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# Investigating causality between transport infrastructure and urbanization: A state-level study of India (1991-2011)

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**Abstract**

Transport infrastructure has often been observed to influence urbanization which is again associated with economic development and improvement in quality of life. However, the direction of causality between the two is unclear as it may depend on the particular context which is very much determined by the socio-economic conditions, political policy decisions, etc. Also, the role of different transport sectors (e.g. road, rail, port, etc.) may change in different phases of development and historic condition. This study, thus, attempts to investigate the causal direction between transport infrastructure and urbanization for the post-liberalization period (1991-2011) in India. It has used eleven variables to represent various transport sectors and also categorizes the Indian states into leading, intermediate and lagging groups to find out how the role of various transport sectors changes with various phases of development. The study has used dynamic time series models such as Vector Error-Correction and Vector Auto-Regression for this purpose, which is absent in the present literature. Results showed support in favor of modernization theory of urbanization in most of the cases.


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*Keywords:* *Transport infrastructure; Urbanization; Cointegration; Granger causality; Vector Error-Correction; Vector Auto-Regression.*

## 1. Introduction

Urbanization is often considered as the by-product of the sectoral shift from agriculture to industry and service sector as economy progresses (Henderson, 2003). The level of urbanization, therefore, has been observed to be much higher in developed countries compared to the developing countries (Ray Chaudhuri, 2001, pp. 49-50). Mills and Becker (1986, pp. 17-19) have tried to provide an explanation for this sectoral shift. First, capital accumulation and technological change affect the demand and supply of various goods. As the income elasticity for food items is lesser

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compared to that of industrial goods and services, the return to labor and other inputs is much higher in industry and service sector compared to the agricultural sector. Second, technological progress in industry is likely to be faster than in agriculture partly because the former is easily transferable from developed to the developing countries as the latter depends more on indigenous geographical factors. Third, an educated labor force may be more beneficial for the industry and service sector than the agricultural sector. Also, in an open economy, the demand for trade commodities increases, leading to increase in output and employment. Therefore, the demand for industrial and service goods increases while costs fall relative to the agricultural sector, resulting in sectoral shift in production and employment. Many researchers consider urbanization to be the engine for economic development due to presence of various agglomeration economies (Iimi, 2005; Panudulkitti, 2011; Ray Chaudhuri, 2001, pp. 48-49). Urban areas, apart from being the focal point for economic growth, innovation and employment, are centers for modern facilities (e.g. better healthcare facilities), literacy, women's status and social mobility, and are also important cultural centers with theatres, museums, art galleries, fashion houses etc (Cohen, 2006). It, therefore, also represents quality of life.

Pradhan (2007) found that infrastructure development and level of urbanization is correlated for the Indian states and the value of correlation coefficient has increased over time, i.e., infrastructure has emerged to be a more important factor in determining urbanization in India over time. Urbanization has been observed to occur sooner when cost of transportation is lower (Motamed et al., 2014). It is also found that most of the primate cities in developing world are situated along seaboard (Brutzkus, 1975) and according to the theorists of economic geography, coastal regions are more developed and densely populated compared to interior regions (Hausmann, 2001; Sachs et al., 2001). This indicates that access to major ports plays a significant role in determining the level of urbanization. However, it is not clear whether improvement in transport infrastructure in a region attract people due to improvement in accessibility and thus productivity (by reducing cost of transportation) and subsequently urbanization, or agglomeration of people create demand first and this in turn cause investment in infrastructure, or they happen simultaneously (feedback hypothesis).

As per the Census, India was 31.2% urbanized in 2011. This is quite low compared to the urbanization level of the developed countries like the United States of America (82.4%) and Japan (91.3%) or other fast growing developing countries such as China (50.6%) and Brazil (84.6%) or even the global average of 52.1% (United Nations, 2012). However, the pattern of investment and urbanization varies across India. Disparities between states have been steadily increasing over time in India, especially after liberalization (Bhattacharya and Sakthivel, 2004; Dholakia, 2003; Ghosh et al., 1998; Kar and Sakthivel, 2006; Marjit and Mitra, 1996). On one side, there are states such as Maharashtra and Gujarat which has urbanization level of more than 40%, on the other side, the states such as Bihar and Odisha has urbanization level of less than 20%. The increasing disparities in terms of regional economic growth in India have impacted urbanization also. For the last two decades coastal districts in India have raised their share of national investment by more than ten percent (Chakravorty and Lall, 2007), and most of the foreign investments have been dictated by the location of ports which have caused high urbanization rate in those states, leaving the interior states less urbanized. Moreover, Hansen (1965a, 1965b) showed that the effect of infrastructure investment can be different in different types of region. Therefore, planners have to decide the most suitable strategy for development of a region, which requires proper understanding of the nature of development and how investment in transport infrastructure can affect that region.

The increase in the share of urban population can be due to several reasons, such as, natural increase in urban population, migration from rural to urban areas, geographical expansion of existing urban areas and reclassification and transformation of rural villages into small urban settlements. As the rate of natural increase of population is generally lower in the urban areas than the rural areas, the other three factors are considered to be more important for increasing urbanization (Cohen, 2006). However, migration or change of location of people from rural to urban areas is considered to be the principal mechanism for rapid increase in urban population in developing countries (Ramachandran, 2001, pp. 90-91; Sovani, 1966). About one-third to half of the increase in urban population in the developing countries is due to migration (London, 1987). The causes of this high rate of urban population growth seem to be very important. Three theories of urbanization dominate in this context, namely, *modernization*, *urban-bias* and *dependency*. The relationship between the pattern of investment in infrastructure and urbanization can be studied in the light of these theories.

According to modernization theory (Hawley, 1944, 1971; Wilson, 1984), urbanization happens with the advancement of technology and sectoral shift from primary to secondary and/or tertiary sector activities and depends on indigenous characteristics of that region. It is, thus, in line with endogenous growth theory and indicates that investment in infrastructure in a particular region will lead to development and thus urbanization in that region. Urban-bias theory (Bezemer and Headey, 2008; Bradshaw, 1987; Lipton, 1977; London and Smith, 1988), on the other hand, emphasizes on the increasing rural-urban disparity and deteriorating condition in the rural areas and says migration happens due to urban 'pull' and rural 'push'. Therefore, in this case, urbanization happens due to the difference in investment in infrastructure between urban and rural areas, with urban areas getting the higher share of investment. Supporters of dependency theory (Chase-Dunn, 1975; Clark, 2008; Kentor, 1981, 1998; Smith, 1987; Timberlake and Kentor, 1983) think economy of the peripheral (developing) countries is controlled by core (developed) countries. Due to high dependency on foreign investment, there is uneven development and unequal exchange between regions in developing countries, as profitable areas get most of the investment for infrastructure development and other areas are neglected. Therefore, as per this theory, the high rate of migration to urban areas is the outcome of unequal development and exploitative nature of the capitalist system. Lipton (1977), on one side, stressed on Urban-bias theory, on the other side, Smith (1987) feels dependency theory as dominating in the 'Third World' countries, whereas London and Smith (1988) finds both factors to be significant simultaneously. London and Smith (1988), moreover, pointed out that there is a high correlation between urban bias and dependency. Bradshaw (1987), on the other hand, got evidence in support of all the three theories for the 'Third World' countries.

Therefore, to know the effect of transport infrastructure investment on urbanization, it is important to know the pattern of investment in the light of the theories of urbanization, which can help in taking policy decisions for investment judiciously. If the causality runs from transport infrastructure representing indigenous investment (e.g. total road density) to urbanization, then support in favor of modernization theory will be obtained. Urban-bias theory will be said to be dominating if the causal factor for urbanization is found to be the variable representing the difference in investment in the transport sector between urban and rural areas (e.g. urban road versus rural road). On the other hand, if the causality is found to run from transport infrastructure representing international goods movement (e.g. port) to urbanization, then dependency theory may be considered to be more important than others.

The present study attempts to investigate the causal relationship between transport infrastructure and urbanization for India by using state level data. It has categorized the states into leading, intermediate and lagging regions and tried to find out whether the relationship changes with the type of region. To understand the relationship in the present context, the study focuses on the post-liberalization period (1991-2011) as there has been significant changes in the policies compared to the previous period, such as, reduction in state control over prices and economic activities, privatization of state assets and easing rules for Foreign Direct Investment (Ghosh, 2013; Kohli, 2006). The study has also used dynamic models such as Vector Error Correction (VEC) and Vector Auto-Regression (VAR) instead of static models such as correlation and regression which can only establish contemporaneous association between variables, and not causality (Wooldridge, 2013, pp. 334-336, 631-632). The dynamic time series approach, whereas, talks about causality in a temporal sense, i.e., precedence and predictability. This is quite absent in the present literature.

After introduction, Section 2 reviews literature on the changing relationship between transport infrastructure and urbanization over various historic periods. Section 3 discusses the method adopted in the study and sources of data. Section 4 discusses the results. The final section concludes the study and discusses on the relevant policy implications in the light of the theories of urbanization.

## 2. Literature review

Urbanization has a very close relation with regional development. The coefficient of correlation across countries between urbanization and per capita Gross Domestic Product (GDP) was found to be 0.85 (Henderson, 2003). Improved transport infrastructure improves access to the market and profitability of the urban firms by lowering transport cost. Urbanization can lead to improvement in quality of life; however, excessive urbanization (or over-urbanization) may pose several economic and social problems (Davis and Golden, 1954; Gugler, 1982; Smith 1987; Timberlake and Kentor, 1983). The pattern of investment in transport infrastructure and its relationship with urbanization may also change across various historic periods. Table 1 attempts to capture this for India.

Table 1: Development of transport infrastructure and urbanization in India

| Period | Description | Sources |
|---|---|---|
| Pre-British-Colonial period (Mughal period, 1526-1757) | The need for building good transport system was not felt in the feudal system. Inland connectivity in terms of road was very poor. Pack animals were only means of inland transport. This led to fragmented regional markets. Some grain shipment can be observed via river (mainly the Ganges) and sea, and expensive goods were exported via maritime trade. Urbanization was also very much limited. Large number of small towns was there with few capital towns. Most of the towns and major cities were located in the northern India which was dominated by the Mughals. | Ramachandran, 2001; Raychaudhuri, 2013; Rothermund, 1988 |
| Establishment of the British rule (1757-1850) | The British were busy with increasing political power and trading via port, than concentrating on development of transport infrastructure within India. Only few roads were built for military purposes. However, from 1830s funds were allocated for road construction on a regular basis. Dependence on boats and ships for carrying cargo was increasing. Trading along the Ganges became very important. It also acted as a link to the world via Calcutta for import and export of commodities. There was decline or stagnation of older cities and a rapid growth of the new colonial metropolis which were located near the ports. There was rapid growth of the cities and towns of the Ganges valley due to expansion in trade along the river. | Bhattacharya and Chaudhuri, 2013; Chaudhuri, 2013; Kessinger, 2013; Ramachandran, 2001 |
| Development of Modern Industry and Railway (1850 – 1900) | Expansion of railways after 1853 helped in easy freight movement within India. Opening of the Suez Canal in 1869 reduced distance between India and Great Britain. The major railway lines connected the ports with the production centres or urban markets. Development of roads was complementary to the railways. There were also some 'Famine Lines' and some lines for military concern. Increase in the level of urbanization can be observed in between 1870 and 1900, which could be due to expansion of railways and industrial activities. Industries were located mainly in and around major cities e.g. Bombay, Calcutta and Madras. Thus, growth of metropolitan cities along with some major inland towns can be observed. Several new railway towns also emerged. | Hurd, 2013; Rothermund, 1988 |
| Era of World Wars and Independence (1900-1947) | Connection of maritime trade with Europe was disrupted during the two World Wars. Local transport attracted great deal of investment in the 1930s. Private investment in road transport increased a lot. The period of urban stagnation or slow growth can be observed until 1931, whereas, there was rapid increase in urban population after that. Calcutta, Bombay and Madras were the leading cities. Rapid increase in urban population after 1930 could also be due to improvement in urban amenities and administration and rapid migration from rural to urban areas. | Morris, 2013; Ramachandran, 2001; Rothermund, 1988 |
| Development in Statist Model (1947-1980) | Investment in infrastructure development was stepped up after independence. The first two five year plans tried to serve passenger and goods movement to and from the steel plants and coal mines; but special emphasis on transport and communication was given during the third plan. However, railways were neglected. Subsequent plans emphasized on modernization and increased efficiency rather than augmentation of its capacity. Although, the rate of urbanization was not very high after independence, urban population grew rapidly, especially the one lakh (population greater than 100,000) and metropolitan cities. On the other hand, smaller towns started to stagnate or decline. Several new state capitals and industrial towns were built. | Datt and Mahajan, 2013; Kundu, 1983; Ramachandran, 2001; Rothermund, 1988 |
| A. Domestic Reform (1980-1990) | Public investment as percentage share of GDP increased after 1980 and peaked during 1986-87; however, after 1987, public investment started to decline and private investment accelerated. Urbanization increased from 23.7% in 1981 to 25.7 % in 1991. | Ramachandran, 2001; Rothermund, 1988 |
| B. External Reform and Liberalization (1991 onwards) | In 1990s, public investment in urban infrastructure declined considerably. Poor states failed to attract more investment due to poor level of infrastructure. Although, road construction, especially highway construction, increased rapidly as it provides much flexibility in movement, railways stagnated, though some form of modernization was tried. Shipping through port and civil aviation saw tremendous increase in goods and passenger movement. Higher rate of urbanization was observed, though there was a decline in the growth rate of urban population. The trend of increasing concentration of population in metropolitan cities and class I towns and stagnation and decline in the percentage share of population for smaller towns continued. Total number of towns also increased rapidly. There was also trend for increasing number of urban agglomeration and outgrowth. Cities specialized in service sector, especially IT, prospered more than others. | Datt and Mahajan, 2013; Ghosh, 2013; Kohli, 2006; Sridhar and Reddy, 2011; Zhang, 2012 |

Table 1 shows that transport infrastructure and urbanization has remained interlinked over various historic periods. However, it must be mentioned that factors such as major economic and political changes can influence the relationship. Moreover, various sectors of transport infrastructure (e.g. road, rail, port etc.) can dominate various phases of development.

Dynamic approach involving concepts such as cointegration and Granger causality which uses time series data to find out stationarity and causality (in terms of precedence and predictability) between variables and does not impose the restriction of exogenity on the variables has emerged in the last few decades. Although, some recent studies have incorporated this approach to investigate the relationship between transport infrastructure and economic development (e.g. Hu et al., 2015; Keho and Echui, 2011; Marazzo et al., 2010; Pradhan, 2010a, 2010b; Pradhan and Bagchi, 2013; Tripathi and Gautam, 2010; Yu et al., 2012) and also between economic development and urbanization (e.g. Ghosh and Kanjilal, 2014; Kasman and Duman, 2015; Sahu, 2013; Shahbaz et al., 2014; Solarin and Shahbaz, 2013), studies on the causal relationship between transport infrastructure and urbanization were not found. This present study attempts to fill up this gap by adopting dynamic models for analysis.

## 3. Method and sources of data

As mentioned earlier, state level data has been used for analysis in the present study. Currently, India has 29 states which form its main administrative units. Indian states are comparable with many European countries in terms of population size. Originally, the states were formed based on language, but one can also observe diversity in terms of topography, culture, mineral resources etc. across the states. There is also considerable variation between the states in terms of economic development, urbanization and the degree of investment in transport infrastructure. The federal structure of India allows its states to take independent decisions in many policy issues.

However, the present study attempts to find out the causal relationship between transport infrastructure and urbanization using panel data of 15 major states in India. The study essentially excluded the north-eastern and northern hilly states because of the drastic difference in their geographical nature which may distort the results by acting as outliers. As per the Census of India 2011, these 15 states constitute more than 90% of India's population. The states are Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh and West Bengal. Three new states namely Jharkhand, Chhattisgarh and Uttarakhand were formed in the year 2000 dividing Bihar, Madhya Pradesh and Uttar Pradesh respectively. Therefore, the data for Bihar, Madhya Pradesh and Uttar Pradesh includes the data for the new states for the year 2000 and onwards. Another new state, Telangana, was formed from the state of Andhra Pradesh in 2014. However, as this does not come within the period of study of the present research, this did not affect the database.

The study tries to categorize the Indian states to find out the relationship between transport infrastructure and urbanization separately for different regions. This is to understand how the relationship changes with different phases of development. For this purpose, the study has adopted the categorization proposed by Narayan et al. (2012) and related literature (Bandyopadhyay, 2011; Lall, 1999; Rao, 2000; Rao et al., 1999), which divides Indian states predominantly based on their income level. The states are classified into leading, intermediate and lagging categories and are shown in table 2.

Table 2: Classification of Indian states

| Type | Name of the states |
|---|---|
| Leading | Gujarat, Haryana, Maharashtra and Punjab. |
| Intermediate | Andhra Pradesh, Karnataka, Kerala, Tamil Nadu and West Bengal. |
| Lagging | Assam, Bihar (including Jharkhand), Madhya Pradesh (including Chhattisgarh), Odisha, Rajasthan and Uttar Pradesh (including Uttarakhand). |

While investigating the relationship between transport infrastructure and urbanization, the major problem faced was to get the annual data for urbanization at the state level as data is available only for the census years (i.e. 1991, 2001 and 2011). Therefore, these figures have been estimated using cohort component method which has been discussed in details in Appendix A.

Indian transport system can be categorized under four broad heads based on the modes of transportation, namely, road, rail, water, and air. Among these, road and rail dominate the transport system in India. The water transport system can be categorized as inland water or river transport and coastal or marine transport. As the inland water transport carries only a negligible part (about 0.15%) of the domestic freight transport (Datt & Mahajan, 2013, p. 148), therefore, this study considers road, rail, port, and airways infrastructure only. Total eleven variables have been used to represent the four sub-sectors of transport infrastructure. Table 3 shows the list of variables and their units of measurement. Six variables, which also represent the various types/hierarchies of road in India, have been taken to represent road sub-sector; whereas, railway density represents the rail sub-sector. As only number of airports does not adequately capture airways infrastructure, therefore, two variables have been taken to represent airways infrastructure – airways passenger and airways freight. Similarly, port infrastructure is represented by cargo handled through ports as number of passenger carried through seaports is negligible compared to the cargo handled. Moreover, total government expenditure in the transport sector has been taken to understand the overall influence of all the sub-sectors. Urbanization, on the other hand, has been represented by only one variable (percentage share of population in the urban areas). Annual time series data has been used for all variables. The variable Urban Road (UB), which measures the share of road in the urban areas out of total road, can also be considered to represent urban bias (especially, in road infrastructure), as it indicates the difference in investment between urban and rural road. The data for expenditure has been adjusted for inflation using Wholesale Price Index (WPI) series data over time. As separate series is not available for individual states, WPI data for India has been used as a proxy for the same. Natural logarithm of all variables has been taken to reduce heteroscedasticity (Cheng, 2012; Yu et al., 2012).

Table 3: List of variables and their units of measurements

| Variables | Units |
|---|---|
| *Transport Infrastructure (TRI):* | |
| *Road Infrastructure* | |
| Total Road Density (ROAD) | Total length of all roads (km) per 1000 sq km area |
| Surfaced Road Density (SROAD) | Total length of surfaced roads (km) per 1000 sq km area |
| National Highway Density (NH) | Total length of National Highways (km) per 1000 sq km area |
| State Highway Density (SH) | Total length of State Highways (km) per 1000 sq km area |
| Other PWD Road Density (PWD) | Total length of Other PWD roads (km) per 1000 sq km area |
| Urban Road/Bias (UB) | Length of urban roads (km) per 100 km of total road |
| *Rail Infrastructure* | |
| Railway Density (RAIL) | Total length of Railways (km) per 1000 sq km area |
| *Airways Infrastructure* | |
| Airways – Passenger (AIRP) | Airways passenger per 100,000 population |
| Airways – Freight (AIRF) | Airways freight (in tons) per 1000 population |
| *Port Infrastructure* | |
| Port (PORT) | Cargo handled at ports (in thousand tons) per 100,000 population |
| *Total Expenditure on Transport Infrastructure* | |
| Total Transport Expenditure (TREX) | Per capita combined expenditure (capital + revenue) by the state in transport and communication sector (inflation adjusted using WPI series data for India) in Rupees |
| *Urbanization:* | |
| Urbanization (URB) | Urban population as a percentage share of total population |

*Surfaced* road means *Paved* road, PWD: Public Works Department, WPI: Wholesale Price Index.

The source of the data for total expenditure in transport sector is the Reserve Bank of India (compiled from statistics released over the time). Urbanization data for the years 1991, 2001 and 2011 were taken from the Census of India. The source of the data for airways infrastructure is Airport Authority of India, whereas data for other transport infrastructure variables has been taken from basic road and port statistics of India, published by the Ministry of Road Transport and Highways and Ministry of Shipping, Government of India, over various years. However, it is to be noted that the data for RAIL (Railway Density), AIRP (Airways-Passenger) and AIRF (Airways-Freight) was available for the period 2001 to 2011 only and for TREX (Total Expenditure on Transport Infrastructure), it was available for the period 1991 to 2010, whereas, for other variables, the time period is 1991 to 2011.

The present study uses dynamic time series analysis to investigate causal relationship between variables. The basic approach constitutes three steps, namely, test for order of integration (or unit root test), test for cointegration and Granger causality test. In this method, first, the variables are analyzed for their stationarity and level of integration, i.e., whether the mean and variance change over time. Second, the variables with same level of integration are checked for cointegration, which means checking existence of long-run relationship between variables. After that, the causality (Granger causality) between variables is tested in terms of precedence and predictability. All these tests have been conducted in panel framework. They are discussed below.

### *3.1. Panel unit root test*

For a panel data, an AR(1) process can be represented by Eq. 1:

$$y_{it} = x_{it}'b_i + \rho_i y_{it-1} + \varepsilon_{it} \tag{1}$$

Where, $y_{it}$ is the panel data series, $i$ represents the cross section unit and $t$ is the time period, $x_{it}$ are exogenous variables, $b$ and $\rho$ are parameters to be estimated and $\varepsilon_{it}$ are the error terms. If $|\rho_i|<1$, the series is said to be stationary (weakly); on the other hand, if $|\rho_i|=1$, the series contains unit root, and in that case it is non-stationary.

The present study adopts four types of panel unit root tests as different tests have different types of shortcomings. The Levin, Lin and Chu (2002) test assumes that $\rho_i = \rho$ for all $i$, whereas, Im, Pesaran and Shin (2003) and Fisher-type tests using ADF (Augmented Dickey-Fuller) and PP (Phillips-Perron) tests allows $\rho_i$ to vary across all $i$. The Fisher-type tests were developed by Maddala and Wu (1999) and Choi (2001). They used Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979, 1981) and Phillips-Perron (PP) test (Phillips and Perron, 1988) for checking individual unit root. Then they considered Fisher's (1932) results to combine the *p*-values from individual unit root tests. Majority's decision has been considered in case the results were found to be contradictory in different tests.

If a variable is found to be stationary at level (i.e. without differencing), then its order of integration is zero and is represented by I(0). If a variable becomes stationary after differencing '*d*' times, then its order of integration is '*d*' and is denoted by I(*d*).

### *3.2. Panel cointegration test*

Although, the linear combinations of non-stationary variables, say I(1), are generally non-stationary, however, if they are integrated of same order, their linear combination can be stationary i.e. I(0), and then the variables are said to be cointegrated which represents long-run equilibrium relationship (Engle and Granger, 1987).

Engle and Granger (1987) test of cointegration method tests unit root for the residuals estimated from the cointegrating regressions between variables. This method has been extended for panel data by Pedroni (1999, 2004) and Kao (1999).

On the other hand, Johansen (1991, 1995) test of cointegration approach tests cointegration in a vector framework. For cointegration test using panel data, Maddala and Wu (1999) developed Fisher type test combining results of individual tests and following Johansen's methodology, and this has been adopted in the present study.

### 3.3. Panel Granger causality test

A variable $x$ is said to be Granger causal to variable $y$ if lagged values of $x$ can improve the predictability of $y$ provided all other information is present (Gujarati et al., 2012, pp. 687-688). This concept can be extended to multivariate and panel framework.

Granger causality (Granger, 1969) is tested in Vector Error Correction (VEC) framework when variables are cointegrated i.e. when they have long-run relationship. The VEC model for testing Granger causality between Transport Infrastructure (TRI) and Urbanization (URB) is shown in Eq. 2:

$$\begin{bmatrix}\Delta lnTRI_{it}\\ \Delta lnURB_{it}\end{bmatrix} = \begin{bmatrix}\emptyset_{1i}\\ \emptyset_{2i}\end{bmatrix} + \sum_{k=1}^{l}\begin{bmatrix}\emptyset_{11ik} & \emptyset_{12ik}\\ \emptyset_{21ik} & \emptyset_{22ik}\end{bmatrix}\begin{bmatrix}\Delta lnTRI_{it-k}\\ \Delta lnURB_{it-k}\end{bmatrix} + \begin{bmatrix}\theta_{1i}\\ \theta_{2i}\end{bmatrix} EC_{it-1} + \begin{bmatrix}v_{1it}\\ v_{2it}\end{bmatrix} \quad (2)$$

Here, $EC_{it-1}$is the lagged error correction term representing long-run relationship between variables, $\emptyset$s and $\theta$s are the coefficients to be estimated, $l$ is the maximum lag length and $\Delta$ is the first difference operator. Long-run causal relationship is said to exist when $\theta$ is negative and significantly different from zero, whereas short-run causality is represented by the coefficients of the lagged (and differenced) independent variables. Wald test has been used to know the joint significance of the lagged independent variables when the number of lag is more than one.

The transport infrastructure (TRI) variables which were not found to be cointegrated with Urbanization (URB), have been included in Vector Auto-Regression (VAR) model for testing short-run Granger causality. In case of VAR model, all variables have been taken in stationary form. The VAR model for testing Granger causality between Transport Infrastructure (TRI) and Urbanization (URB) has been shown in Eq. 3:

$$\begin{bmatrix}lnTRI_{it}\\ lnURB_{it}\end{bmatrix} = \begin{bmatrix}\varphi_{1i}\\ \varphi_{2i}\end{bmatrix} + \sum_{k=1}^{l}\begin{bmatrix}\varphi_{11ik} & \varphi_{12ik}\\ \varphi_{21ik} & \varphi_{22ik}\end{bmatrix}\begin{bmatrix}lnTRI_{it-k}\\ lnURB_{it-k}\end{bmatrix} + \begin{bmatrix}v_{1it}\\ v_{2it}\end{bmatrix} \quad (3)$$

Where, $\varphi$s are the coefficients to be estimated, $l$ is the maximum lag length and $v_{it}$ are the error terms.

Maximum lag length has been determined using Akaike (1974), Hannan-Quinn (1979) and Schwarz (1978) information criteria for both VAR and VEC models. In case the results are contradictory, majority's decision has been considered.

## 4. Summary of results

### 4.1. Panel unit root test results

The results of panel unit root tests for leading, intermediate and lagging states along with panel of all 15 states are shown in table 4. Results show that Urbanization (URB) is I(2) for the leading and intermediate states, whereas, it is I(1) for the lagging states and also when all 15 states are considered together, whereas, transport infrastructure variables are either I(0) or I(1). Hence, the variable Urbanization (URB) is non-stationary (i.e. its mean and variance is not constant over the time), whereas, transport infrastructure variables are stationary (i.e. its mean and variance is constant over the time) in some cases (when they are I(0)) and non-stationary in other cases (when they are I(1)). The time trend present in Urbanization (URB) is, therefore, different from those of transport infrastructure variables, especially, in case of leading and intermediate states. On the other hand, in case of lagging states and when all 15 states were considered together, the trends may be similar (i.e. they may have long-run relationship) when both Urbanization (URB) and transport infrastructure variables are I(1).

Table 4: Summary of results for panel unit root tests

| Variable | Type of states/ region | | | |
|---|---|---|---|---|
| | Leading | Intermediate | Lagging | All 15 states |
| lnURB | I(2) | I(2) | I(1) | I(1) |
| lnROAD | I(1) | I(0) | I(1) | I(0) |
| lnSROAD | I(1) | I(0) | I(1) | I(1) |
| lnNH | I(1) | I(1) | I(1) | I(1) |
| lnSH | I(1) | I(1) | I(0) | I(1) |
| lnPWD | I(1) | I(1) | I(0) | I(1) |
| lnUB | I(1) | I(1) | I(1) | I(1) |
| lnRAIL | I(1) | I(1) | I(0) | I(0) |
| lnAIRP | I(0) | I(1) | I(0) | I(0) |
| lnAIRF | I(1) | I(1) | I(0) | I(0) |
| lnPORT | I(1) | I(0) | I(0) | I(0) |
| lnTREX | I(1) | I(1) | I(1) | I(1) |

### *4.2. Panel cointegration test results*

As Urbanization (URB) was found to be I(2) for the leading and intermediate states, it cannot be cointegrated with Transport Infrastructure (TRI) variables for those states as all of them are either I(1) or I(0). However, test of cointegration is possible in case of the lagging states and also when all 15 states are taken together, as Urbanization is I(1) for those cases. All Transport Infrastructure (TRI) variables which are I(1) in those two categories, therefore, have been tested for cointegration. Table 5 shows the results for Johansen Fisher type panel cointegration test for those variables.

Table 5: Results for Johansen Fisher panel cointegration test

| Variables | Fisher Stat | | Remarks |
|---|---|---|---|
| | Trace test | Max. Eigen test | |
| *Lagging states* | | | |
| lnURB and lnROAD | 41.92*** | 29.85*** | Cointegrated |
| lnURB and lnSROAD | 59.95*** | 44.75*** | Cointegrated |
| lnURB and lnNH | 51.12*** | 48.09*** | Cointegrated |
| lnURB and lnUB | 52.28*** | 42.96*** | Cointegrated |
| lnURB and lnTREX | 26.03** | 19.87* | Cointegrated |
| *All 15 states* | | | |
| lnURB and lnSROAD | 120.10*** | 98.04*** | Cointegrated |
| lnURB and lnNH | 141.70*** | 122.90*** | Cointegrated |
| lnURB and lnSH | 71.98*** | 54.20*** | Cointegrated |
| lnURB and lnPWD | 107.40*** | 88.84*** | Cointegrated |
| lnURB and lnUB | 74.34*** | 59.89*** | Cointegrated |
| lnURB and lnTREX | 110.50*** | 96.56*** | Cointegrated |

***significant at 1% level, **significant at 5% level, *significant at 10% level.

Table 5 shows that for lagging states, Total Road Density (ROAD), Surfaced Road Density (SROAD), National Highway Density (NH), Urban Road (UB) and Total Expenditure on Transport Infrastructure (TREX) have been found to be cointegrated with Urbanization (URB) (i.e. those transport infrastructure variables have long-run relationship with Urbanization for the lagging states). When all 15 states are taken together, Urbanization (URB) has been found to be cointegrated with Surfaced Road Density (SROAD), National Highway Density (NH), State Highway Density (SH), Other PWD Road Density (PWD), Urban Road (UB) and Total Expenditure on Transport Infrastructure (TREX). Therefore, these transport infrastructure variables have long-run relationship with Urbanization when all 15 states were considered together. However, final decision on the long-run relationship has been taken if the lagged error correction term in the VEC model is found to be negative and significant.

### *4.3. Panel Granger causality test results*

#### *4.3.1 VEC model test results*

As cointegration was possible only in case of the lagging states and when all 15 states are taken together, therefore, VEC model is considered for those two categories only. Table 6 shows the results of the VEC model for the lagging states. The Wald test results for joint significance of the lagged independent variables for the lagging states have been reported in Table 7.

Table 6 shows long-run unidirectional causality from Urbanization (URB) to National Highway Density (NH) and Urban Road (UB). Also, short-run unidirectional causality has been observed from National Highway Density (NH) to Urbanization (URB) and from Urbanization (URB) to Urban Road (UB) (Table 7). No long-run causal relationship has been found in case of the relationships between Urbanization (URB) and Total Road Density (ROAD), Surfaced Road Density (SROAD) and Total Expenditure on Transport Infrastructure (TREX).

Table 6: Results of VEC model for lagging states

| VEC model of lnURB and lnROAD | | |
|---|---|---|
| Dependent variable: | Δ(lnURB) | Δ(lnROAD) |
| C | 0.0011*** | -0.0054 |
| Δ(lnURB(-1)) | 0.6096*** | 2.0098 |
| Δ(lnURB(-2)) | 0.2736*** | 2.6169 |
| Δ(lnROAD(-1)) | -0.0014 | 0.0461 |
| Δ(lnROAD(-2)) | -0.0024 | 0.1445 |
| EC(-1) | -0.0002 | -0.0123 |
| Adjusted R-squared | 0.8566 | 0.0154 |
| VEC model of lnURB and lnSROAD | | |
| Dependent variable: | Δ(lnURB) | Δ(lnSROAD) |
| C | 0.0009*** | 0.0288 |
| Δ(lnURB(-1)) | 0.6532*** | -5.0179 |
| Δ(lnURB(-2)) | 0.2382*** | 5.9841 |
| Δ(lnSROAD(-1)) | 0.0008 | 0.0008 |
| Δ(lnSROAD(-2)) | -0.0010 | 0.1962** |
| EC(-1) | -0.0007 | -0.0259 |
| Adjusted R-squared | 0.8571 | 0.0017 |
| VEC model of lnURB and lnNH | | |
| Dependent variable: | Δ(lnURB) | Δ(lnNH) |
| C | 0.0006* | 0.0386* |
| Δ(lnURB(-1)) | 0.6248*** | 0.7252 |
| Δ(lnURB(-2)) | 0.2831*** | -1.9840 |
| Δ(lnNH(-1)) | 0.0034** | 0.1650* |
| Δ(lnNH(-2)) | -0.0004 | 0.1662* |
| EC(-1) | 0.0003 | -0.0562*** |
| Adjusted R-squared | 0.8591 | 0.1088 |
| VEC model of lnURB and lnUB | | |
| Dependent variable: | Δ(lnURB) | Δ(lnUB) |
| C | 0.0008*** | 0.0350 |
| Δ(lnURB(-1)) | 0.6674*** | 37.6363*** |
| Δ(lnURB(-2)) | 0.2269** | -10.9294 |

| | | |
|---|---|---|
| Δ(lnURB(-3)) | -0.0051 | -30.1745*** |
| Δ(lnUB(-1)) | 0.0001 | -0.0689 |
| Δ(lnUB(-2)) | 0.0004 | -0.1120 |
| Δ(lnUB(-3)) | -0.0001 | 0.0006 |
| EC(-1) | -0.0001 | -0.0693** |
| Adjusted R-squared | 0.8678 | 0.1480 |
| VEC model of lnURB and lnTREX | | |
| Dependent variable: | Δ(lnURB) | Δ(lnTREX) |
| C | 0.0011* | 0.0240 |
| Δ(lnURB(-1)) | 0.6134*** | 12.0228 |
| Δ(lnURB(-2)) | 0.2462*** | -5.2318 |
| Δ(lnTREX(-1)) | -0.0004 | -0.1513 |
| Δ(lnTREX(-2)) | -0.0002 | 0.0021 |
| EC(-1) | -0.0007 | -0.0426 |
| Adjusted R-squared | 0.8525 | -0.0052 |

***significant at 1% level, **significant at 5% level, *significant at 10% level.

Table 7: Results of Wald test for joint significance (lagging states)

| Dependent variable | Independent variable | F-statistic | Chi-square |
|---|---|---|---|
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnNH | | | |
| ΔlnURB | ΔlnNH | 2.3172 | 4.6344* |
| ΔlnNH | ΔlnURB | 0.1979 | 0.3959 |
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnUB | | | |
| ΔlnURB | ΔlnUB | 0.0915 | 0.2746 |
| ΔlnUB | ΔlnURB | 5.9878*** | 17.9635*** |

***significant at 1% level, **significant at 5% level, *significant at 10% level.

Table 8 shows the results for VEC model when all 15 states are considered together. Long-run unidirectional causality has been observed from Surfaced Road Density (SROAD) to Urbanization (URB) and from Urbanization (URB) to National Highway Density (NH), Other PWD Road Density (PWD) and Urban Road (UB). On the other hand, long-run bidirectional causality has been found between Urbanization (URB) and State Highway Density (SH). The Wald test results for joint significance of the lagged independent variables, when all 15 states are taken together, have been reported in Table 9.

Table 8: Results of VEC model for all 15 states

| VEC model of lnURB and lnSROAD | | |
|---|---|---|
| Dependent variable: | Δ(lnURB) | Δ(lnSROAD) |
| C | 0.0015*** | 0.0324** |
| Δ(lnURB(-1)) | 0.8990*** | 1.3314 |
| Δ(lnURB(-2)) | 0.0045 | -0.8390 |
| Δ(lnSROAD(-1)) | -0.0009 | 0.0235 |
| Δ(lnSROAD(-2)) | -0.0015 | 0.0618 |
| EC(-1) | -0.0021*** | -0.0327 |
| Adjusted R-squared | 0.8562 | -0.0077 |
| VEC model of lnURB and lnNH | | |
| Dependent variable: | Δ(lnURB) | Δ(lnNH) |
| C | 0.0008* | 0.0256*** |
| Δ(lnURB(-1)) | 0.9216*** | -0.1853 |
| Δ(lnURB(-2)) | 0.0151 | 0.4495 |
| Δ(lnNH(-1)) | 0.0032 | 0.1876*** |
| Δ(lnNH(-2)) | 0.0050 | 0.0492 |
| EC(-1) | 0.0004* | -0.0398*** |
| Adjusted R-squared | 0.8544 | 0.0715 |

| VEC model of lnURB and lnSH | | |
|---|---|---|
| Dependent variable: | Δ(lnURB) | Δ(lnSH) |
| C | 0.0010** | 0.0099 |
| Δ(lnURB(-1)) | 0.9297*** | -0.8256 |
| Δ(lnURB(-2)) | 0.0174 | 1.8078 |
| Δ(lnSH(-1)) | 0.0001 | -0.1128* |
| Δ(lnSH(-2)) | -0.0017 | -0.0794 |
| EC(-1) | -0.0012** | -0.0689*** |
| Adjusted R-squared | 0.8535 | 0.0474 |
| VEC model of lnURB and lnPWD | | |
| Dependent variable: | Δ(lnURB) | Δ(lnPWD) |
| C | 0.0010** | 0.0097 |
| Δ(lnURB(-1)) | 0.9389*** | -0.1563 |
| Δ(lnURB(-2)) | 0.0064 | 1.8156 |
| Δ(lnPWD(-1)) | -0.0004 | -0.0057 |
| Δ(lnPWD(-2)) | 0.0005 | 0.0320 |
| EC(-1) | -0.0001 | -0.1414*** |
| Adjusted R-squared | 0.8512 | 0.0719 |
| VEC model of lnURB and lnUB | | |
| Dependent variable: | Δ(lnURB) | Δ(lnUB) |
| C | 0.0009** | 0.0190 |
| Δ(lnURB(-1)) | 0.9408*** | 2.3471 |
| Δ(lnURB(-2)) | 0.0125 | -3.7533 |
| Δ(lnUB(-1)) | 0.0013 | 0.0114 |
| Δ(lnUB(-2)) | 0.0003 | -0.0739 |
| EC(-1) | -0.0001 | -0.0475** |
| Adjusted R-squared | 0.8507 | 0.0212 |
| VEC model of lnURB and lnTREX | | |
| Dependent variable: | Δ(lnURB) | Δ(lnTREX) |
| C | 0.0011** | 0.0614*** |
| Δ(lnURB(-1)) | 0.9354*** | 2.8134 |
| Δ(lnURB(-2)) | -0.0003 | -2.1032 |
| Δ(lnTREX(-1)) | -0.0006 | -0.1106* |
| Δ(lnTREX(-2)) | 0.0011 | 0.0073 |
| EC(-1) | -0.0004 | -0.0472 |
| Adjusted R-squared | 0.8390 | 0.0138 |

***significant at 1% level, **significant at 5% level, *significant at 10% level.

Table 9: Results of Wald test for joint significance (all 15 states)

| Dependent variable | Independent variable | F-statistic | Chi-square |
|---|---|---|---|
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnSROAD | | | |
| ΔlnURB | ΔlnSROAD | 0.4584 | 0.9168 |
| ΔlnSROAD | ΔlnURB | 0.3073 | 0.6146 |
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnNH | | | |
| ΔlnURB | ΔlnNH | 1.9702 | 3.9403 |
| ΔlnNH | ΔlnURB | 0.1686 | 0.3373 |
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnSH | | | |
| ΔlnURB | ΔlnSH | 0.5409 | 1.0819 |
| ΔlnSH | ΔlnURB | 0.6766 | 1.3531 |
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnPWD | | | |
| ΔlnURB | ΔlnPWD | 0.3358 | 0.6716 |
| ΔlnPWD | ΔlnURB | 0.3426 | 0.6852 |
| Wald test for joint significance of lagged variables of ΔlnURB and ΔlnUB | | | |
| ΔlnURB | ΔlnUB | 0.3524 | 0.7048 |
| ΔlnUB | ΔlnURB | 1.7098 | 3.4196 |

***significant at 1% level, **significant at 5% level, *significant at 10% level.

Table 10 presents a summary of results of panel Granger causality test using VEC model for Transport Infrastructure (TRI) and Urbanization (URB). Long-run causal relationships were observed only for the lagging states and also when all 15 states were considered together. It has been observed that, in general, the direction of long-run causality is from Urbanization (URB) to Transport Infrastructure (TRI). Only, Surface Road Density (SROAD) showed long-run influence on Urbanization (URB) when all 15 states were taken together. Moreover, National Highway Density (NH) showed short-run influence on Urbanization (URB) and Urbanization (URB) showed short-run influence on Urban Road/Bias (UB) for the lagging states.

Table 10: Summary of test results of Granger causality in VEC framework

| Variables Considered | Long-run causality | Short-run causality |
|---|---|---|
| *Lagging states* | | |
| lnURB and lnNH | lnURB → lnNH | lnNH → lnURB |
| lnURB and lnUB | lnURB → lnUB | lnURB → lnUB |
| *All 15 states* | | |
| lnURB and lnSROAD | lnSROAD → lnURB | |
| lnURB and lnNH | lnURB → lnNH | |
| lnURB and lnSH | lnURB ↔ lnSH | |
| lnURB and lnPWD | lnURB → lnPWD | |
| lnURB and lnUB | lnURB → lnUB | |

*x*→*y* means *x* Granger causes *y*, *x*↔*y* means *x* and *y* have bidirectional Granger causality.

### *4.3.2 VAR model test results*

A summary of test results of Granger causality between Transport Infrastructure (TRI) and Urbanization (URB) in VAR framework has been presented in table 11. This shows the direction of causality in those cases only where the relationship were observed to be statistically significant.

Table 11: Summary of test results of Granger causality in VAR framework

| Variables Considered | Chi-square | Short-run causality |
|---|---|---|
| *Leading states* | | |
| lnURB and lnSH | 16.2738*** | lnURB → lnSH |
| lnURB and lnPWD | 13.0796*** | lnPWD → lnURB |
| lnURB and lnAIRF | 29.3738*** | lnAIRF → lnURB |
| lnURB and lnPORT | 5.7058* | lnPORT → lnURB |
| lnURB and lnTREX | 4.8075* | lnURB → lnTREX |
| *Intermediate states* | | |
| lnURB and lnNH | 5.7495* | lnNH → lnURB |
| *Lagging states* | | |
| lnURB and lnSH | 12.4589*** | lnURB → lnSH |
| *All 15 states* | | |
| lnURB and lnROAD | 8.5522** | lnROAD → lnURB |

***significant at 1% level, **significant at 5% level, *significant at 10% level.
*x*→*y* means *x* Granger causes *y*.

The VAR model results for the leading states show short-run unidirectional causality from Other PWD Roads (PWD), Airways-Freight (AIRF) and Port Infrastructure (PORT) to Urbanization (URB), and from Urbanization (URB) to State Highway Density (SH) and Total Expenditure on Transport Infrastructure (TREX). In case of intermediate states, VAR results show short-run unidirectional causality from National Highway Density (NH) to Urbanization (URB) only. VAR results show short-run unidirectional Granger causality from Urbanization (URB) to State Highway Density (SH) only in case of lagging states. When all 15 states were taken together, short-run unidirectional causality has been found using VAR model to run from Total Road Density (ROAD) to Urbanization (URB) only.

## 5. Conclusions

To understand the role of Transport Infrastructure (TRI) in promoting Urbanization (URB) in India, especially during the post-liberalization period, the direction of causality between the two has been discussed in the light of the three urbanization theories.

When all 15 states were taken together for testing Granger causality, the results showed long-run unidirectional causality from Surfaced Road Density (SROAD) to Urbanization (URB), long-run bidirectional causality between State Highway Density (SH) and Urbanization (URB), and short-run unidirectional causality from Total Road Density (ROAD) to Urbanization (URB). These findings predominantly establish support in favor of modernization theory which emphasizes the role of indigenous investment on urbanization. As both surfaced road and total road represent development of indigenous infrastructure, therefore, the results support the modernization theory both in the long and short-run. Long-run bidirectional causality between State Highway Density (SH) and Urbanization (URB) also indicates support for modernization theory as state highways are indigenous infrastructure of the states. However, they also have the character of favoring major urban centers as these roads are meant for connecting major cities and other important administrative towns at the state level. Urbanization, on the other hand, increases demand for more linkages between urban centers within the state leading to more investment for state highways. Similarly, with urbanization, demand for increasing connectivity with the cities at the national level also increases leading to investment for national highways, which may be the reason behind the observed long-run unidirectional causality from Urbanization (URB) to National Highway Density (NH). Urban Road (UB) which also represents urban bias was not found to promote urbanization; rather, urbanization was found to cause urban bias as long-run unidirectional causality has been observed to run from Urbanization (URB) to Urban Road (UB).

In case of leading states, Urbanization (URB) has not been found to be cointegrated with Transport Infrastructure (TRI) variables. Thus, there is no long-run causal relationship between them. Short-run unidirectional causality has been observed from Urbanization (URB) to State Highway Density (SH) and Total Expenditure on Transport Infrastructure (TREX). Short-run unidirectional causality has also been found from Other PWD Road Density (PWD), Airways-Freight (AIRF) and Cargo handled through ports (PORT) to Urbanization (URB). This primarily establishes support in favor of dependency theory which considers foreign investment and trade to be most important for urbanization in developing countries. Thus, as per the theory, development of infrastructure which facilitates foreign trade is given more importance. As, both Airways-Freight (AIRF) and Cargo handled through ports (PORT) reflects the extent of foreign trade, therefore, dependency influences urbanization in the leading regions, though for short-run only. Also, short-run causality from Other PWD Road Density (PWD) to Urbanization (URB) draws support for the modernization theory to some extent as these roads represent indigenous infrastructure development. However, unidirectional short-run causality has been observed from Urbanization (URB) to Total Expenditure on Transport Infrastructure (TREX). This may be due to the fact that urbanization causes demand for investment in transport infrastructure in the leading region to ease development of businesses.

For intermediate states, Transport Infrastructure (TRI) and Urbanization (URB) have also not found to be cointegrated as they are integrated of different order. Only short-run unidirectional causality has been observed to run from National Highway Density (NH) to Urbanization (URB). Although national highways are major regional roads, they are primarily meant for easy goods movements by linking cities and major towns at national level. It also helps in movement of goods to and from major urban centers (also areas of major foreign investment) to ports. National Highway Density (NH), therefore, can be considered to represent modernization on one side, on the other side, they have character which favors urban bias and dependency.

In case of lagging states, long-run unidirectional causality has been found from Urbanization (URB) to National Highway Density (NH) and Urban Road (UB). Short-run unidirectional causality has been found to run from Urbanization (URB) to State Highway Density (SH) and Urban Road (UB). So, urbanization is creating demand first for linkages with the cities, which then leads to investment in national and state highways and urban roads for the lagging states. However, short-run unidirectional causality has also been observed from National Highway Density (NH) to Urbanization (URB). The probable reason could be that investment in national highways in the lagging region helps in agglomerating services in the initial period only, which then creates demand for long term investment in the national highways. The results did not bring any direct evidence in favor of the urbanization theories for the lagging states. However, it has been observed that urbanization promoted urban bias (in road infrastructure).

Overall, in the long-run, support in favor of modernization theory has been obtained for India, as long-run unidirectional causality has been found from Surfaced Road Density (SROAD) to Urbanization (URB) and short-run unidirectional causality has been found from Total Road Density (ROAD) to Urbanization (URB). On the other hand, no direct support in favor of urban bias theory has been observed; rather, it has been found that urbanization leads to urban bias (in road infrastructure) in India, and especially in the lagging region both in long and short-run. Support in favor of dependency theory has been found in case of leading states, though only in the short-run.

It may, however, be mentioned that the results obtained for India for the post-liberalization period may not be same for other countries and for different time periods. The literature review, too, suggests that the direction of causality may change with changing political and economic scenario and major policy reforms. The results, therefore, may be interpreted with reference to the present context only. Also, the reference to the urbanization theories with respect to transport infrastructure is only indicative and not complete. To have a comprehensive understanding of the various urbanization theories, it is required to look into other sectors of infrastructure and overall development, which is beyond the scope of the present study.

## Appendix A. Model for estimating urbanization at state level

First, urban population and total population at state level are estimated for each year using the following method. After that, urbanization is estimated as a percentage share of urban population in total population.

For the cohort-component method of population estimation, consider Eq. A1:

$$P_{t+1} = P_t + B_1 - D_1 + IM_1 - OM_1 \tag{A1}$$

Where,
$P_t$= Population at time *t*;
$P_{t+1}$= Population at time *t*+1;
$B_1$= Number of births during the interval (*t*,*t*+1);
$D_1$= Number of deaths during the interval (*t*,*t*+1);
$IM_1$= Number of inmigrants during the interval (*t*,*t*+1);
$OM_1$= Number of out-migrants during the interval (*t*,*t*+1).

Eq. A1 can also be written as:

$$P_{t+1} = P_t + NI_1 + NM_1 \tag{A2}$$

Where,
$NI_1 = B_1 - D_1$, i.e., natural increase of population during the interval (*t*,*t*+1);
$NM_1 = IM_1 - OM_1$, i.e., net inmigration during the interval (*t*,*t*+1).

As state level annual data for Crude Birth Rate (CBR) and Crude Death Rate (CDR) were available for both urban and total population from ‘Data-book for use of Deputy Chairman, Planning Commission’, these have been used to represent birth rate and death rate respectively, and therefore, Eq. A2 is written as:

$$P_{t+1} = P_t + (CBR_1 - CDR_1)P_t + NM_1 \tag{A3}$$

Or,

$$P_{t+1} = P_t + (RNI_1 * P_t) + (k * P_t) \tag{A4}$$

Or,

$$P_{t+1} = P_t(1 + RNI_1 + k) \tag{A5}$$

Where,
$RNI_1 = CBR_1 - CDR_1$, is the rate of natural increase of population.
As yearly data for migration at state level was unavailable, net in-migration has been assumed to be proportional to the population size (as larger urban centres and states are prone to attract more people than smaller ones), and therefore, $NM_1 = k * P_t$, where *k* is some constant.
Similarly,

$$P_{t+2} = P_{t+1}(1 + RNI_2 + k) \tag{A6}$$

Or,

$$P_{t+2} = P_t(1 + RNI_1 + k)(1 + RNI_2 + k) \tag{A7}$$

Similarly,

$$P_{t+10} = P_t(1 + RNI_1 + k)(1 + RNI_2 + k) \dots (1 + RNI_{10} + k) \tag{A8}$$

This equation has been solved for *k* using Newton-Raphson method of iteration.

*A.1. Newton-Raphson method of iteration*

This is an iteration method used to find successively better approximation for the root of a function (Kreyszig et al., 2011, pp. 801-802). If $x_0$ is an initial guess for the root of a function $f(x)$, then, a better approximation for the root is $x_1$, such that:

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} \tag{A9}$$

Where, $f'(x)$ represents first order derivative of the function $f(x)$.
Similarly,

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{A10}$$

This process is repeated until a satisfactory (accurate) value of the root is obtained.
After solving Eq. A8 using this iteration method, the estimate for urban population and total population can be easily obtained from Eq. A5.

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