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Review Paper

Does Road Infrastructure Drive Income Growth? Panel Evidence on Roads, Power, and Structural Change in Indian States

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Abstract

The paper examines the role of road infrastructure in economic development using state-level panel data from 2004–05 to 2023–24. The paper uses static and dynamic panel methods for analysis. The paper observe that road density and power supply significantly increase per capita GSDP. The study also shows that improvements in power availability results in higher economic benefits than improvements in roads infrastructure. The fixed effects model estimates indicate significant short-run impacts of both road density and power availability. The dynamic System results suggest strong persistence in economic performance. It validates the presence of positive long-run effects of infrastructure on growth. Hausman tests indicate correlation between state-specific effects and infrastructure variables, justifying the estimation of fixed-effects. The findings suggest that although expanding road networks supports regional growth, improving power availability may generate higher economic returns. Therefore, infrastructure policy should be framed to match the economic structure of the state and more emphasis in needed to be on strengthening power infrastructure in lagging states.

Keywords: Infrastructure, Energy Infrastructure, Road infrastructure, Panel Data, Fixed Effects, System GMM.

Introduction

The road network is an important infrastructure variable effecting standard of living of the people and plays a crucial role in the economic development of a region. Access to a good road network is essential for reliable supply chains. The supply chains are a prerequisite for attracting investment and promoting growth within an economy. The extant research demonstrated a synergistic between the correlates of road infrastructure and economic development[1-14]. Investment into road infrastructure has an enabling effect on reduction in cost of production and thereby stimulating investment. It is empirically demonstrated that public infrastructure investment significantly raises total factor productivity by lowering transportation and transaction costs, which may encourage private investment rather than displacing it[15].

The investment in public infrastructure indirectly accelerates the human capital development as it enables individuals to attend school and seek health care thereby improving education and health outcomes. A study using cross-country data found that improved physical infrastructure enhances school enrolment and health indicators by increasing accessibility to educational and medical facilities, thereby accelerating human capital accumulation[16]. Similarly, it is also found that rural road connectivity significantly increases school attendance and utilisation of primary healthcare services in developing economies[17].

The investment in road infrastructure also enables the lagging region/states to catch-up with the advanced regions/ states by its synergising effect. The investment in road infrastructure is considered as stimuli to economic activities, augment economic development, and improve living standard. This may also ensure optimal resource allocation within and between states. In theory, infrastructure is regarded as both a catalyst and a prerequisite for economic growth. However, a comprehensive review observed that although most studies found a synergistic relationship between infrastructure and development but no consensus exists on the degree of this impact[14].

In India, the progress made in road infrastructure growth has played a transformative role in national development. The post-colonial road system, initially inadequate and uneven, was progressively strengthened through Five-Year Plans, and flagship programmes such as the National Highways Development Project (NHDP). Appendix table-1 which depicts the expansion of India's road network, during the period 1950-51 to 2020-21, depicts that the total road network in India grew considerably from 3.99 lakh km in 1950-51 to 63.31 lakh km in 2020-21. National Highways though expanded significantly (19,811km to 1,32,499km) but still they form only a small portion of the total. State and District Roads share was initially high but their prominence has declined with time. The highest growth was observed in rural roads with significant increase in both length (2,06,408 km to 45,22,228km) and share (51.6% to

71.4%). The urban and project road has also increased steadily to meet the growing need arising from urbanization.

Though a substantial portion of public investment on infrastructure is directed towards the road infrastructure through the programs like the NHDP and the PMGSY but their varied impact across states/regions remains underexplored. For instance the impact of India's Golden Quadrilateral highway project shows stronger manufacturing growth in districts close to the network than in more distant districts[18]. Similarly the analysis of PMGSY reveals that rural connectivity and economic outcomes vary significantly across states and local conditions[19,20]. Improved rural and national connectivity has facilitated industrial and trade expansion, mobility of labor, access to markets and delivery of public services, accelerated agricultural supply chains, and enhanced regional integration. There are many studies highlighting contribution of improved road networks reducing transportation and transaction costs, strengthening agricultural & non-agricultural supply chains, enhancing labour mobility and local economic activity, and promoting regional integration and convergence[17,21-23].

Drawing on the studies mentioned above, we can understand infrastructure gaps in India's regional development. First, the studies lack analysis of relative effectiveness of different type of physical infrastructure such as road infrastructure, rail infrastructure, communication infrastructure etc. Second, these India specific studies provided limited evidence on the varied impact according to the economic structure of the states. To overcome these shortcomings, the study uses a panel analysis to i. compare the developmental impacts of road infrastructure (also distinguishing between network density and highway length) and power availability ii. Implements rigorous model specification through formal Hausman testing and dynamic System GMM estimation to account for state-specific heterogeneity and iii. Examines conditional effects through interaction models. The findings suggest that power supply is more important than the road availability in explaining interstate differences and a considerable share of regional income advantages - estimated to be in the range of 80–91 per cent - appears to persist from one period to the next. Moreover, the results suggest that the economic returns to highway investments tend to rise with increasing levels of industrialization. The results suggested the need for separate infrastructure prioritization, that is, power infrastructure emerges as the higher-return investment, while road infrastructure requires tailoring to regional economic structures.

The rest of the paper is structured in six more sections. Section 2 presents reviews of the related studies and section 3 describes methodological plan for the paper. Section 4 presents static panel results with model selection tests. Section 5 introduces dynamic panel estimates and long-run effect calculations. Section 6 discusses policy implications whereas section 7 discusses limitations.

Literature review: Various economic theories have recognised the role of infrastructure in economic development[24]. The debate ranges from early growth models that emphasized physical capital[25] to current approaches that consider institutional and social factors along with traditional economic variables[26]. Endogenous growth models consider infrastructure as a key enabler that enhances productivity through positive spillover effects and increasing returns[16,27]. Within this framework, road and power infrastructure contribute to economic expansion as it lowers production and transaction costs, accelerate the spread of technology, and encourage private sector investment. New Economic Geography models, developed by Krugman and expanded by Fujita and others looks at how infrastructure influences location choices[28,29].

Improvement in road infrastructure is very crucial because it affects the moving cost of goods, capital and workers. These results in formation of industrial clusters in the places where these cost are considerably lower than other places. Consequently, the economic impact of infrastructure tends to vary across regions. Alternatively, the Institutional economics highlights that the interaction of infrastructure quality and accessibility with institutional frameworks have significant impact on developmental outcomes[30,31]. This underscores the importance of quality of institutions in achieving optimum gains from infrastructure improvement. This inter-alia means that building roads or power plants leads to better results in places where institutional quality is high. Where governance is strong, property rights are protected, and market function is efficient. Without these institutional foundations, physical infrastructure may be unable to deliver desired benefits.

The association between road infrastructure and economic development is widely studied. Many empirical studies consistently highlight the positive role of transport infrastructure in accelerating economic activity, reducing production costs, and improving human development outcomes[1,2,4,5,7,8,12,13,15]. Reductions in transport costs resulting from expanded road networks corresponds to higher trade flows, specifically in the previously less connected areas[3]. Infrastructure investment adds to growth when it is efficiently implemented and supported by institutional capacity[6]. The progress in transport connectivity is linked to better resource allocation and increased economic activity[11]. These studies highlight an important aspect of regional development and convergence across regions, although the net benefit varies across regions depending on other enabling factors.

There exist a significant forward linkages effects and ripple effects with favorable impact of economic development[12]. Various infrastructure components such as transport, telecommunications, and power have a positive impact on productivity improvements[32].

A rapid growth of the interstate road network from 1953 to 1973 resulted into large productivity gains in the US (adding about

1.4 percent per year to growth)[33]. After that, between 1973 and 1989, the contribution dropped to roughly 0.4 percent annually. This decline suggests diminishing returns as the highway network became more mature. The presence of bidirectional causality between road infrastructure growth and economic growth and railway infrastructure shows a unidirectional causality from infrastructure to growth. A cross-country study found that high-income economies have far larger stocks of paved roads per person (8550 Km per million) than middle (470 Km per million) and low-income countries (40 Km per million)[34].

From the above discussions it emerge that a strong relationship between a country's income level and its availability of road infrastructure. However, the conclusions must be interpreted with some caution. First, the magnitude of the impact varies across studies, with older studies often reporting larger returns than more recent studies[35]. This may be attributed to onset of diminishing returns or due to methodological refinements. Second, the outcomes are affected not only by the scale of infrastructure but on its quality and composition also[36]. It is easy to understand that well-maintained paved roads are bound to generate higher returns than poorly-maintained or unpaved roads. Third, the effects of infrastructure investment could be affected by factors such as human capital, institutional quality, and initial levels of development. This helps in explaining - why similar investments can produce different outcomes across regions/states.

Road infrastructure receive more attention, but a number of studies highlight that power infrastructure affects productivity more in developing economies[37]. Using data from Nepal, a study finds emergence of significant benefits, especially to the poor households, due to improved road access[1]. A study related to Bangladesh finds that improved road infrastructure reduced poverty mainly through improvements in production, higher wages to workers and lower cost to producers[2]. The rural roads have significant effects on expenditure, schooling, and prices in Bangladesh[2].

Recent studies hinted that improved rural road connectivity may also affect farm-related decision making by the farmers. Improvements in road connectivity enable farmers to diversify crops, adopt new technologies, and adjust labour use according to the requirements[21,38,39]. Rural road network expansion significantly influences crop choices[39]. Road investments are found to have increase agricultural output, encourage fertilizer use, and improve access to formal banking[40]. Taken together, these studies indicate that rural roads affect not only agricultural sector growth, but also productivity, input mix, and financial inclusion through multiple channels.

A number of studies from India show that improvements in indicators of infrastructure are closely associated with higher output and economic growth[41-45]. The study distinguishing between infrastructure types show that their growth effects are not uniform[41].

The infrastructure indicators contribute between 5% and 21% to income levels with magnitude of the effect varying due to specifications and measurements[42]. There exists a long-term relationship between public investment in infrastructure—such as transport, education, and energy—and per capita GSDP across Indian states[43]. The infrastructure contributes more significantly to output growth than private or public investment alone, with unidirectional causality from infrastructure to economic output[44]. While these studies establish a positive association, many suffer from methodological limitations that this study addresses. Several employ time-series methods for individual states without exploiting cross-sectional variation, while others use panel methods but neglect formal specification testing or fail to account for state-level persistence. Few distinguish between different types of road infrastructure (highways vs. rural roads) or systematically compare transport against energy infrastructure.

State-level studies also confirm that road infrastructure expansion contributes positively to economic performance[46-51]. The road length per capita, exports, education expenditure, and stock of physical capital together influence economic growth[11]. Studies also detect both short-run and long-run relationships and, in some cases, bidirectional causality[46,47]. The state level study for Karnataka examined how road infrastructure influences economic growth using time-series data. The study shows that the expansion of road networks improves connectivity and encourages economic activities, thereby lowering transaction costs and enabling farmers to obtain higher prices and undertake more profitable activities[48].

The micro-level Indian studies reveal strong socio-economic spillovers. The households located near national highways usually have higher incomes, better mobility, and improved access to education[49]. This shows that living close to major transport routes can provide important economic benefits that may not always be visible in overall productivity statistics.

Methodology

Data Sources and Variables: The study uses a balanced panel dataset for 28 major Indian states covering the period 2004-05 to 2023-24, resulting in a total of 560 state-year observations. Data were collated from following secondary sources: road infrastructure indicators from the Ministry of Road Transport and Highways (MoRTH); economic indicators from the Reserve Bank of India (RBI) Handbook of Statistics on Indian States and the Central Statistics Office (CSO).

The dependent variable is Per Capita Gross State Domestic Product (PCGSDP) at constant 2011-12 prices, deflated using state-specific GDP deflators from the RBI database. Key explanatory variables include: i. Highway Length **(***Hwy Length)*:

Total length of National and State Highways (km), capturing inter-regional connectivity. ii. Road Density (*Road Density*): Total road length per 100 sq km of geographical area, measuring network accessibility. The road density measure is preferred over total road length and highway length, as density better reflects accessibility and network coverage. iii. Per Capita Power Availability *(PC PowerAv)*: Total power availability (Kilowatt-Hour) divided by state population. Per Capita Power Availability is included as a complementary infrastructure variable reflecting industrial and household energy access. iv. Industry Share *(Industry Share)*: Percentage share of Industry in GSDP. v. Agriculture Share (*Agrishare*): Percentage share of Agriculture in GSDP.

Structural characteristics of state economies are captured using Industry Share and Agriculture Share in GSDP, reflecting the degree of structural transformation. All continuous variables (first three listed above) are log-transformed to interpret coefficients as elasticity and mitigate skewness.

Preliminary Diagnostics and Variable Selection: Prior to model estimation a correlation analysis was conducted to guide variable selection and detect potential multicolinearity.

The results (Appendix Table-2) indicate that road density has a stronger positive correlation with per capita income than total road length or highway length. Road Length and Highway Length exhibited strong correlation (r = 0.80). Therefore, highway length was retained because it captures economically useful transport networks. In the baseline model, road density is kept as the main measure of road infrastructure, while other road indicators are used for robustness checks (Highway Length measures arterial, long-distance connectivity (for trade, logistics, integration) whereas Road Density measures local network penetration and accessibility (for market access, factor mobility).

This distinction allows us to test which type of connectivity matters more for income levels). Industry Share and Service Share in GSDP were strongly negatively correlated (r = –0.78), implying structural substitution. The share of industry in GSDP was kept in the model because it is strongly linked to both infrastructure and productivity growth.

The share of agriculture, on the other hand, showed a negative relationship with income and industrialization, so it was included as a indicator of structural backwardness. Including both sectoral shares as control variables helps us to isolate the effect of infrastructure on income when comparing states with similar economic structures. Per capita power availability also showed a strong relationship with income and industry share, so it was included as an important infrastructure variable. The GSDP growth rate showed weak correlations and was therefore used only for robustness checks. Overall, this process helped ensure that the final model is both theoretically meaningful and econometrically stable.

To assess multicolinearity, we computed Variance Inflation Factors (VIFs) for our baseline specification. All VIF values range from 1.07 to 1.71, with a mean VIF of 1.39. These values are well below the conservative threshold of 5.0 and far below the conventional concern level of 10.0, indicating minimal multicollinearity[53].

Table-1: Descriptive Statistics of Variables.

Variable	Mean	SD	Min	Max
lnPCGSDP	11.18	0.58	9.87	12.45
lnHwy_Length	7.45	1.12	4.61	9.88
lnRoad_Density	3.21	0.89	1.05	5.12
lnPCpowerAv	6.78	0.95	4.56	8.89
Industry Share	22.45	8.67	8.12	45.23
Agrishare	18.34	9.12	5.67	35.45

Estimation Methodology: Static Panel Models: We begin with a static panel specification and we estimate three static specifications:

Model 1: Baseline with contemporaneous variables.

$$\ln(PCGSDP_{it}) = \alpha + \beta_1\ln(Hwylength_{it}) + \beta_2\ln(RoadDensity_{it}) + \beta_3\ln(PCpowerAv_{it}) + \beta_4 (Industryshare_{it}) + \beta_5 (Agrishare_{it}) + \mu_i+\lambda_t+\varepsilon_{it}$$

where i = 1,...,28 denotes states, t = 1,…,20 denotes time (corresponding to years 2004–05 to 2023–24)**,** μ_i captures unobserved state-specific effects, λ_t represents time-specific effects, and ε_{it} is the idiosyncratic error term assumed to have zero mean and finite variance. α is the constant term, representing the baseline income level when all explanatory variables are zero (after transformation); β_1, β_2 & β_3 are elasticity coefficients and β_4 & β_5 measure the marginal effects of sectoral composition on income.

Model 1A: With one-period lagged infrastructure variables to address immediate reverse causality.

$$\ln(PCGSDP_{it}) = \alpha+ \beta_1\ln(Hwylength_{i,t-1}) + \beta_2.\ \ln(RoadDensity_{i,t-1}) + \beta_3\ln(PCpowerAv_{i,t-1}) + \beta_4 (Industryshare_{it}) + \beta_5 (Agrishare_{it}) + \mu_i+\lambda_t+\varepsilon_{it}$$

Model 1B: With interaction terms to examine heterogeneous effects

$$\ln(PCGSDP_{it}) = \alpha + \beta_1\ln(Hwylength_{it}) + \beta_2\ln(RoadDensity_{it}) + \beta_3(Industryshare_{it}) + \beta_4(PCpowerAv_{it})+ \beta_5 (Agrishare_{it}) + \beta_6[\ln(Hwylength_{it})^* Industryshare_{it}]+ \beta 7\ [\ln(RoadDensity_{it})^* Agrishare_{it}] + \mu_i+\lambda_t+\varepsilon_{it}$$

A positive β_6 means highways are more valuable where industry is larger. A positive β_7 means local roads are more valuable in agrarian economies. For each specification, the study estimate both fixed effects (FE) and random effects (RE) models. We implement the Hausman (1978) test, where a significant χ^2 statistic rejects the null hypothesis favoring the FE estimator[53].

Dynamic Panel Models: Recognizing potential state dependence in economic development, we augment our static models with dynamic specifications:

$$\ln(PCGSDP_{it}) = \alpha + \rho\ \ln(PCGSDP_{i,t-1}) + \beta_1\ln(Hwylength_{it}) + \beta_2 \ln(RoadDensity_{it}) + \beta_3\ln(PCpowerAv_{it}) + \beta_4 (Industryshare_{it}) + \beta_5\ (Agrishare_{it}) + \mu_i+\lambda_t+\varepsilon_{it}$$

where ρ is the persistence parameter, β_1 to β_5 are coefficients for the explanatory variables, μ_i denotes state-specific effects, λ_t denotes year-specific effects, and $\varepsilon\_$ it is a normally distributed error term.

The models are estimated using the GMM for panel data. The study applies the Difference GMM method developed by Arellano and Bond[54] and the System GMM method proposed by Blundell and Bond[55]. These techniques help deal with endogeneity by using lagged values of the dependent and explanatory variables as instruments. The consistency of GMM estimates relies on valid instruments, which we test via: i. AR(2) tests: For second-order autocorrelation, ii. Hansen tests: For instrument validity. The study estimated three dynamic specifications parallel to our static models and calculates long-run effects as $\frac{\beta}{1-\rho}$

Inference and Diagnostic Testing: Several diagnostic tests were carried out using standard panel data methods as suggested by Wooldridge[56]. The tests include the Welch F-test to check group heterogeneity, Wooldridge test for first-order autocorrelation, the Wald test for heteroskedasticity, and Breusch –Pagan LM test for random effects. In addition, cluster-robust standard errors at the state level were also used to control for heteroskedasticity and autocorrelation within states[57].

Addressing Endogeneity Concerns: A possible issue in the estimation is the endogeneity of some explanatory variables, especially power availability. Higher state income level may increase the demand for electricity, which can create reverse causality. To address this problem, following steps were taken. First, the static model using one-period lagged values of infrastructure variables are estimated (Model 1A). In addition, dynamic panel models are estimated using the System Generalized Method of Moments (GMM) as suggested by Blundell and Bond[55]. This method uses past values of the variables as instruments, which helps in tackling possible correlation between the explanatory variables and the error term.

Results and Discussion

Model Selection Tests: Before examining the coefficient estimates, several specification tests were conducted (Table-2). The Breusch–Pagan Lagrange Multiplier test rejects pooled OLS and supports the use of panel data methods ($\chi^2 > 2200$, $p < 0.001$). The Hausman test rejects the random effects model for all three specifications, indicating that state-specific effects are correlated with the explanatory variables. Therefore, the fixed effects model is considered more appropriate. The Welch F-test also confirms significant differences across states. In addition, the Wooldridge test indicates the presence of first-order serial correlation, while the Wald test shows heteroskedasticity in the residuals. For this reason, cluster-robust standard errors are used in the estimation.

Main Regression Results: Table-3 presents fixed effects estimates along with random effects for comparison purpose. Column 1 shows baseline FE results: road density (0.233, $p < 0.01$) and power availability (0.634, $p < 0.01$) significantly increase per capita output. A 1% increase in road density raises GSDP by 0.23%, while a 1% increase in power availability raises it by 0.63%. Highway length shows a positive but statistically non-significant effect (0.121, $p = 0.278$). Industrial share exhibits a positive effect (0.0077, $p < 0.05$), indicating that a one percentage point increase in industrial share increases output by 0.77%. Agricultural share shows a marginally significant positive effect (0.0101, $p < 0.10$).

Table-2: Specification Test Results.

Test	Model 1	Model 1A	Model 1B	Interpretation
Breusch–Pagan LM	2310.19*	2253.01*	2225.82*	RE preferred over pooled OLS
Hausman Test	16.65*	19.77*	21.16*	FE preferred over RE
Welch F-test	91.10*	106.45*	85.55*	Significant group heterogeneity
Wooldridge Test	167.61*	—	—	First-order autocorrelation present
Wald Test	4825.68*	—	—	Heteroskedasticity present

Note: * denotes significance at the 1 percent level ($p < 0.01$).

Table-3: Infrastructure and Regional Economic Development-Static Panel Estimates. **(**Dependent Variable**:** ln(Per Capita GSDP)).

Variable	Model-1 FE Baseline	Model-2 RE Baseline	Model-3 FE Lagged IV	(4) RE Lagged IV	(5) FE Interaction	(6) RE Interaction
(HwyLength)	0.121 (0.109)	0.089* (0.027)	0.100 (0.098)	0.070 (0.081)	0.102 (0.110)	0.069 (0.092)
ln(Road_Density)	0.233* (0.052)	0.240* (0.024)	0.235* (0.052)	0.240* (0.048)	0.207* (0.052)	0.215* (0.048)
ln(PCpowerAv)	0.634* (0.108)	0.638* (0.034)	0.607* (0.115)	0.613* (0.104)	0.627* (0.110)	0.632* (0.101)
Industry Share	0.0077** (0.0030)	0.0080* (0.0010)	0.0071** (0.0030)	0.0074** (0.0030)	—	—
AgriShare	0.0101*** (0.0053)	0.0097* (0.0020)	0.0101*** (0.0050)	0.0098*** (0.0050)	—	—
Highway × Industry	—	—	—	—	0.00100** (0.00043)	0.00103** (0.00043)
Road Density × Agriculture	—	—	—	—	0.00117 (0.00078)	0.00113 (0.00078)
Observations	560	560	532	532	560	560
Number of States	28	28	28	28	28	28
Within R^2	0.808	—	0.803	—	0.807	—
Overall R^2	—	0.534	—	0.543	—	—
Hausman Test χ^2 (p-value)	16.65 (0.005)	—	19.77 (0.001)	—	21.16 (0.001)	—

Notes: Cluster-robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. Models (3) and (4) use one-period lagged infrastructure variables.

Robustness Analysis: Columns 3-4 of Table-3 address reverse causality concerns through lagged infrastructure variables. The coefficients remain largely stable: road density (0.235, $p < 0.01$), power availability (0.607, $p < 0.01$), and industrial share (0.0071, $p < 0.05$). The results are consistent for both current values and lagged values. This strengthens the argument that infrastructure leads to better economic performance, rather than other way around, that is, economic growth improving infrastructure. To examine if the affects of infrastructure changes with the economic structure of states, interaction terms are added between highway length and the shares of different sectors in GSDP. The results (presented in column 5 and 6), suggest that the interaction term representing highway length and the industrial share in GSDP is statistically significant and positive at the 5 percent level. This indicates that the benefits of highway expansion are likely to be stronger in states where industrial share is higher. The interaction between highways and the agricultural share, although positive but statistically insignificant. This implies that though transport infrastructure can support agriculture dominant states but its growth-enhancing effects seems to be less compared with those in more industrialized states.

Dynamic Panel Results: Dynamic Model Estimates: The results from the dynamic panel models are presented in Table-4. As dynamic models estimated with fixed effects can suffer from small-sample bias, importance is placed on the estimates obtained using the System GMM approach. The results depicts a strong degree of persistence in regional economic performance. The estimated persistence parameter (ρ) lies between 0.81 and 0.91, implying that roughly 80–91 percent of the existing income advantages of states tend to carry over from one year to the next. It is also worth noting that the short-run coefficients from the System GMM specification appear imprecise to some extent. However, the sign of the estimates are consistent theoretical expectations and conforms to the results obtained using the static regression models.

Table-4: Dynamic Panel Estimates - Infrastructure and Economic Development (Dependent variable: ln(Per Capita GSDP)).

Variable	Model-D1 FE Dynamic	Model-D2 FE Dynamic Lagged	Model-D3 System GMM	Model-D4 System GMM Lagged
lnPCGSDP(t−1)	0.883* (0.030)	0.883* (0.017)	0.805* (0.041)	0.913* (0.031)
Highway Length	−0.004 (0.011)	−0.015 (0.011)	0.036 (0.029)	−0.010 (0.007)
Road Density	0.016* (0.008)	0.025** (0.010)	0.027 (0.031)	0.012 (0.010)
Power Availability	0.080** (0.036)	0.073* (0.017)	0.114* (0.044)	0.045** (0.021)
Industry Share	0.001 (0.001)	0.001 (0.0004)	—	0.001 (0.001)
Agriculture Share	0.001 (0.001)	0.001 (0.001)	—	−0.001 (0.001)
Long-Run Effects				
Road Density	0.133	0.210	0.138	0.136
Power Availability	0.682	0.624	0.585	0.514
AR(2) test (p-value)	—	—	0.588	0.856
Hansen test (p-value)	—	—	0.076	0.080
Number of Instruments	—	—	23	25
Observations	532	532	504	532
Within R^2	0.969	0.969	—	—

Notes: 1. Standard errors in parentheses. 2. p<0.01, ** p<0.05, * p<0.10. 3. Long-run effects calculated as β/(1-ρ). 4. Models 3-4 are System GMM estimates with AR(2) and Hansen tests validating instrument validity.

Specification Validity: The System GMM estimates satisfy key diagnostic criteria for dynamic panel consistency. AR(2) tests (p > 0.50) indicate no second-order autocorrelation in the first-differenced errors, supporting the validity of moment conditions. Hansen tests (p ≈ 0.08) indicate instrument validity, though the borderline p-values suggest some caution in interpretation. The number of instruments (23-25) is reasonable given our sample size, minimizing concerns about instrument proliferation.

Short-run versus Long-run Effects: Once persistence in regional income levels is taken into account, the estimated short-run elasticities of infrastructure become smaller, but the long-run effects appear considerably larger.

In the System GMM estimates, the short-run impact of road density ranges from 0.012 to 0.027, whereas the corresponding long-run elasticity range from 0.136–0.210. Similarly, short-run power availability effects range from 0.045 to 0.114, with long-run effects of 0.514 to 0.585. These differences are due to the high persistence parameters which increases the cumulative impact of infrastructure over time. This suggests that improvements in power infrastructure may have strong long-term growth implications. Largely, the dynamic multipliers indicate that the benefits of infrastructure investments tend to build up gradually.

Discussion: Interpretation of Key Findings: The results support with endogenous growth theory, which underlines positive impact of infrastructure in productivity enhancement[15].

However, the effects differ across sectors. The elasticity of power availability (0.51–0.68) is higher than road infrastructure (0.14–0.21), suggesting that energy constraints may be more binding (The critical nature of power stems from its non-storable character; unlike transport services, an electricity outage can halt production and commercial activity completely. As a result, availability of power acts as a binding constraint on economic activity, which helps explain its stronger impact). The results also support the New Economic Geography which explains that economic activities concentrate in certain regions due to economies of scale, transport costs, and market size[28].

Highways tend to give more benefits in areas where industries are already concentrated, because firms are better connected to each other. This means highway investment may work better if focused on industrial corridors rather than spread equally across all regions. The high persistence ($\rho = 0.81–0.91$) shows that past conditions continue to shape current outcomes. This may be attributed to factors such as geography, institutions, and human capital, which change slowly over time. In the Indian context, it points to the difficulty of reducing long-standing regional disparities between less developed and more advanced states. It also suggests that these gaps cannot be closed quickly.

Policy Implications: The results offer a few policy lessons for infrastructure planning in India. First, the magnitude of the effect of road density and highway are not the same. Highways effect is more in the industrialized states, so a uniform strategy may not be suitable for all states. Improving local roads should be a priority in less developed areas, while highway projects can be in the states with stronger industrial base. Second, power availability has a larger impact on income-levels than transport infrastructure. This highlights the importance of mitigating power shortages, especially in weaker states on a priority basis. Third, the high value of persistence parameter indicates that the gains from infrastructure development are not realised in short-run. Policies should therefore focus on long-term goals rather than short-term results. It also means that reducing regional disparities requires sustained efforts.

Limitations: The study has some limitations. Although lagged variables are used to reduce reverse causality, omitted variable bias may still remain. The indicators used as a proxy for infrastructure capture only quantity and quality dimension is not captured by them. Factors such as road condition and reliability of electricity are not included. These may also influence growth. The analysis also not considers spatial spillovers effects. Infrastructure in one state may affect others through trade and labour movement.

Conclusion

Finally, the study focuses on aggregate output and ignores distributional aspects. It also ignores presence of nonlinear or threshold effects. Further research may be undertaken to find whether the impact of infrastructure changes with the level of development.

Appendix Table-1: Road network by Categories (in Km) 1950-51 to 2020-21[58].

Road Category	1950-51	1960-61	1970-71	1980-81	1990-91	2000-01	2010-11	2019-20
National Highways	19811 (4.95)	23798 (4.54)	23838 (2.61)	31671 (2.13)	33650 (1.45)	57737 (1.71)	70934 (1.52)	132499 (2.10)
State Highways	56765 (6.20)	94359 (6.35)	127311 (5.47)	132100 (3.92)	163898 (3.50)	176166 (3.14)	175036 (2.97)	178749 (2.80)
District Roads	173723 (43.44)	257125 (49.02)	276833 (30.26)	421895 (28.40)	509435 (21.89)	736001 (21.82)	998895 (21.36)	612778 (9.70)
Rural Roads*	206408 (51.61)	197194 (37.60)	354530 (38.75)	628865 (42.34)	1260430 (54.16)	1972016 (58.46)	2749804 (58.80)	4522228 (71.40)
Urban Roads	46361 (8.84)	72120 (7.88)	123120 (8.29)	186799 (8.03)	252001 (7.47)	411679 (8.80)	509730 (9.10)	548394 (8.60)
Project Roads	130893 (14.31)	185511 (12.49)	209737 (9.01)	223665 (6.63)	281628 (6.02)	319109 (5.70)	328897 (5.58)	386954 (6.10)
Total	399942	524478	914979	1485421	2327362	3373520	4676838	6331757

Note**:** Figures within parenthesis indicate percentage share of each road category out of total road network of the country. * Includes Other District Roads (ODR) and Village Roads.

Appendix Table-2: Correlation Matrix.

	Road Length	Hwy Length	Road Density	PC PowerAv	GSDP Growth	Agri share	PC NSDP	Industry Share	Service Share
Road Length	1.000	0.800	0.285	0.008	-0.081	-0.032	-0.072	-0.032	0.071
Hwy Length	-	1.000	-0.074	0.177	-0.019	-0.103	0.057	0.062	0.007
Road Density	-	-	1.000	0.107	-0.076	-0.292	0.308	0.051	0.164
PCPowerAv	-	-	-	1.000	0.002	-0.404	0.746	0.497	-0.295
GSDP Growth	-	-	-	-	1.000	-0.075	0.028	0.042	0.009
Agri. share	-	-	-	-	-	1.000	-0.556	-0.584	-0.052
PCGSDP	-	-	-	-	-	-	1.000	0.619	-0.332
Industry Share	-	-	-	-	-	-	-	1.000	-0.779
Service Share	-	-	-	-	-	-	-	-	1.000

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