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Spatio-temporal evolution of cities and regional economic development in Nepal: Does transport infrastructure matter?

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ABSTRACT

The literature on the New Economic Geography (NEG) suggests that transport cost is a major driving factor for the emergence of core-periphery patterns within a country. However, very few studies have tested this theoretical explanation in the context of transport infrastructure networks in developing countries. This paper takes a closer look at Nepal and tests four expectations that are drawn from the NEG, which highlight different aspects of the formation of core-periphery dynamic as determined by infrastructure quality. The expectations are tested by relating spatial-temporal patterns of road development to the growth and distribution of cities and examining the transport infrastructure contribution to shaping the patterns of regional economic development. We used intercity travel time estimates, based on the design speed of roads, length of sections and pavement type (from 1961 onwards in 10-year segments) as an indicator for the quality of infrastructure (transportation cost). Next, we computed hubness and accessibility indices of cities, defined by means of a gravity model and as a function of transportation cost, to undertake a cross-city comparison. We applied GIS mapping, multiple regression and mediation analysis techniques to relate these transport and accessibility characteristics to spatio-temporal patterns in city size and GDP per capita. Our study broadly confirms the core expectation derived from the NEG that transport improvements facilitate urbanization and that higher urbanization leads to higher regional GDP per capita. Two independent effects were identified in qualification of these overall patterns – the impact of market potential on city primacy and the impact of highly localized, immobile resources on GDP.

1. Introduction

In the face of unprecedented transport investment demand, developing countries face serious challenges to adequately and equitably distribute their limited resources among different regions. Transport infrastructure investment is considered as a tool to reduce the economic gap between core and periphery of a country by providing accessibility to lagging regions (Rietveld and Bruinsma, 1998). However, in spite of the numerous theories that aim to guide transport planning along regional economic development considerations, a general consensus on the most promising approach has not yet been reached by testing these theories against empirical evidence.

Urban areas in developing countries are experiencing massive in-migration from rural areas, rapid growth of cities (Brueckner and Lall, 2015), increasing incomes and exploding travel demand (Morichi and Acharya, 2013) – all factors that spur investment in capital infrastructure projects. For instance, the Indian government is currently planning metro rail projects for more than 50 major cities (Sharma and Newman, 2017). In peripheral areas, transport infrastructures are of poor quality or absent, resulting in poor accessibility to food, health, education, livelihoods, and other basic resources, services and markets. One of the reasons for the underdevelopment of the north-east region of India is the poor quality of transport infrastructure – more than 70% of roads are not paved (Nandy, 2014). In fact, large urban areas in developing countries are quickly becoming the loci of economic activities, while peripheral areas continue to lag behind, and the contrast is only increasing.

One prominent mainstream theory, the New Economic Geography (NEG), argues that transport cost is a major driving factor for the emergence of core-periphery patterns within a country (Krugman, 1991). In this context, transport cost is understood as the cost of transporting goods or passengers and can be ‘expressed in terms of length,
travel time, economic cost and amount of energy used (Rodrigue, 2017). In the light of the NEG, the World Bank, a major influential donor in the transport sector in developing countries, prescribed several do’s and don’ts in its 2009 World Development Report. According to the World Bank, transport investment decisions should be made in locations with higher economic growth; transport infrastructure investment in lagging areas does not attract private investors until cities have reached a satisfactory threshold level; it can further lead to the loss of population and economic activities in poor areas (World Bank, 2009, p. 184 & 223). However, the World Bank’s recommendation largely relies on scant anecdotal evidence, and the empirical examination of NEG propositions is still limited.

Several studies in China (e.g., Chen and Haynes, 2017; Yu et al., 2012) found that transport investment facilitates reduction in regional disparity; however, these findings seem to contradict other studies that found that large scale transport investment further concentrates economic activity in core areas and reduces it in peripheral regions in China (see Roberts et al., 2012; Faber, 2014; Yu et al., 2016). Bosker et al. (2015) found that the construction of the national expressway network resulted in more concentrated development in large urban areas in China. Only a few research efforts look into the situation in other developing countries. Da Mata et al. (2005) found that improvement of the interregional transport infrastructure leads to the population growth of cities in Brazil. Maparu and Mazumder’s (2017) investigation of India showed that railways can impact economic growth in the long run, while highways have more short-term effects. Other studies have examined NEG arguments, particularly the role of transportation cost in convergence or divergence of economic activities. Vickerman (1995) argued that only a very high or very low level of transport cost can affect the decision of firm’s location. Very high transport cost leads to decentralization, while very low transport cost facilitates concentration. Similarly, Banister and Berechman (2000) questioned the key assumptions behind the NEG. They argued that with the advancement of technology, the growing dominance of the service sector, the emergence of a highly skilled and flexible labour market, transportation cost alone cannot determine the location decisions of firms. Banister and Berechman (2001) listed a set of necessary conditions that should be fulfilled to achieve the desired economic development through transport investment.

In general, the NEG provides a promising framework to understand the impact of transport infrastructure in regional economic development and the emergence of core-periphery patterns within countries. However, the theory needs to be tested against empirical evidence, as existing empirical evaluations are still rather limited. Furthermore, only a relatively small body of literature has examined the impact of spatial-temporal patterns of transport network development in the emergence, growth and distribution of cities as well as the associated contribution to shaping patterns of regional economic development in the context of developing countries. Most studies focus on China (see Wang et al., 2009) and do not directly test NEG propositions. This is an important research gap, because in developing countries the level of urbanization is low and transport improvement can ignite the emergence of new cities and the distribution of cities can shape regional economic development patterns.

In this context, this paper looks at the case of Nepal to assess the following research question based on the implications of NEG: To what extent does transport infrastructure improvement facilitate urbanization in one region within a country and does higher urbanization lead to greater regional GDP per capita? Urbanization in this research is understood as a transformation of rural into urban populations, either by establishing new cities or by migration into existing cities and via internal population growth in existing cities (Muzzini and Aparicio, 2013). Transport improvement in this research is understood as the reduction of travel time between cities following upgrading earthen roads to gravelled roads or gravelled roads to pitched roads (see appendix A) or following construction of new or alternative road sections between cities. Therefore, it seeks to evaluate the role of the spatio-temporal evolution of different quality of transport infrastructure (roads in this research) networks and its impact on the size and distribution of cities and regional economic development.

While acknowledging the debate that multiple factors and feedback mechanisms influence the growth of cities and therefore the necessity to extend the NEG into a dynamic framework (see e.g. Fujita and Mori, 2005), we test the four expectations derived from the NEG theory in its simplest form. We do this, because it is in this form that the theory (1) still influences policy decisions, especially regarding allocations of investments in a developing country context (e.g. World Bank, 2009), and (2) still is in use as a framework for scientific research (e.g. Chen and Haynes, 2017). Moreover, an extended, dynamic framework is not yet established (see for some debate: Garretsen and Martin, 2010; Gaspar, 2020). Therefore, this paper aims to examine the main conceptual instrument in the context of a developing country, suggest policy implications and explore ways forward for a future extension. The rest of the paper is organized as follows. The next section explains the NEG theory and its expectations. In Section 3, we outline the research design and testing methodology. Section 4 analyses the results, while Section 5 provides the key conclusions and recommendations for further research efforts, and Section 6 presents the limitations.

2. Theory

The New Economic Geography (NEG) is the most recent advancement of location theories, which reach as far back as the work of Von Thünen (1826), and seeks to explain ‘how a country can endogenously become differentiated into an industrialized core and agricultural periphery’ (Krugman, 1991, p. 483). According to NEG, the spatial concentration or dispersion of economic activities is the product of a ‘tug of war’ between centripetal and centrifugal forces. The centrifugal forces that promote concentration are market size effects (e.g. of the labour market) and external economies (lower average cost, including transport of input and output materials, etc.), while land and other stationary factors and other external diseconomies (higher averaged cost, etc.) are the centrifugal forces that strengthen dispersion. The change in transport cost determines the strength of these forces and leads to concentration of economic activities in some places and dispersion in others. Transport cost is a key incentive for firms to locate within or near larger markets (Krugman, 1991, 1998, 1999, 2011; Fujita et al., 1999). The reduction of transport cost, via improved quality of infrastructure (roads, railways, ports etc.), makes a location more attractive for firms and labour, leading to the creation of an industrial core. The peripheral areas with higher transportation cost are less attractive and ultimately lag behind. As a result, a pattern of core-periphery emerges within a country, leading to regional income inequality (Krugman, 1996, 1999).

Within the framework of NEG, a broad expectation derived for empirical testing is defined as follows: ‘Improvement of transport infrastructure facilitates urbanization in a region and higher urbanization leads to greater regional GDP per capita.’ We unpack this main theoretical expectation into four sequential expectations to be examined in this study, as outlined in the sub-sections below.

1 Several empirical expectations can be drawn from the NEG literature in various fields of research such as urban and regional economics, economic geography, transport planning, regional planning and many more. The expectations that are tested in this paper are related to the change in transport cost (effectuated by improving transport infrastructure), urbanization and distribution of cities and their size as well as the associated impacts on regional GDP per capita.
2.1. Cities in transportation nodes

Transportation nodes have a hub-effect, which provides a driving force for the emergence of cities by attracting firms and labour (Krugman, 1993). The production of goods and services tends to locate in transport hubs, seeking to reduce the costs for transporting input and output materials. Transportation nodes dominantly grow above other places. Ports (including sea, river and lake ports) and other transport nodes provide an extra advantage for cities to flourish. Most of today’s great cities are located next to ports (Fujita and Mori, 1996), and cities tend to sprout near the most efficient transport systems (World Bank, 2009). Following this argumentation, the first expectation is defined as follows:

Expectation 1. All cities emerge and grow in transportation nodes.

2.2. Transport improvement and growth of cities

Transportation nodes have a different degree of hubness, and cities emerge and grow differently in such nodes. Transportation cost differences between locations determine which place (transportation node) can serve as a hub (Krugman, 1993), and transportation cost varies with the quality of transport infrastructures between locations (Krugman, 1996). Krugman (1993) explains this variation in Fig. 1. In general, given three locations (nodes), they are equally entitled to produce and consume both goods and services. A node can emerge as a big city, where transportation cost to other locations is lowest. For example, if the transportation costs between nodes 1 and 3 as well as 1 and 2 are lower than the costs between nodes 2 and 3; node 1 can be a transportation hub and a big city emerge there. Therefore, it can be reasoned from this theory that a transportation node with a higher degree of ‘hubness’ should attract a larger population and be a bigger city. Considering this argumentation, the second theoretical expectation is drawn as follows:

Expectation 2. The degree of hubness significantly influences the size of cities.

2.3. The growth of the primate city

The development of the primate city, or heavy concentration of population in a few regions or cities, can lead to the widening of regional inequalities within a country (Krugman, 1999, 1996). There are at least three explanations in the NEG literature about the growth of primate cities.

First, in developing countries, transportation cost is higher if one moves away from the biggest, usually capital, city as roads often ‘peter out quickly’ (Krugman, 1996). If a city has better access with respect to other cities, it leads to a concentration of population in the ‘superior access’ city. A transportation system centred on a single city promotes the concentration of economic activities in this largest city (Krugman, 1996).

The second explanation is the size of the city itself. In a city that is sufficiently large in size, all production sectors become concentrated in that city, which is called the ‘home market effect’. Producers can save the transport cost of goods on the route, if they are located in the big city (Krugman, 1993). When transport costs are high, local production in other regions still can survive and flourish. But, with the gradual improvement of transport infrastructure and falling transport cost, larger firms located in the big city can capture the local market in the periphery. Eventually, the big city attracts local firms and labour from the periphery. Finally, the big city attracts local firms and labour from the periphery (Puga, 1998), further accelerating its growth due to the strong home market effect.

The third explanation is that a capital city can easily become the primate city as the government creates a large number of jobs in the capital city. Because of easy access to the government, private firms and lobbyists also concentrate in the capital, making it a very attractive location for labour and firms (Krugman, 1999, 1996).

Among these explanations, we are interested in the role of transport infrastructure in the emergence of the primate city, and thus in the first two explanations. In summary, the first explanation states that transport improvement is highly correlated with the growth of the primate city, making it the city with the highest accessibility. In this research, accessibility is understood as a measure of the capacity of people and goods to reach the city or for people and goods from the city to reach other cities (Rodrigue, 2017); i.e. a city which has the highest accessibility index would be the most accessible city. For details regarding the measurement of the accessibility index see Section 3. The second explanation states that the population size of the city itself (i.e. its market potential) is key for the growth of the primate city. Based on these two explanations, we draw the following two expectations:

Expectation 3.a. The city that is the most accessible will emerge as the biggest city in a country.

Expectation 3.b. The city with the highest market potential will emerge as the biggest city in a country.

2.4. Transport improvement, the growth of cities and regional GDP per capita

Krugman (1996) argued that the region that contains a big city has higher regional GDP per capita. Transport improvements facilitate city growth and a big city generates many economic activities that spur regional economic growth. Considering this argument, the fourth expectation is stated as follows:

Expectation 4. A higher hubness index of transportation nodes leads to the creation of larger cities (in terms of population), which in turn leads to higher regional GDP per capita.

3. Research design

3.1. Case selection

This study conducts a case study of a developing country, to explore and test the explanatory power of the theoretical expectations outlined above. A theory can be confirmed or invalidated by testing it against the most likely or least likely case (Gerring, 2006). Yin (2009) also suggests that a single case study can be relevant to test a well-formulated theory with a clear set of expectations. To test the expectations, we choose the spatio-temporal evolution of the transport network, location of cities and their growth as well as their impact on the regional economy in Nepal as a case study.

The following characteristics make Nepal a relevant case to test the NEG theory. First, the transport development history of Nepal can be traced from its earliest stages. The first highway opened in 1957, and classified quality of road network data is available from 1961 onwards. Second, Nepal’s hills and mountains create a unique environment for transport development, requiring substantial financial resources and innovative technologies, which is likely to make the impacts of spatial and temporal differences in transport infrastructure availability and quality especially significant. Third, cities are emerging in Nepal by
internal migration from scattered rural areas to the newly developed transport nodes. Considering these dynamics and the low level of urbanization, any sizeable transport project is likely to trigger the development of cities in favourable locations.

The case study will not only explore and test the explanatory power of NEG in a developing country but also highlight the policy implications of transport infrastructure projects in relatively less urbanized environments with rugged geography.

3.2. Data

3.2.1. A brief overview of Nepal’s transport, urbanization and regional development

Nepal borders with India in the east, south and west and China in the north. It was largely inaccessible by any modern means of transport (e.g., motor vehicles) until 1950. The first highway opened in 1957, by connecting the capital city Kathmandu to the Indian border in the south. Starting in 1956 and guided by 5-year development plans, Nepal built about 13,000 km of the strategic road network, including highways and feeder roads. More than 50% of the network is still unpaved, and its distribution is geographically uneven (DOOR, 2016).

Following road construction, growth centres and numerous cities have evolved, mostly along highway corridors and other accessible regions, such as the Nepal–India border (Portnov et al., 2007). Massive internal migration from mountainous and hilly areas to the southern plains and the capital city is the main drive for urbanization in these regions (Gurung, 1989; KC, 2003). A formal record of urbanization in Nepal started from the 1952/54 census. The census does not mention specific criteria for defining a city but lists 10 urban settlements as such, five in the Kathmandu Valley and others along the border with India. The total share of the urban population was set at 2.9%, with the vast majority (83%) living in the Kathmandu Valley. Since the 1961 census, settlements have been classified into two categories: Nagar (municipalities in English) and Guan (villages in English). Municipalities are considered as cities in Nepal (for details see Note i). According to the latest 2011 census, 17% of the 26.5 million inhabitants of Nepal reside in 58 municipalities. In 2014 and 2015, 133 new rural bazaars were upgraded to cities. In 2017, the number of municipalities increased to 293. From 2014 to 2017, the criteria defining a municipality were altered significantly, under strong political influence; therefore, for our analysis we used all municipalities from 1961 to 2011, as classified by the CBS. Fig. 2 shows the urbanization trends from 1954 to 2011, expressed as a percentage of the population living in municipalities.

Formal regional planning was initiated in the 4th development plan (1970–75) with the objective of reducing regional disparity. Nevertheless, regional income inequality remains high in Nepal, with a GINI coefficient of 0.57 in 2011. Fig. 3 shows the income per capita distribution in the top 5 and bottom 5 districts of Nepal in 2011. The ratio of the highest earners to the lowest is 6.60 (UNDP and GON, 2014).

3.2.2. Data selection

Intercity travel time, population of municipalities, and regional GDP per capita were used to test each theoretical expectation. Since only roads are available in Nepal, intercity travel is understood in this research as road travel. Intercity travel times were estimated based on the quality of existing road network, using data for 10-year intervals (1961 to 2011). The population data was collected for the respective years, and GDP per capita numbers were obtained for 34 urbanized regions for 2001 and 2011.

3.2.2.1. Intercity travel time data. Intercity travel times in every census year from 1961 to 2011 are estimated. Travel time depends on the quality of the existing road network (see appendix A) and design speed. We elaborated a database of the existing road network with details such as classification, pavement quality of each section, and design speed for each year. The data is retrieved from the government’s road network inventory of every census year, which provides details on the existing road network in operation in that year. For the existing road network in 1961 and 1971, the data is taken from the fourth five-year periodic plan document, while the data from 1981 to 2011 is compiled from the road statistics archive published by the Ministry of Transport. The travel time estimate was calculated as follows:

$$T(A – B) = \sum \frac{L_j}{V_{ij}}$$

where,

- **T(A–B)** = Shortest travel time in hour(h) between city A and city B in year *j*
- **L** = Length of road section *i* in kilometre (km)
- **V** = Average travel velocity in the road section *i* in year *j* in km/h

$$V_{ij} = \begin{cases} V_{rd} & \text{if road section is pitched} \\ V_{gr} & \text{if road section is gravel} \\ V_{earth} & \text{if road section is earthen} \end{cases}$$

$$X = \begin{cases} 0.50^* & \text{for the design speed} \\ 1.00 & \text{for the road section is in a hill or mountain, 20 km/h for plains} \\ 1.00 & \text{for the road section is in a hill or mountain, 10 km/h for plains} \\ V_{rd} & \text{if road section is pitched} \\ V_{gr} & \text{if road section is gravel} \\ V_{earth} & \text{if road section is earthen} \end{cases}$$

$$V_{rd} = \begin{cases} 85 \text{km/h for hills, 25 km/h for plains} \\ 100 \text{km/h for hills, 20 km/h for plains} \end{cases}$$

$$V_{gr} = \begin{cases} 50 \text{km/h for hills, 25 km/h for plains} \\ 60 \text{km/h for hills, 20 km/h for plains} \end{cases}$$

$$V_{earth} = \begin{cases} 40 \text{km/h for hills, 20 km/h for plains} \\ 50 \text{km/h for hills, 20 km/h for plains} \end{cases}$$

$$i = \text{Section of road 1, 2, \ldots, n}$$

$$j = \text{Analysis year (1961, 1971, 1981, 1991, 2001 and 2011)}$$
The reduction factor was estimated based on the 2018 travel time survey (details are provided in appendix B).

** Design speed depends on the road classification. Nepal Road Standards (NRS, 1970, 1988 and 2013) classifies roads in Nepal. Based on this classification and geographical location (hill or plain) design speed is determined. Roads are constructed or upgraded following NRS guidelines. Design speed could be changed in a later year if the road section was upgraded.

*** During the 2018 travel time survey all the national highway sections were paved. To estimate travel speed on other road surfaces, the lead author conducted interviews with 5 retired engineers, each with more than 25 years of experience in road construction in Nepal. They agreed on the following travel speeds for gravel roads (15 km/h in hills and 20 km/h in plains) and earthen roads (8 km/h in hills and 10 km/h in plains) for all time periods of analysis.

3.2.2.2. Population data. Population data for cities and regions was obtained from the census reports published by the Central Bureau of Statistics (CBS) Nepal, segregated in 10-year intervals (1961 to 2011). The largest city of each district (75 districts in total) was selected for the analysis. The logic behind this selection is the theoretical expectation that the region that contains a bigger city will have higher regional GDP per capita (see Section 2.4). We consolidated the populations of multiple cities into a single unit for those cities that lie within commuting range of each other. Most districts have either a single city or cities that lie within commuting range (30 km). Following these criteria, only four cities were excluded from the analysis (Waling, Tikapur, Siraha, and Inaruwa), because the biggest cities in those districts were already selected.

3.2.2.3. Regional GDP data. The segregated GDP of 75 district is available for 2001 and 2011 from the Human Development Report (HDR), jointly published by UNDP and Government of Nepal, for 2004 and 2014, respectively. Due to the lack of segregated regional GDP data older than 2001, we used the data sets for these two year for the analysis.

3.3. Methodology

As already illustrated, the four expectations from NEG are tested by using the following methodologies.

3.3.1. Cities on transportation nodes

** Expectation 1. All cities emerge and grow in the transportation nodes.

The road networks with their classifications (earthen, gravel and paved) were plotted in 10-year intervals using GIS mapping technique. A layer of the existing road network in 2015 was obtained from the Department of Roads (DOR), Nepal. Road network layers of previous years from 1961 to 2011 were created by making separate columns in the attribute table. The quality of each section of the existing road network for each year was assigned in the attribute table. Road network sections that did not yet exist in that particular year were assigned as ‘NA’ in the attribute table. Road sections which were changed or upgraded from the previous years were updated in the attribute table of the respective year. The data for past years was obtained from the printed archive of road network statistics, which includes maps as well as length and quality of road sections. Similarly, layers of the location of the cities were obtained from the Department of Urban Development and Building Construction (DUBDC). The location of all designated cities with their population size are overlaid on the road network map for each time segment. The patterns of road network development and evolution and growth of cities are visualized and mapped.

The regression analysis tests the significance of the relationship between the hubness index, an indicator of transport improvement of nodes (cities), and population size. Details about the hubness index are presented in the section below.

3.3.2. Transport improvement and growth of cities

** Expectation 2. The degree of hubness significantly influences the size of cities.

3.3.2.1. Hubness index. In order to quantify the improvement of transport infrastructure, a hubness index is used. The hubness index of a location is defined as the cost of travelling or transporting goods from that location to all other locations. A location is labelled as a hub when it has the lowest transport costs relative to other locations (Krugman, 1993). Transportation cost is a function of distance, which impacts accessibility as expressed from a geographical point of view, in terms of length, travel time, economic cost or amount of energy required (Rodrigue, 2017). Hubness is higher at a particular location when the total transport cost is lower. The major determinant of transport cost is infrastructure, i.e. availability and quality of infrastructure (Limao and Venables, 2001). Many researchers have used the following formula as an accessibility index of a node (e.g., Bruinsma and Rietveld, 1998, 1993; Spiekermann and Neubauer, 2002; Spiekermann and Wegener, 2006), which we adapt and call hubness index:

\[ H_i = \sum_{j=1}^{J} \frac{1}{t_{ij}} \]  

In this formula, \( H_i \) stands for the hubness index of city \( i \); \( t_{ij} \) is travel time between city \( i \) and \( j \); \( J \) is the total number of cities.

3.3.2.2. Intercity comparison and significance testing. To understand the impact of transport improvement on city growth, we first compare the hubness index and size of cities (10-year intervals, from 1961 onwards) and then we estimate an econometric model. The model explains the population growth of cities by the degree of hubness. The analysis tests the significance of the relationship between the degree of hubness and population size of cities, after controlling for the attributes of the capital city, regional headquarters, and border towns. We estimated the following fixed effects model:

\[ \ln \text{POP}_i = \alpha + \beta HUBL_i + \delta X_i + \theta + \epsilon_i \]  

where \( \ln \text{POP}_i \) is the natural log of population in city \( i \) in time \( t \); \( HUBL_i \) is the hubness index of city \( i \) in time \( t \) (estimated by using Eq. (2)); \( X_i \) is the vector of covariates for city \( i \) that includes national capital, regional headquarters and border towns; \( \theta \) is the time-fixed effect that captures the time-invariant differences across years; \( \epsilon_i \) is the error term that captures the impact of all other unobserved variables that vary across cities and over time.

3.3.3. Growth of primate city

** Expectation 3.a. The city that is the most accessible will emerge as the biggest city in a country.

** Expectation 3.b. The city with the highest market potential will emerge as the biggest city in a country.

To examine the impact of transport infrastructure on the growth of the primate city, we used two indices that were adopted from previous studies.

3.3.3.1. Accessibility index. We used an accessibility index that is widely proposed or used in various studies (see Hansen, 1959; Linneker and Spence, 1992; Bruinsma and Rietveld, 1993, 1997; Vandenbulcke et al., 2009; Koopmans et al., 2012; Kim and Sultana, 2015). According to these studies, accessibility indicates the opportunities available to the
people and firms in a location affected by specific impedance (transportation cost). The accessibility index of a city is defined by

$$ACC_j = \sum_{j=1}^{J} \left( \frac{P_i}{t_{ij}} \right)$$  \hspace{1cm} (4)

### 3.3.3.2. Market potential.

The second index is the market potential. To estimate the effect of ‘home market’, the population of a city is added to the accessibility index (in Eq. (4)). This formulation takes into account both home market effects and transport improvements. Holl (2012) used the following formula to evaluate the impact of the Spanish road network by calculating the market potential of 573 cities, which we adopted for our research:

$$MP_j = P_i + \sum_{j=1}^{J} \left( \frac{P_j}{t_{ij}} \right)$$  \hspace{1cm} (5)

In Eqs. (4) and (5), \(A_i\) is the accessibility index of city \(i\); \(MP_i\) is market potential of city \(i\); \(P_i\) is the population of the origin city; \(P_j\) is the population of destination city; \(t_{ij}\) is travel time between cities \(i\) and \(j\); \(J\) is the total number of cities. Cities were selected with the same criteria as in Section 3.3.2. In order to access the effects of accessibility and market potential on the primate city, we first compare the population of cities, accessibility, and market potential, to then go on to estimate an econometric model. The econometric model explains the population growth of cities by the relative level of accessibility. The regression analysis evaluates whether the relationship between the relative level of accessibility and population size of cities is significant or not. We estimate the following fixed effects model:

$$\ln POP_i = \alpha + \beta \ln ACC_i + \delta X_{it} + \theta_i + \epsilon_i$$  \hspace{1cm} (6)

In this model, \(\ln POP_i\) is the natural log of population in city \(i\) in time \(t\); \(\ln ACC_i\) is the natural log of the accessibility index of a city \(i\) in time \(t\) (estimated by using Eq. (4)); \(X_{it}\) is the vector of covariates (control variables) for city \(i\) that includes national capital, regional headquarter and border town; \(\theta_i\) is the time-fixed effect that captures the time-invariant differences across years; and \(\epsilon_i\) is the error term that captures the impact of all other unobserved variables that vary across cities and over the time period.

### 3.3.4. Transport improvement, the growth of cities and regional GDP per capita

**Expectation 4.** A higher hubness index of transportation nodes leads to the creation of larger cities, which in turn leads to higher regional GDP per capita.

#### 3.3.4.1. Mediation analysis.

In a widely cited article, Baron and Kenny (1986) proposed a statistical testing method to determine the effects of the independent variable to the dependent variable through a third variable called mediator. In our case, we consider regional GDP per capita as the dependent variable, hubness as the independent variable, and population size of the largest city in the region as the mediator. As suggested by Baron and Kenny (1986), Judd and Kenny (1981) and James and Brett (1984), we adopted the following three separate regression equations and four steps to establish the mediation:

$$\text{GDPpc} = \beta_0 + \beta_1 \text{HUB} + \epsilon$$  \hspace{1cm} (7)

$$\ln \text{POP_BIG} = \beta_0 + \beta_1 \text{HUB} + \epsilon$$  \hspace{1cm} (8)

$$\text{GDPpc} = \beta_0 + \beta_1 \text{HUB} + \beta_2 \ln \text{POP_BIG} + \epsilon$$  \hspace{1cm} (9)

In all those models, \(\beta_0\) are the intercepts; \(\beta_1\) and \(\beta_2\) are the slope coefficients of each regression equations. In the diagrammatic format given in Fig. 4, \(\beta_1\) in Eq. (7) is \(c\); \(\beta_1\) in Eq. (8) is \(a\); \(\beta_1\) in Eq. (9) is \(c'\), and \(\beta_2\) in Eq. (9) is \(b\). In all those models, \(\epsilon\) are the error terms.

The three models are based on a four-step procedure. The objective of steps 1 through 3 is to establish the zero-order relationships between (1) regional gross domestic product per capita (GDPpc) and hubness (HUB), (2) the population size of the biggest city in a region (lnPOP_BIG) and hubness (HUB), and (3) GDPpc and the population size of the biggest city in the region (lnPOP_BIG). If one or more of these relationships are statistically insignificant, mediation is not possible or likely (although this is not always true, see MacKinnon et al., 2007). If the relationships in steps 1, 2 and 3 are statistically significant, we proceed to step 4. In step 4, after controlling for HUB (i.e. the independent variable, \(X\)), if the effect of lnPOP_BIG (i.e. the effect of the mediator, \(M\)) on GDPpc (i.e. the dependent variable, \(Y\)) remains significant, some form of mediation is supported, and if HUB is no longer significant when controlled for lnPOP_BIG, the finding supports full mediation (Baron and Kenny, 1986).

#### 3.3.4.2. Indirect effect. As illustrated earlier, the goal of the mediation analysis is to estimate the indirect effect and test its significance. As shown in Fig. 4, the indirect effect is in this case the effect of hubness (HUB) on regional GDP per capita (GDPpc) through a third variable, population in the biggest city of a region (lnPOP_BIG). Estimating the indirect effect and testing its significance helps evaluate expectation 4, that is, whether the effect of hubness on regional GDP per capita through the population of the biggest city in the region is significant. Baron and Kenny (1986) recommend first estimating the Eqs. (7), (8), and (9), and then calculating the indirect effect by multiplying two regression coefficients \((a \times b)\). Then, they recommend the Sobel z-test (Eq. (10)) to assess the statistical significance of the indirect effect.

$$z = \frac{a \times b}{\sqrt{s_a^2 + s_b^2}}$$  \hspace{1cm} (10)

In Eq. (10), \(a\) and \(b\) are coefficients in Eqs. (8) and (9), and \(s_a\) and \(s_b\) are the standard error of \(a\) and \(b\), respectively. The above four-step approach is commonly and widely used by many researchers; however, it does have several limitations. First, it does not test the significance of the indirect pathway, i.e. the effect of HUB on GDPpc through the compound pathway of \(a\) and \(b\). Second, the Baron and Kenny (1986) approach tends to miss some mediation effects (Zhao et al., 2010). Recent literature on mediation analysis recommends bootstrapping methods over the Sobel z-test (e.g., Preacher and Hayes, 2004; Zhao et al., 2010; Hayes, 2013, 2018). Preacher and Hayes (2004) and Hayes (2013, 2018) recommend a regression-based PROCESS tool in SPSS, for estimating regression equations and calculating indirect effects. Thus, following the extension made by Zhao et al. (2010) and Hayes (2013, 2018) as well as the steps for mediation analysis of Baron and Kenny (1986), we used the PROCESS tool in SPSS to estimate the regression equation, to calculate the indirect effect and to investigate the statistical significance of the indirect effect – the relationship between transportation cost (i.e. hubness) and the regional GDP per capita through the size of the largest city in a region.

### 4. Results

#### 4.1. Cities on transportation nodes

Cities in Nepal are settlements that have been officially categorized as municipalities by the government in a census, and each census uses slightly revised criteria for this classification (see Note 1). Before 1953, all the settlements (including cities) were connected by tracks and trails: no modern transport infrastructures such as roads and railways were present. Numerous internal tracks and trails from these settlements connected to the border cities of India and China where roads and railway networks were present (IBRD, 1965).
Fig. 4. Relationship between variables (adapted from Baron and Kenny, 1986).

Fig. 5. Development of cities and road networks in Nepal (1961–2011).
Data source: Department of roads (DOR) and Department of Urban Development and Building Construction (DUDBC) and National Planning Commission (NPC).
In 1952, there were ten cities in Nepal, including five border cities at the junctions of Nepalese trails and stations of the Indian railways and five cities in Kathmandu valley (now considered as one metropolitan area). The time-series maps in Fig. 5 show a pattern that illustrates that the formation of cities and their growth follow the expansion of the road network. In total, sixteen cities were recorded in 1961 and 1971. In 1961 two cities, Pokhara and Dharan, appeared after the construction of roads in the inner valleys; two more cities appeared at the junctions of trails and the Indian border, and two more old towns located on the trade trails between India and Tibet (China) were recognized as cities. In 1971, three more cities emerged after the construction of roads, while three former cities lost their status due to population decline.

From 1981 to 2011, all cities emerged after the construction of roads in the inner valleys and border. The growth of cities was slow, totalling 23 cities in 1981 and 1991. More cities appeared in 2001 along the East-West Highway Corridor in the southern plain, and other hill cities appeared along the Prithvi Highway and Siddhartha Highway, situated in a relatively rugged topography. For instance, in 1981 there were only 3 cities along the East-West Highway. This number reached 5 in 1991 and 10 in 2001, when the highway was completed. District headquarters, which are the government services employment centres, did not grow when they were not connected by the budding road network. These district headquarters received the official status of municipalities only after road connectivity was established and population growth. Only one district headquarters without connecting roads was recognized as a city in 2001, being located along the trail. Despite large populations residing in the northern hills, very few cities appeared there because hills have very few roads. The Nepalese government expects 10 more cities to emerge along the Mid-Hill Highway Corridor once it is completed (GON, 2017). The regression analysis further develops this argument in the next section.

4.2. Transport improvement and growth of cities

Fig. 6 shows the size and respective hubness index of selected cities for specific years, sorted in descending order according to population size. The chart demonstrates that the hubness index of many smaller cities increased over time, while bigger cities such as Kathmandu and Pokhara do not have substantially higher hubness compared to others. It seems that higher hubness is not the only factor to influence the growth of cities.

Table 1 shows the regression results with or without Kathmandu Valley. Due to its large population, Kathmandu Valley is an outlier; therefore, we need to estimate models for both cases. All models fit moderate to higher values, see goodness of fit ($R^2$), except in the first model. In all models, the coefficient of hubness is highly significant at less than 1% level. When the Kathmandu valley, the national capital is controlled in the model, the model fits much better than before (see columns 2 and 3 in Table 1) and the primate city effect of the national capital city is high and highly statistically significant. The time-fixed effects are not statistically significant. Models 2, 3, 5 and 6 show that border towns are significant at less than 5% level. In all models, hubness is highly significant for population growth.

4.3. Growth of the primate city

Fig. 7 shows the ranked size distribution of major cities and the population share of the Kathmandu Valley since 1961. The capital city, Kathmandu, always held the number one position with the highest primacy ratio. The urban primacy ratio in 1961 was 6.33; it declined steadily until 1981 and has rebounded since, reaching 6.5 in 2011. The accessibility index and market potential of selected cities are calculated based on Eqs. (4) and (5) for each year since 1961. The

![Fig. 6. Comparison of population size and hubness index, accessibility index, and market potential of selected cities in specific years.](image-url)
comparative charts (see Fig. 6) show that Kathmandu consistently had the highest market potential, while its accessibility is relatively lower than in other cities. Some other cities have higher accessibility and market potential with lower population.

Considering the accessibility index of cities in Nepal, Table 2 shows the regression results with or without Kathmandu valley. All models fit in the moderate to high scope, except the first model. In all models, accessibility is significant at the less than 5% level. In model 2, 3, 4 and 5, accessibility is highly significant at less than 1%. The second and third models show that the outlier case Kathmandu Valley is also highly significant at the less than 1% level. We further used the city-fixed effect models. In models 2, 3, 5, and 6, border towns are significant at the less than 5% level. The time-fixed effects in all cases are not significant. After controlling for city- and time-fixed effects, the accessibility index is still significant at the less than 5% level in models 1 and 6 and at the less than 1% level in models 2, 3, 4 and 5.

4.4. Transport improvement, the growth of cities and regional GDP per capita

A mediation analysis was conducted in order to understand the significance of the effect of hubness on regional GDP per capita through the mediator variable ‘population of the biggest city in the region’. For this, we used the pooled data from 2001 and 2011 for all 43 urbanized districts (from 75 districts in total). For the analysis, we selected a total of 34 regions by consolidating two or more districts that fall within the commuting distance (e.g., the Kathmandu Valley consists of Kathmandu, Lalitpur, Bhaktapur and Kavre districts). Table 3 presents the regression results of Eqs. (7), (8), and (9). First, hubness (HUB) significantly affects the mediator, the population size of the largest city in a region (lnPOP_BIG) (i.e. a is significant at less than 1%, see row 2 of Table 3). Second, hubness significantly affects regional GDP per capita (i.e. c is also significant at less than 5%, see row 1 of Table 3). Third, the mediator, i.e. the population of the largest city in a region, significantly affects regional GDP per capita when controlling for hubness (i.e. b is significant at less than 1%, see row 3 of Table 3).

### Table 1

| Variables          | Including Kathmandu Valley | Excluding Kathmandu Valley |
|--------------------|---------------------------|----------------------------|
|                    | (1)                       | (2)                        | (3)             | (4)          | (5)          | (6)          |
| Constant           | 9.982                     | 9.494                      | 9.373           | 9.673        | 9.519        | 9.446        |
|                    | (0.176)                   | (0.147)                    | (0.346)         | (0.136)      | (0.151)      | (0.397)      |
| Hubness            | 0.25***                   | 0.319***                   | 0.330***        | 0.306***     | 0.311***     | 0.331***     |
|                    | (0.053)                   | (0.039)                    | (0.06)          | (0.04)       | (0.04)       | (0.061)      |
| City Dummies       |                           |                            |                |             |             |             |
| National Capital   | 3.082***                  | 3.122***                   | (0.286)         | (0.289)      | (0.286)      | (0.289)      |
|                    | (0.286)                   | (0.289)                    |                |             |             |             |
| Regional Headquarters | 0.271                    | 0.255                      | (0.186)         | (0.187)      | (0.189)      | (0.19)       |
|                    | (0.186)                   | (0.187)                    |                |             |             |             |
| Border Town        | 0.277*                    | 0.284*                     | (0.133)         | (0.135)      | (0.135)      | (0.137)      |
|                    | (0.133)                   | (0.135)                    |                |             |             |             |
| Time-fixed Effect  |                           |                            |                |             |             |             |
| 1971               | –0.134                    | (0.405)                    | (0.405)         | (0.405)      | (0.405)      | (0.405)      |
| 1981               | 0.175                     | (0.374)                    | (0.374)         | (0.374)      | (0.374)      | (0.374)      |
| 1991               | 0.238                     | (0.379)                    | (0.379)         | (0.379)      | (0.379)      | (0.379)      |
| 2001               | –0.084                    | (0.414)                    | (0.414)         | (0.414)      | (0.414)      | (0.414)      |
| 2011               | 0.173                     | (0.415)                    | (0.415)         | (0.415)      | (0.415)      | (0.415)      |
| Observation        | 121                       | 121                        | 121             | 115          | 115          | 115          |
| R-Squared          | 0.157                     | 0.579                      | 0.598           | 0.337        | 0.365        | 0.392        |

Note: The variable population of cities is transformed logarithmically because of skewness.

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**Fig. 7.** Urban primacy: city size distribution (left) and urban primacy over time (right).
Fourth, hubness is not significant after we control for the size of the population in the big cities (\(\text{lnPoP BIG}\)) (i.e., \(c'\) is not significant, see the \(HUB\) coefficient in row 3 of Table 3). In summary, the analysis demonstrates full mediation.

To investigate the significance of the indirect effect, a bootstrapping method was employed. Table 4 illustrates the bootstrapping results with and without the Kathmandu Valley, with hubness as the dependent variable, regional GDP per capita as the independent variable, and the population of the biggest city in the region as the mediator. The indirect effect of hubness on GDP per capita through city population size equals 2728.32 when including the Kathmandu Valley in the analysis and 1859.55 when it is left out. Both of those effects are significant because in both cases the lower and upper bounds of the 95% confidence interval do not include zero. In summary, the indirect effect estimated in model 3 (Table 3) is significant. That is, the analysis supports the fourth hypothesis: improvement of transport infrastructure leads to the growth of population in cities which in turn leads to the higher regional GDP per capita.

5. Discussion and conclusion

This paper aimed to test the expectations drawn from the New Economic Geography (NEG) to understand the impact of transport improvement in regional economic development in the context of a developing country. The core research question was: To what extent does transport infrastructure improvement facilitate urbanization in a region within a country and does higher urbanization lead to greater regional GDP per capita? The findings largely confirm the theoretical expectations. This section will outline the specific findings for each theoretical expectation and provide suggestions for further research.

5.1. Cities on transportation nodes

Expectation 1. All cities emerge and grow in the transportation nodes.
We found that all cities evolved either at the nodes of the road network, at historical trade route or at the southern border areas that are connected by the Indian railway system as well as later by the East-West Highway and connecting roads. The time-series maps of road network development in Nepal and the significance testing of hubness over population size of the cities confirmed the first expectation. This result suggests that transport connectivity is a necessary condition for cities to emerge and flourish. In the context of developing countries such as Nepal, where the level of urbanization is still low and large populations still reside in scattered and inaccessible villages, improvement in transport infrastructure can ignite the emergence and growth of cities in newly established nodes. This observation is in line with the findings of the study by Portnov et al. (2007) on Nepal: (1) rapidly growing urban centres are situated close to major markets, along highway corridors, and at the border with India; and (2) cities with poor road connections grow more slowly.

5.2. Transport improvement and growth of cities

**Expectation 2.** The degree of hubness significantly influences the size of cities.

The result of the model estimates shows that hubness is statistically significantly correlated with city size, in line with the NEG-postulated explanation of urban concentration (Krugman, 1993). This indicates that transport improvement (hubness) can be one of the major facilitating factors for city growth. Several empirical studies also found similar impacts of transport accessibility on population growth (e.g., Akgüng et al., 2011; Kotavaara et al., 2011). Looking at individual cities in Nepal, the population numbers for Kathmandu and Pokhara are significantly higher, but their corresponding hubness indices are less than those for Hetauda and Lahan. This finding suggests that transport improvement alone does not automatically lead to city growth and other important factors also need to be considered.

5.3. Growth of the primate city

**Expectation 3a.** The city that is the most accessible will emerge as the biggest city in a country.

**Expectation 3b.** The city with the highest market potential will emerge as the biggest city in a country.

Our findings confirmed that the market potential of a city has a proportional impact on the growth of the primate city. For instance, the market potential of Kathmandu, the biggest city in Nepal, has remained in the dominant position since 1971. This finding is in line with the NEG explanation of ‘home market effects’ (Krugman, 1993). However, our results do not confirm the first expectation about the primate city. While six times larger in population than the second largest city in Nepal, Kathmandu has not held the highest accessibility position (superior access) since 1971. This finding is also contrary to the expectation from Krugman (1996). One of the reasons for the growth of Kathmandu not being affected by its accessibility might be a long history of political centralization. Kathmandu has served as the political and cultural centre of Nepal for at least 250 years of its modern history. The cultural and political history of Kathmandu dates back at least 2000 years (Thapa et al., 2008). This reasoning is also in line with Galiani and Kim (2008), who found that political centralization caused urban primacy in major Latin American countries. On the other hand, the regression analysis showed that accessibility is statistically significantly correlated to the size of cities in Nepal. Together these findings indicate that transport accessibility is one of the factors that facilitate city growth, in line with the study by Holl (2007) on the impact of motorway accessibility in Spain’s peripheral regions, but that also other factors (in particular, home market potential) are relevant.

5.4. Transport improvement, the growth of cities and regional GDP per capita

**Expectation 4.** A higher hubness index of transportation nodes leads to the creation of larger cities, which in turn leads to higher regional GDP per capita.

The findings from the regression-based mediation analysis confirmed that transport improvement facilitates urbanization in regions, which in turn leads to growth of regional GDP per capita. However, in particular cases, as most notably in the Kathmandu valley, although the hubness is relatively low, urban population and GDP per capita is higher. This is because of the effect of Kathmandu, the primate city. In all models, both including and excluding the Kathmandu Valley in the analysis, the findings support the NEG argument that ‘the region that contains the biggest city will have higher regional GDP per capita’ (Krugman, 1996).

In summary, the Nepal case study broadly confirms the core expectation derived from the NEG that transport improvement facilitate urbanization in a region and higher urbanization leads to greater regional GDP per capita. Conversely, the study indicates that regional income inequality is associated with the uneven distribution of transport infrastructure and cities. Our results are in line with several previous studies in other contexts that found a positive impact of transport investment on urbanization (see Hong et al., 2011; Kasraian et al., 2015; Long et al., 2018). However, this study also found that the growth of the primate city, considered as one of the key factors for regional inequality, has no direct relationship with transport improvement. Also, areas with low hubness and population size can have relatively high GDP, due to location-specific conditions (e.g., access to highly localized, immobile resources such as touristic assets).

The study uncovered the following potential policy implications beyond the existing practices and policy recommendations from the World Bank (World Bank, 2009). First, in a low-level urbanized country, transport improvement distribution can contribute to determining urban distribution patterns and city size and, in turn, to shaping regional economic development patterns. Second, excessive delays in establishing good connections with peripheral regions can lead to delayed urbanization and, in turn, lagging economic development. Consequently, peripheral regions can experience extreme depopulation, leading to excessive concentrations in a few cities. Both implications suggest that, in order to reduce regional income inequality, the selection and timing of transport infrastructure projects should be carefully considered.

Some of the theoretical aspects explored in this study need to be further extended. The first aspect concerns the dynamics of transport and urban development. The future extension should be able to explain how transport infrastructure, including its timing, shapes cities, their growth and distribution, and the patterns of the regional economy. In particular, it should address how these developments reinforce or impede each other. Further research can be performed through an evolutionary perspective. An evolutionary perspective has already been introduced in the NEG domain (see Fujita and Mori, 1996) and can be developed further. The second aspect regards how different factors interact to create the favourable conditions that spur the growth of cities at transportation nodes and shape regional economic development patterns. The hub effect is not necessarily the main explaining factor, and other intervening factors need to examined in depth. This call for a broader investigation is also supported by Krugman (1994), who
emphasized the importance of complexity, and Fujita and Mori (2005), who suggested to extend the NEG into a dynamic framework.

6. Limitations

The research provides empirical insights into the relationships between improvement of road infrastructure, the emergence and growth of cities, and regional economic development, in a developing country. This context is often overlooked in academic debates, due to the barriers associated with obtaining the necessary data. While we could secure access to adequate data for this study, several limitations need to be highlighted and considered.

First, travel time was selected as an indicator of transport cost. However, the monetary costs of transporting people and goods might be a more appropriate measure, especially for time-series comparison. We recommend for future research efforts to explore carrying out such an analysis. Second, travel time data for previous years was estimated based on the 2018 travel survey and the design speed of roads. Actual travel time might have differed from this estimate, and future research attempts could assess real-life travel time. Third, we used the CBS definition of municipalities as an urban unit; however, this definition is not consistent over time. Also, some settlements with rural characteristics have been included in the designated municipalities, while some settlements that have urban characteristics were not designated as municipalities. Actual number and size of urban units might differ from that of CBS definition. Future research could explore a more consistent definition of an urban settlement, in order to provide more accurate insight into urbanization. Fourth, due to the lack of data on regional GDP per capita, we used this variable only for two years (2001 and 2011); therefore, the indirect effect (i.e. the impact of hubness on regional GDP per capita through the population size of the biggest city in a region) was investigated only for the short term. Future research can consider and deploy other methods to reliably estimate regional GDP per capita data for the more distant past.

Notes

i. The definition of cities has been revised in each census. The 1961 census specified the criteria for categorization as a city as having a population of 5000 and above. The 1962 Town Council (panchayat in Nepali) Act increased the population threshold to 10,000, and the 1971 census specified further indicators such as the existence of schools, public service offices and commercial facilities. Altogether, 4% of the population resided in a designated urban settlement in 1971. In 1976, the 1962 Town Council Act was amended and the population threshold was reduced to 9000. With this revision, the 1981 census recorded the number of cities and the share of the urban population as 23 and 6.4%, respectively. From 1987 to 1990, the government of Nepal declared 10 new cities. In the 1991 census, the total urban population reached 9.2%, distributed in 33 cities. The 1999 Self Governance Act set up criteria and classified local bodies into two categories Gaun Vikas Samitee (village development committee, VDC in English) and Nagarpalika (municipality in English). VDCs are rural settlements and Nagarpalika, i.e. municipalities are known as cities in Nepal. There were 3914 VDCs and 58 municipalities at the time of the 2001 census. Municipalities have been further classified into three categories: metropolitan cities, sub-metropolitan cities and municipalities. For a metropolis, the following criteria were introduced: population of 300,000 and above, annual income (from local tax etc.) greater than 400 million Nepalese Rupees (USD 5.2 million), electricity access, water supply facilities, hospitals, stadium, and at least one university. Any area which has at least 20,000 inhabitants in the terai (plains) and 10,000 in mountainous areas with such facilities can be declared as a municipality. In the 2001 census, the share of the urban population reached 13.9% in 58 designated cities. There were no any changes that happened from 2001 to 2001. In 2014 and 2015, 133 new rural bazaars were upgraded as cities. In March 2017, the local level restructuring commission further increased the number of municipalities to 293. However, the declaration of municipalities being political in nature, many declared municipalities are in fact still rural settlements. Our analysis covers the designated cities up to 2011.

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Appendix A. Road network quality in Nepal

The road network inventory is categorized in three types based on construction quality (see Figure below). The first is an earthen road that is used immediately after clearance and filling of soil without any surface treatment or drainage infrastructure. The second type is a gravel road, constructed with compacted gravel and minor drainage infrastructure. The third is a pitch road, a complete black asphalt cover, topped with a permanent layer and drainages infrastructure.
Appendix B. Calculation of reduction factor

The design speed of a road is the maximum speed that can be achieved by a vehicle. The actual speed of average passenger vehicles in real-life conditions is always lower – i.e. actual speed is always a fraction of design speed, what we call a 'reduction factor'. To calculate this factor, 38 sections of national highways, 2393 km (75%) of the 3178 km total length, were selected for travel time measurement (see figure below). Travel time for each section was measured by direct travel by the lead author with public transport (bus) in September 2018. The travel time for two sections (Surkhet–Jumla and Kathmandu–Hetauda via Daman) was measured via interviews with public transport bus drivers. The detailed estimation method is described as follows:

Length of section $i = L_i$
Design speed of section $i$ in 2018 (according to NRS) = $V_{Dei}$
Travel time measured in section $i = T_i$
Actual average speed $A_{Vi} = \frac{L_i}{T_i}$
Fraction of design speed $X_i = \frac{A_{Vi}}{V_{Dei}}$

Mean fraction $\bar{x} = \frac{\sum X_i}{n}$
where $i = 1, 2, ..., n$; section of roads on which travel time was measured.

Through this calculation, the mean fraction of 0.52 was obtained, with a standard deviation of 0.1, and a confidence interval of 0.48 to 0.55 from one sample z-test ($n > 30$). Accordingly, a reduction factor of 0.50 was adopted for estimating travel time between cities in Eq. (1). The sensitivity analysis, conducted to determine whether the result varies with the confidence interval, indicated that the results of the analysis (Sections 4.2, 4.3 and 4.4) were not affected.
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Corrigendum to ‘Spatio-temporal evolution of cities and regional economic development in Nepal: Does transport infrastructure matter?’

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