productivity in all spheres of economic activities are essential to fulfil the basic needs of the citizens of a nation to pursue a higher level of welfare. In a country like India where high-income inequality, poor health, low quality of life, and low environmental standard are big threats to its self-sustained growth path, infrastructural development may act as a catalyst for augmenting the pace of economic development of the country. Several studies in India (Dadibhavi, 1991; Ghosh and De, 1998; Lall, 1999; Zhang and Fan, 2004; Majumder, 2005; Sahoo and Dash 2009, Dash and Sahoo 2010; Ghosh, 2011; Koner et al. 2012; Mishra, 2013; Bajar and Rajeev, 2016; Kumari and Sharma, 2017, etc.) observe a strong association between infrastructure and economic growth at both national as well as the regional level and conclude the important role of infrastructure in shaping the developmental profile. Most of these studies have taken into account either physical measures of infrastructure (Ghosh and De, 1998 Zhang and Fan, 2004; Ghosh, 2011) or that of social (Dadibhavi, 1991) or both (Lall, 1999; Majumder, 2005; Dash and Sahoo 2010; Kumari and Sharma, 2017) for estimating the relationship between infrastructure and economic growth in India. However, an aggregate measure of infrastructure is essential to estimate the growth achievements of a country in terms of its infrastructural availability and to ensure the feasibility of inter-regional comparisons in terms of stock of infrastructure (i.e. physical, social, and financial).

In this context, the present study develops a composite index of infrastructure with the number of performance indicators proposed by research scholars, economists, and policymakers in the different discourse of policy debates. This index incorporates all the dimensions of infrastructure. The present study employs a weighting scheme using principal component analysis (PCA) in constructing the index. Then the study applies Engle-Granger two steps procedures to quantify the nexus between infrastructure and economic growth in India from 1991 to 2016. However, to test the hypothesis i.e. whether provisioning of infrastructure stimulates economic growth or economic growth acts as a stimulus for any consequent growth in the stock of infrastructure or both, the study applies VAR based Granger causality approach. Such dependency between infrastructure and economic growth would be vital for designing and implementing an effective infrastructure policy in a country like India.

The rest of the paper is organized as follows: Section two describes the motivation for using cointegration analysis on growth – infrastructure nexus and the issue of causality in the context of infrastructure development from an economic theoretic standpoint. Section three outlines the sources of data used in this study. Section four specifies the methodology for the study. Section five discusses empirical findings and analyses the results. Finally, Section six draws some concluding observations.

2. Motivation

This section attempts to identify the equilibrium relationship between income and infrastructure from an economic standpoint and justifies the use of co-integration analysis and the nature of causal relation between them. Let us construct a simple theoretical argument for it. Following Holtz-Eakin and Schwartz (1994), consider a one-good economy. Let the production function be

$$Y = F(K, G, L) = AK^{\alpha}G^{\beta}L^{1-\alpha-\beta} 0 \leq \alpha, \beta \leq 1 \tag{1}$$

Where Y is output, K is capital, G is infrastructure (or public capital), L is number of effective labour, and A is technology[6]. Dividing both sides of eq. (1) by number of effective labour L, we get the intensive form of production and it can be expressed as per capita form of output, capital, and infrastructure. Hence, the intensive production function is:$y = Ak^{\alpha}g^{\beta}$.

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[6] Over time, technology, *A*, and labour, *L*, are assumed to grow at constant rates, (say) λ and *n*, respectively.

Consider θ fraction of output is used for infrastructure formation[7], its depreciation rate is δ_g *(>0)*, and infrastructure accumulation evolves as

$$\dot{G} = \theta Y - \delta_g G \tag{2a}$$

Let us consider *L=1* for simplicity. Dynamics of infrastructure accumulation is

$$\dot{G} = \theta A K^{\alpha} G^{\beta} - \delta_g G \tag{2b}$$

Capital accumulation is

$$\dot{K} = Y - C - \delta_k K \tag{3a}$$

or

$$\dot{K} = A K^{\alpha} G^{\beta} - C - \delta_k K \tag{3b}$$

The infinite time horizon inter-temporal consumption choice problem for this economy may be specified as

Maximize Welfare, *W*, for given capital and infrastructure. In brief, the optimization problem is

$$\max_{c} W = \int_0^{\infty} U(C_t) e^{-\rho t} dt \tag{4}$$

Subject to constraints

$$\dot{K} = A K^{\alpha} G^{\beta} - C - \delta_k K \tag{5}$$

and

$$\dot{G} = \theta A K^{\alpha} G^{\beta} - \delta_g G \tag{6}$$

Where $\rho(>0)$ is the rate of time preference. Clearly first (eq. 5) and second (eq. 6) constraints relate to capital and infrastructure accumulation, respectively. Solving the above optimization problem, we get economic growth which is associated with infrastructure and find income path measured in terms of C.

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[7] See, Holtz-Eakin and Schwartz (1994)

Let us search for long-run equilibrium relationship between income, *C*, and infrastructure, *G*, underlying the optimization problem. To do so, consider the steady-state solution[8], where $\dot{G} = \dot{\tau} = 0$, i.e., a situation where infrastructure stock reaches a stable level. Now,

$$\dot{G} = 0, => \ \theta A K^{\alpha} G^{\beta} - \delta_g G = 0$$

$$f_1 (K, G) = 0, \tag{7}$$

for given parameters; and

$$\dot{K} = \dot{\varphi} = \gamma, \text{ (say)}$$

Where τ and φ are the shadow prices of infrastructure and capital, respectively.

$$\dot{K} = \gamma, \qquad => \ A K^{\alpha} G^{\beta} - C - \delta_k K - \gamma = 0$$

$$f_2 (C, K, G) = 0, \tag{8}$$

for given parameters.

Combining eq (7) and eq (8) we get equilibrium relationship between *C* and *G*, say,

$$f_3(C, G) = 0, \tag{9}$$

or equivalently,

$$C = f(G) \tag{10}$$

which may be recognized as long-run relationship between income (*C*) and infrastructure (*G*).

From the above said theoretical construct is used to rationalize co-integration analysis in this paper. Let (C_t, G_t) denote the time series of observed income and infrastructure variables, which has two components – optimum value and a random component. Consider $C_t = C_t^* + \varepsilon_t$ and, $G_t = G_t^* + v_t$, where (C_t^*, G_t^*) are optimum values and (ε_t, v_t) are random disturbances. The observed data set is consistent with optimization, however, differs from corresponding optimum values only by

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[8] See Coondoo and Dinda (2002).

stationary random disturbances. So, as being consistent with optimization, C_t and G_t might be co-integrated and they certainly obey eq. (10) with possible stationary deviations. Co-integration shows the long-run equilibrium relationship between income and infrastructure. Stationary deviations provide short-run variations or Granger causality which might be examined with the help of the error correction model (ECM) as a part of the co-integration analysis.

When C_t, and G_t time series are non-stationary and integration of order of one[9] [i.e., *I(1)*], and the variables are cointegrated, so, they admit the *Granger representation*[10] and in this context, the *ECM* can be expressed as

$$\Delta C_t = \sum_{i=1}^{m} \beta_{C_i} \Delta C_{t-i} + \sum_{i=1}^{m} \pi_{C_i} \Delta G_{t-i} + \eta_C \big(C_{t-1} - f(G_{t-1})\big) + \varepsilon_{Ct} \tag{11}$$

Or, equivalently as

$$\Delta G_t = \sum_{i=1}^{m} \beta_{G_i} \Delta C_{t-i} + \sum_{i=1}^{m} \pi_{G_i} \Delta G_{t-i} + \eta_G \big(C_{t-1} - f(G_{t-1})\big) + \varepsilon_{Gt} \tag{12}$$

Where ε_{Ct} and ε_{Gt} are pure white noise random disturbances, β_C, β_G, π_C, π_G, ηC *and* ηG are parameters, and $\big(C_{t-1} - f(G_{t-1})\big)$ is known as error correction term and is a measure of observed value at time t-1 deviate from long-run equilibrium relationship. It indicates that as variables are cointegrated, any deviation at *t-1* tends to change in the values of variables in the next point of time *t* in an attempt to force variables back to the long-run equilibrium. The coefficients η_C and η_G of the error correction term in eq (11) and eq (12) are called adjusted parameters and are expected to be negative. Statistically significant parameters π_{C_i} in eq (11) and β_{G_i} in eq (12) determine the nature of causality between *C* and *G*. In case of the absence of Granger causality, cointegrated variables need an additional condition that the speed of adjustment coefficients be statistically insignificant or equal to zero. Other results are incorporated in a similar manner.

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[9] Correspondingly their first difference is stationary.

[10] See Hamilton (1994).

3. Data

In order to examine the relationship between infrastructure and economic growth, we have used annual time series data[11] of India from 1991 to 2016. We have used per capita GDP and infrastructure index[12] for the present analysis. per-capita GDP (at 2010 constant US dollar) is obtained from the 'World Development Indicators' of the World Bank and corresponding infrastructure variables are taken from the CMIE database of India. Variables that have taken for constructing the composite index of infrastructure are road density (Road length per 1,000 sq km area), rail density (Railway length per 1,000 sq km area), air density (Domestic aircraft flown per 1,000 sq km), tele density (Fixed telephone users per 100 population), installed plant capacity (per 10,000 population), number of schools (per 10,000 population), number of hospitals (per 1,00,000 population), and commercial bank branches (per 1,00,000 population), etc.

4. Methodology

4.1. Construction of composite infrastructure index using PCA

A composite index of infrastructure has been constructed using Principal Component Analysis (PCA)[13] on normalized infrastructure indicators. PCA is sensitive to units of measurement of variables. Therefore, study uses normalization method for each of the indicators to make every variable unit free and lies within the range of 0 to 1. The study has adopted the following formula for calculating the normalized values of the variables:

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[11] See Table A.3 in the Appendix

[12] The infrastructure index is constructed using principal component analysis (PCA) on several infrastructure variables. See section IV. A

[13] PCA is a multivariate statistical technique where mutually correlated variables are summarized by a fewer number of uncorrelated factors (known as principal component) through an orthogonal transformation to reduce the variability in a data set (Mitra & Das, 2018)

$$NV_i = \frac{Y_{i-Min\,Y_i}}{Max\,Y_i - Min\,Y_i} \forall\, i,$$

Where NV_i is the normalized value of i^{th} indicator, and $0 \leq NV_i \leq 1$.

After computing the normalized values for the variables, the study has assigned suitable weights to them and has constructed the composite infrastructure index (INFI). We assume that the infrastructure index can be expressed as a linear function as follows:

$$INFI = \alpha_1 rodn + \beta_1 rldn + \gamma_1 ardn + \delta_1 tldn + \epsilon_1 inpc + \theta_1 schl + \vartheta_1 hosp + \mu_1 cmbn + \varepsilon_1 \quad (13)$$

Here, rodn stands for road density, rldn stands for rail density, ardn stands for air density, tldn stands for tele-density, inpc stands for installed plant capacity, schl stands for number of schools, hosp stands for number of hospitals, and cmbn stands for commercial bank branches. We denote σ_n^{INFI}(n= 1, 2… 8) as the n^{th} Eigen values in case (13). Here, subscript n refers to the number of principle components that is exactly equal to the number of corresponding indicators and the value of σ_n falls gradually as the suffix increases. We now denote P_n^{INFI}(n= 1, 2… 8) as the n^{th} principal component in case (13). Finally, the normalized explanatory variables are given weights accordingly and the corresponding infrastructure index is calculated according to the following weighted average:

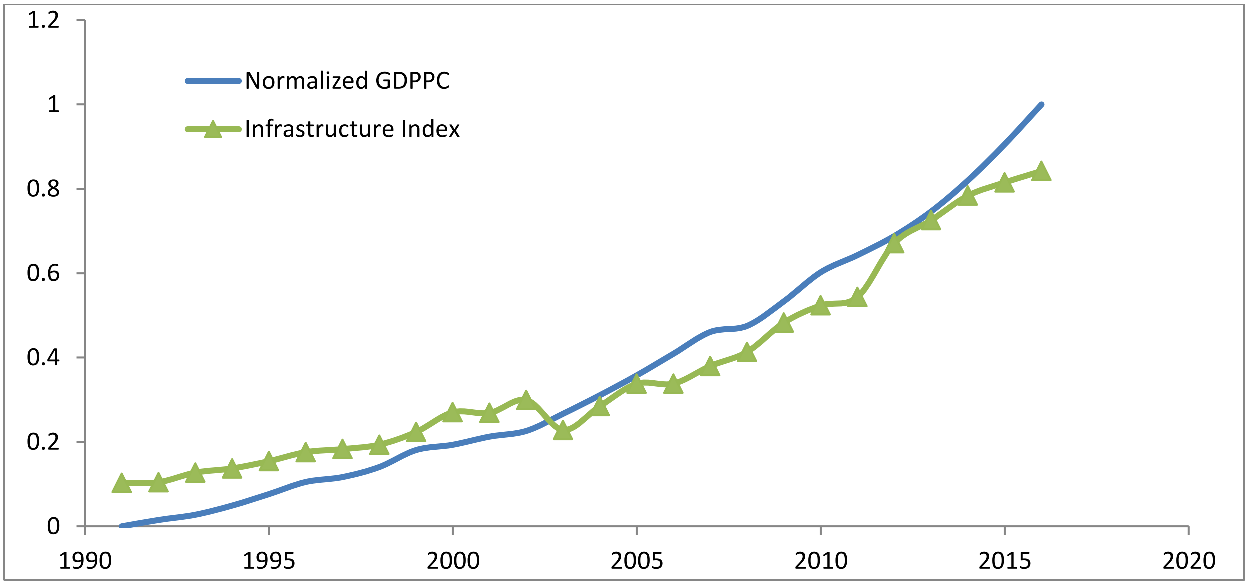
$$INFI = \left[\sum_{n=1}^{8} \sigma_n' P_n' / \sum_{n=1}^{8} \sigma_n' \right] \quad (14)$$

Where, σ_n', is the highest weight attached to the first principal components as it explains the largest proportion of the total variation in all the explanatory variables

4.2. Nature of variables: Analysis of Trends

Initially, we judge the nature of variables viewing figures or diagrams. Figure 1 displays trends of Infrastructure Index and normalized income per capita for the period of 1991-2016. Both variables rise over time with a shift of infrastructure in 2002-2003[14]. It is clearly visible a structural break in infrastructure in 2003. Infrastructure increases at a faster rate after 2003 than that of earlier periods.

Figure 1: Trends of Infrastructure Index and normalized income per-capita during 1991-2016



Source: Author's computation

Next, the study measures it quantitatively. Applying time series techniques, the time series nature of each indexed variable is examined. Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests are performed to examine the stationary properties of all indexed variables and also determine their order of integration. For the exercise as mentioned, this study has examined the

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[14] Total number of hospitals reduced from 2003 due to exclusion of CHCs and non-reporting. (see Public Health Statistics, Indian Statistical Abstract 2005& 06).

unit root test for all variables to judge the nature of time-series data. Table 1 provides the results of unit root tests of constructed index variables. Results of ADF and PP test statistics suggest that infrastructure and per-capita GDP are nonstationary at their level and the null hypothesis of unit roots cannot be rejected for the variables. However, they become stationary after taking their first difference. Both variables are non-stationary with the integration of order one i.e. *I (1).*

Table 1: Results of Unit Root Tests of income and infrastructure variable

	ADF Test		Phillips-Perron Test		Concluding Remark
Variables	at level	1st difference	at level	1st difference	
INCOME Index	1.5626	-3.872**	2.1409	-3.8476**	I(1)
INFRA Index	0.3113	-4.3489**	0.2993	-4.3404**	I(1)

Source: Author's computation

Note: Here ***, **and *are statistically significant at the 1%, 5% and 10% levels, respectively. I (1) indicate integrated of order one.

The study further repeats the unit root test for infrastructure considering the break in 2003, however, the conclusion of the unit root test for infrastructure remains unchanged, i.e., I(1). Therefore, the next step is to examine the linear cointegrating relationship between income and infrastructure.

5. Results and Discussion

Following the results of Table 1, the study conducts the Engle and Granger cointegration test and estimates the error correction model (ECM) for a pair of non-stationary variables i.e., income and infrastructure. Applying OLS, the study finds five different regression results of infrastructure index on income incorporating time trend and structural break dummy. Break dummy is defined as D2003=1, for the period of 2003-2017; otherwise, zero. Table 2 shows the OLS results of the infrastructure index on income for 5 different models[15]. On the basis of fitting criteria, the 5th

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[15] Possible combinations of other control variables are considered in empirical examinations.

model (M5) is the best fittest model while M3 is close to it. The time trend is statistically significant in both M3 and M5. The structural break dummy, D2003, is highly significant and differentiates M5 from M3. So, the estimated linear cointegrating relationship between income and infrastructure is:

$$z_t = -0.0779+0.2843x_t+0.018t+0.0498D2003 \quad (15)$$

where z is normalized income and x is infrastructure index. This estimated empirical finding shows the direct relationship between income and infrastructure. *Ceteris peribus*, the long-run equilibrium relationship between income and infrastructure is $z_t = 0.2843x_t$ (see equation 15), which indicates that normalized income increases by 0.2843 point for every incremental one point of infrastructure index to maintain long-run equilibrium.

Table 2: Regression Results [Dependent Variable: GDPPC]

Variables\Models	M1	M2	M3	M4	M5
Constant		0.0228 (0.89)	-0.0940*** (-9.63)	8.50E-05 (0.006)	-0.0779*** (-7.75)
Infrastructure	0.5797*** (28.73)	0.5574*** (17.3)	0.2608*** (13.48)	0.4364*** (18.63)	0.2843*** (15.34)
Trend			0.0222*** (17.23)		0.0180*** (9.86)
D2003				0.1813*** (7.709)	0.0498*** (2.95)
R^2	0.9233	0.9258	0.9947	0.9793	0.9961
Adj. R^2	0.9233	0.9227	0.9942	0.9774	0.9956
DW	0.1846	0.1779	0.8734	0.5216	1.0073
Sum sq. Resid.	0.1677	0.1623	0.0116	0.0453	0.0084
Log Likelihood	28.6750	29.0984	63.3224	45.6915	67.662
F-statistics		299.4723***	2144.530***	543.9595***	1912.361***
AIC	-2.1288	-2.0845	-4.6402	-3.2840	-4.8971
SIC	-2.0805	-1.9877	-4.4950	-3.1388	-4.7035

Source: Author's computation

Note: Figures in the parentheses are t-values. '***'and '**' denote the level of significance at 1% and 5%, respectively. GDPPC means per-capita GDP.

For performing the Engle and Granger cointegration test, the study examines the stationary nature of the estimated residual series which is generated from the estimated model of M5 (see, the last column of Table 2). Table 3 provides all possible results of unit root test of estimated residuals of M5. Results of Table 3 suggest that the estimated error series is stationary, or integration order of zero, i.e., I (0). This indicates the existence of a linear cointegration between income and infrastructure as per Engle and Granger sense.

Table 3: Results of Unit Root Test of estimated residuals of M5

Augmented Dickey-Fuller Test at level			
Exogenous	**t-statistics**	**p-value**	**Remarks**
Constant	-4.4415	0.0020	I(0)
Constant and Trend	-4.1069	0.0184	I(0)
None	-4.5891	0.0001	I(0)

Source: Author's computation
I (0) indicate variable with integrated of order one.

Table 4 shows all the possible results of the estimated error correction model (or short run dynamics). The coefficient of lag error correction term (ECT $_{(-1)}$) is negative and statistically significant in all the models in Table 4. The significant ECT reflects the short-run dynamics. Here, M3 is the best-fitted model. In M3, the coefficients of ECT_{t-1} and trend are statistically significant. A significant negative coefficient of ECT indicates convergence. This suggests that if any departures from the long-run equilibrium path in short-run it comes back or returns to it. In this context, the speed of convergence or return to the long run equilibrium is around 43%. Change of infrastructure has no instantaneous effect on that of income, while time trend has a certain positive impact on income. The study conducts some diagnostic test to check the robustness of the model. The results of LM test (see Table A4 in Appendix) indicate that the model is free from autocorrelation. Results of Jurque-Brea test (see Table A5 in Appendix) indicate that the residuals of the model are normally distributed. Finally, CUSUM of square test (see Fig. 2 in Appendix) indicates that the model is stable.

Table 4: Results of Estimated Error Correction Model [Dependent Variable: D(GDPPC)]

Variables\Models	M1	M2	M3	M4	M5
ECT(t-1)	-0.6855* (-1.79)	-0.6414** (-2.62)	-0.4332** (-2.35)	-0.5442** (-2.7545)	-0.4482** (-2.40)
D(Infrastructure)	0.3532*** (6.02)	0.1648*** (3.35)	0.0009 (0.02)	0.0600 (1.23)	0.0034 (0.06)
Constant		0.0280*** (5.88)	0.0053 (0.86)	0.0201*** (4.58)	0.0078 (1.13)
Trend			0.0024*** (4.50)		0.0019** (2.20)
D2003				0.0267*** (3.65)	0.0087 (0.83)
R^2	-0.3334	0.4813	0.7361	0.6830	0.7450
Adj. R^2	-0.3914	0.4342	0.6985	0.6377	0.6940
DW	1.0093	1.0981	1.4903	1.1156	1.4630
Sum sq. Resid.	0.01820	0.0071	0.0036	0.0043	0.0034
Log Likelihood	54.8432	66.6474	75.095	72.8000	75.5200
F-statistics		10.2101***	19.5313***	15.080***	14.6053***
AIC	-4.2274	-5.0918	-5.6876	-5.5039	-5.6416
SIC	-4.1299	-4.9455	-5.6335	-5.4500	-5.4000

Source: Author's computation

Note: Figures in the parentheses are t-values. '***', '**' and '*' denote the level of significance at 1%, 5%, and 10% respectively. D(GDPPC) means per-capita GDP at first difference.

Further, the study investigates the inter-relationship between change of income (or economic growth) and that of infrastructure in a feedback system using vector autoregressive (VAR) structure. Before executing VAR model, the study determines the optimum lag length which is one as per AIC and SIC (see Table A.2 in Appendix). Table 5 displays the result of the VAR model.

Table 5: Vector Auto Regression (VAR) Estimates

Independent\Dependent Variables	D(GDPPC)	D(INFSTR)
D(GDPPC$_{t-1}$)	0.5890*** (3.00)	1.1613 (1.54)
D(INFSTR$_{t-1}$)	0.0951* (1.71)	0.3346 (1.57)
Constant	0.0130* (1.84)	0.0023 (0.08)
R^2	0.5577	0.3500
Adj. R^2	0.5156	0.2881
F- statistics	13.2408	5.6545
Sum sq. Resid.	0.0057	0.0846
Log Likelihood	65.9879	33.7144
AIC	-5.2500	-2.5595

SIC	-5.1017	-2.4123

Source: Author's computation
Note: Figures in the parentheses are t-values. '***' and '*' denote the level of significance at 1%, and 10% respectively

From Table 5, it is observed that infrastructural change is autonomous or independent, while change of income or economic growth depends on its own past value as well as that of infrastructure. It shows that last year's infrastructural change affect the current year's change of income or economic growth. So, last year's infrastructural change is the cause of current economic growth. This is also verified in terms of the Granger causality test. Table 6 provides the results of the Granger causality or block exogeneity test. The causality result is significant at 10% level when it runs from infrastructure to economic growth. It indicates that infrastructure is the cause of economic growth.

Table 6: VAR Granger Causality/Block Exogeneity Tests

	Chi-sq	df	Prob.	Remarks
H_0: Infra does not cause GDPPC				
	2.9354^*	1	0.086	H_0 is rejected
H_0: GDPPC does not cause Infra				
	2.3821	1	0.12	H_0 is not rejected

Source: Author's computation
'*' denotes the level of significance at 10%. H_0: X_t doesn't cause

6. Conclusion

This study has empirically examined the role of infrastructure in economic growth in India for the period 1991 – 2016 and answered the question whether a structural break in infrastructural development shifts economic growth in India recently. The study finds a structural break in infrastructure in 2003. Several econometric techniques such as Engle and Granger approach is applied to examine the long-run relationship as well the short-run dynamics between infrastructure and economic growth. The long-run relationship between infrastructure and economic growth indicates that normalized income increases by 0.2843 points for every incremental point of infrastructure index to maintain long-run equilibrium. However, in the short-run the results of the study find no instantaneous effect of change of infrastructure on income/economic growth. The study further employs VAR model to estimate the short-run association between infrastructure and economic growth. Granger causality Block Exogeneity test is then applies to assess the direction of causality between them. The results of VAR shows that change of income/economic growth depends on its own past vale as well as that of infrastructure. Finally, the results of the Granger causality test unveil the causal direction between the infrastructure and economic growth and indicate a unidirectional causality from infrastructure to economic growth. The results of the study suggest that adoption of appropriate infrastructural policies would be an effective tool for achieving sustainable economic growth.

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Appendix

Table A1. Unit root test of the Residuals

Augmented Dickey-Fuller Test at level				
Model 1	**Exogenous**	**t-statistics**	**p-value**	**variable’s type**
	Constant	-1.4830	0.5254	-
	Constant and Trend	-0.9622	0.9317	-
	None	-1.4380	0.1369	-
Augmented Dickey-Fuller Test at level				
Model 2	**Exogenous**	**t-statistics**	**p-value**	**variable’s type**
	Constant	-1.6882	0.4539	-
	Constant and Trend	-1.0186	0.9230	-
	None	-1.6429	0.0938	I(0)
Augmented Dickey-Fuller Test at level				
Model 3	**Exogenous**	**t-statistics**	**p-value**	**variable’s type**
	Constant	-3.0964	0.0404	I(0)
	Constant and Trend	-2.8620	0.1911	-
	None	-3.1910	0.0027	I(0)
Augmented Dickey-Fuller Test at level				
Model 4	**Exogenous**	**t-statistics**	**p-value**	**variable’s type**
	Constant	-2.7680	0.0779	I(0)
	Constant and Trend	-2.7045	0.2434	-
	None	-2.7931	0.0073	I(0)
Augmented Dickey-Fuller Test at level				
Model 5	**Exogenous**	**t-statistics**	**p-value**	**variable’s type**
	Constant	-4.4415	0.0020	I(0)
	Constant and Trend	-4.1069	0.0184	I(0)
	None	-4.5891	0.0001	I(0)

Table A2. Optimum Lag for Vector Auto Regression (VAR) Estimates

Lag	LR	AIC	SIC	HQIC
0	NA	-7.2287	-7.1300	-7.2039
1	17.6733	-7.7646*	-7.4684*	-7.6900*
2	4.0640	-7.6425	-7.1488	-7.5184

‘*’indicates lag order selected by the criterion, LR, AIC, SIC, and HQIC.

Table A3. Data Descriptions

Variable	**Source**	**Time Period**
GDP per capita (constant 2010 US$)	World Development Indicator, World Bank	1991-2016
Road length per 1,000 sq km area	CMIE Database	1991-2016
Railway length per 1,000 sq km area	CMIE Database	1991-2016
Domestic aircraft flown per 1,000 sq km	CMIE Database	1991-2016
Fixed telephone users per 100 population	World Development Indicator, World Bank	1991-2016
Installed plant capacity per 10,000 population	Handbook of Statistics of Indian States, RBI	1991-2016
No. of school per 10,000 population	Various publications of Statistical Abstract of India, MOSPI, Govt. of India, EPWRF India Time Series.	1991-2016
Govt. Hospitals per 1,00,000 population	Various publications of Statistical Abstract of India, MOSPI, Govt. of India, EPWRF India Time Series.	1991-2016

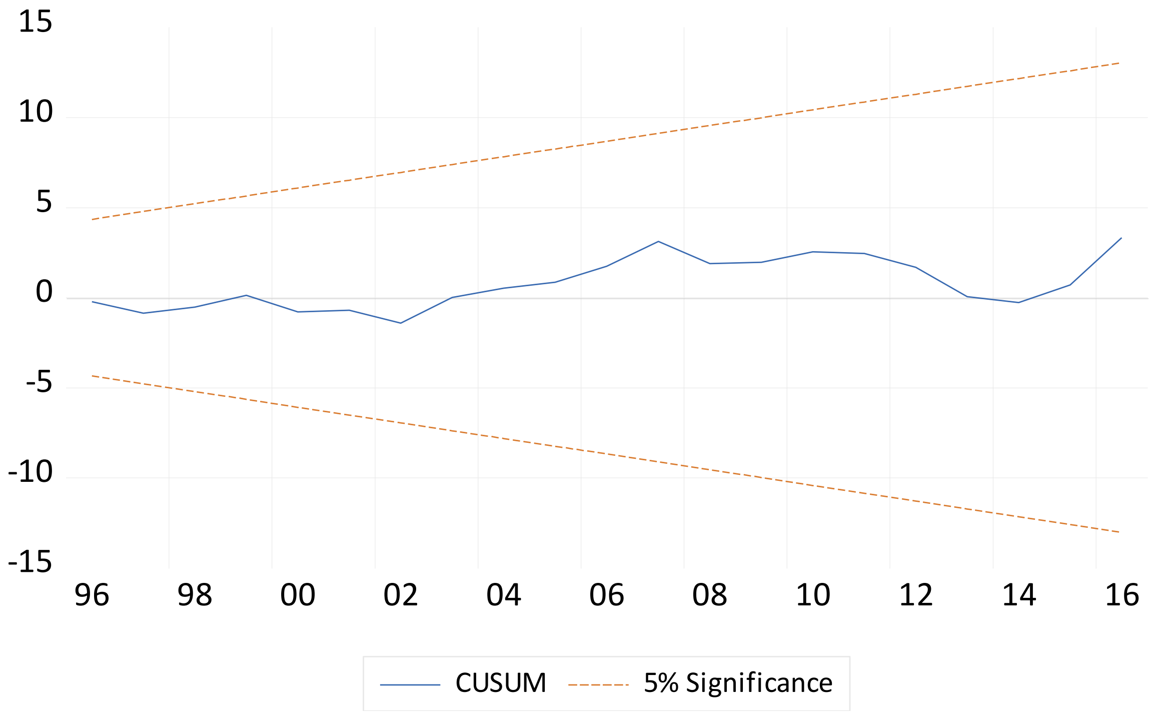
Table A4. Results of Breusch-Godfrey Correlation LM test for Model 3

F-statistic	p-value	Remarks
0.7937	0.4700	Cannot reject

Table A5. Results of Jarque-Bera Normality test for Model 3

Jarque-Bera Statistics	p-value	Remarks
0.0650	0.9681	Cannot reject

Fig 2: CUSUM of Square test for Stability of Model 3



Source: Author's computation

Table A6: Components loadings and Eigen values for different components of infrastructure

Variable	PC 1	PC 2	PC 3	PC 4	PC 5	PC 6	PC 7	PC 8	Eigen values
Road Density	0.4218	-0.0254	0.0857	-0.1304	0.0729	-0.3409	-0.0970	-0.8162	5.5647
Rail Density	0.4170	0.0691	-0.0624	0.3341	0.2190	-0.6555	0.2283	0.4196	1.8737
Air Density	0.4153	-0.0658	0.0733	-0.3306	-0.7785	0.0227	0.2727	0.1658	0.3847
Teledensity	0.1228	-0.6421	0.5565	0.4235	0.0506	0.2262	0.1691	-0.0359	0.1318
Installed plant capacity	0.4164	0.0933	-0.0481	0.3198	-0.1644	0.2078	-0.7881	0.1483	0.0249
Number of schools	0.3995	-0.1658	0.0745	-0.6155	0.5394	0.2479	-0.0593	0.2694	0.0118
Number of hospitals	-0.0193	0.6428	0.7622	-0.0339	0.0369	0.0147	0.0115	0.0513	0.0050
Commercial bank branches	0.3567	0.3586	-0.2914	0.3170	0.1367	0.5455	0.4591	-0.1782	0.0034