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Connectivity Along Overland Corridors of the Belt and Road Initiative

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Abstract

The six land corridors that are the "Belt" part of the Belt and Road Initiative (BRI) connect more than sixty countries. As the initiative progresses, policy makers, analysts and researchers are trying to answer a few open questions of which the most common are: How can a country best benefit from the BRI? How should projects be prioritized and sequenced? What opportunities emerge as a result of participating in the initiative? We use a network economics approach to answer some of these questions and others. Our hypothesis is that the ability of countries to maximize the benefits of BRI will depend on the position of each country in the new connectivity maps that are emerging. Ultimately, an initiative such as the BRI will change the way economic centers, as the most productive nodes in each country, are connected. Productivity, competition, market opportunities, and transport and logistics costs are all likely to be impacted. However, the magnitude of the effects will depend on where along the Belt corridors a city is located relative to all other countries and economic centers. Ultimately, the difference in outcomes will depend on whether a center intermediates trade flows in the network or serves as an end node that generates inbound and outbound flows. Centers that are not well connected in the new BRI maps may not experience much positive impact. Emphasis should therefore be on the weak links within the networks.

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Keywords: Trade, Connectivity, Belt and Road Initiative

Abbreviations

GDP	Gross Domestic Product
BRI	Belt and Road Initiative
OBOR	One Belt One Road
ASEAN	Association of South East Asian Nations
EU	European Union
CEPEC	China Pakistan Economic Corridor
BCIM	Bangladesh-China-India-Myanmar Economic Corridor
NDRC	National Development and Reform Commission (NDRC)
CMREC	China, Mongolia, Russia Economic Corridor
CICPEC	China Indochina Peninsula Economic Corridor
ICT	Information Communication Technology
DC	Degree Centrality
CC	Closeness Centrality
BC	Betweenness Centrality
IP	Internet Protocol
TIR	Transports Internationaux Routiers
WTO	World Trade Organization
TFA	Trade Facilitation Agreement
OECD	Organization of Economic Cooperation and Development

Overview

Even as the world faces headwinds and pushback against globalization, there are significant resources being invested in linking communities and countries. Connectivity, broadly defined, is high on the policy agenda of most countries and global development and financial institutions.[1] This is reflected in the numerous proposals to build transport, energy and telecommunications networks spanning the globe, and to lay the basic infrastructure for economic and social interactions of even greater intensity. The Belt and Road Initiative, first defined in 2013 by the President of China, is the single largest initiative to enhance global connectivity. It encompasses some 65 countries that contain between them more than half of the world's population, 40% of world GDP, and could cost more than one trillion dollars to build.

However, as the BRI is rolled out, participating countries are asking several questions, among them: how can they benefit from the initiative? How are projects going to be prioritized and sequenced? What are the benefits of participation? What are the geopolitical implications of the initiative? Not surprisingly, there is a large and growing volume of analytical work on the initiative (e.g. Kennedy, 2015[2]; Pitlo, 2015[3]; Minnick, 2015[4]; Zhang, 2015[5]; Tian, 2016[6]; etc.). Much of the work explores the political and geopolitical questions. However, the economics of BRI has not been as well studied in academic literature. Yet, there is need for detailed and objective analysis of the initiative to guide countries on investments and how multilateral institutions like the World Bank should respond. In fact, there is strong demand both in World Bank client countries and within the World Bank itself for detailed analytics to support and inform how the OBOR will impact trade and investment flows between China and BRI partner countries.

The present paper aims to contribute to the discussion on the economic impacts of BRI by focusing on the priority corridors, which are the most prominent design feature of the initiative. Ultimately, an initiative such as the BRI should result in an increase in interactions, productivity, competition, and market opportunities deriving from lower transport and logistics costs between connected economic centers[7]. The paper therefore seeks to enhance our understanding of interactions between economic centers along the BRI corridors. To assess levels of connectivity, a simple measure of centrality is used. The measure offers us insights into the degree of connectivity and levels of integration of economic centers along the alignment of the BRI corridors. It allows us to make some important distinctions that have so far not been that apparent, but which are necessary to develop appropriate intervention strategies.

1 The G20 in 2016 launched a Global Infrastructure Connectivity Alliance in order to promote a coherent approach to connectivity.
2 Kennedy, Scott, and David A. Parker. "Building China's 'One Belt, One Road'." Center for Strategic and International Studies (2015): 3-9.
3 Pitlo, Lucio Blanco. "ASEAN Connectivity and China's 'One Belt, One Road'." The Diplomat 26 (2015).
4 Minnick, Wendell. "China's 'One Belt, One Road Strategy." Defense News (2015).
5 Global Asia; Fall2015, Vol. 10 Issue 3, p8
6 McKinsey, 2016
7 See Infrastructure and Economic Growth in East Asia, World Bank Policy Research Working Paper 4589.

Based on the results presented in the paper there are a few high-level messages and conclusions we can draw:

The impacts of BRI corridors will depend on the degree of integration in the connected regions. The analysis identified five communities that are connected by the BRI corridors: a ‘Chinese community’ which includes the densely interconnected Chinese cities; a ‘Southeast Asian community’ centered on Bangkok and Singapore; a ‘Central and West Asian community’; a ‘South Asian’ community; and a ‘North Asian’ community.

It is apparent that centers in China are highly interconnected. As such, improvements of any one link will have magnified impacts through network effects. The same applies also in some of the other regions that are connected by the priority corridors. This applies in particular, to the ASEAN region (and the European Union). Intra-regional connectivity in these regions is already high such that focus should be on building the “bridges” between China on the one hand and the EU or ASEAN countries on the other. In addition, focus should be on the services that run on the existing infrastructure. This can already be seen in the case of the railway services between China and Europe which were in essence designed by the private sector, in this case DHL. Once the core networks are in place this enables the private sector to provide services depending on the needs of markets and their dynamics.

On the other hand, in regions that have poor intra-regional connectivity, the development of core infrastructure should be paramount. Such infrastructure should assume the classical definition of corridors. There needs to be basic infrastructure that has high capacity and connects the major economic centers. The CPEC and BCIM corridors are examples of corridors of such a form. In the first scenario, focus should be on developing core infrastructure as well as services. In addition, it will be important to also invest in productive capacity along the corridors. To a large extent, the approach that has been adopted for CPEC reflects this comprehensive approach, to build connectivity infrastructure and services as well as promote production and productivity through industrial zones.

Trade agreements have a strong influence on BRI corridor connectivity. Community detection analysis shows that borders between trade areas or between countries have important effects on network connectivity. While in general nearby economic centers tend to be in the same community, this effect can be confounded by the effect of national borders. For instance, there are relatively stronger connections between Dhaka and cities in the Middle East such as Dubai and Abu Dhabi than with nearby Indian cities. The impact of borders and geographical proximity is one that runs through our results, though there are always notable exceptions and complex interactions that we also highlight.

In practice the effects of borders manifest through the time and cost it takes to pass through the borders, in other words the “thickness” of the borders. A comparison between the BCIM and China-Indochina corridors illustrates this well. The BCIM corridor at present exists largely on paper and still is a disparate group of economies with limited intra-regional trade. On the other hand, ASEAN shows a much higher degree of integration with many regional supply chains, several of which extend over the wider East Asia and Pacific region, anchored by China and Japan.

The development of the BRI corridors should prioritize existing weak links. The concept of the 'strength of weak ties' is fundamental to how the BRI corridors will impact regional and global connectivity. There is ample empirical evidence that an entity (person, firm, country) can enhance its network by focusing more on its weak connections. Strengthening weak connections to other networks brings benefits to the connected entities. In the context of BRI, identifying these particular 'weak ties' should guide the prioritization of investment needs, and with it the negotiation of trade and other agreements, and improving the regulatory and policy frameworks for the provision of services. The analysis has identified the main links along each corridor that are important to the transmission and facilitation of flows within each corridor. A next step would be to determine the condition and capacity of those links and design holistic solutions covering physical infrastructure, regulation of services and coordination arrangements for cross border components.

Select economic centers along BRI corridors can leverage their positions to maximize benefits of BRI. In China, there are as many as 18 provinces that are officially part of the BRI with several others making submissions to be officially recognized. However, the analyses in this paper suggest that only a few provinces (six) are real gateways to the BRI network of overland corridors. In addition, there are specific centers (seven) in these provinces that can generate and/or mediate trade or people to people flows. These are Baotou (Inner Mongolia), Zhengzhou (Henan), Xian (Shaanxi), Lanzhou (Gansu), Urumqi (Xinjiang Uyghur), Kunming (Yunnan), and Qujing (Yunnan). These centers have high degrees of centrality that enable them to intermediate flows between China and BRI partners and will ultimately be key to the success of the initiative, at least in China.

Similar to the above, along each corridor there are centers in the BRI partner countries that are well placed or connected to benefit most from BRI. Based on the analysis, the centers across the priority corridors are the following Novosibirsk, Irkutsk, Yekaterinburg, and Krasnodar (Russia), Almaty and Astana (Kazakhstan), Tehran (Iran), Istanbul (Turkey), Kabul (Afghanistan), Yangon (Myanmar), Kuala Lumpur (Malaysia), Bangkok (Thailand), Hanoi (Vietnam), Singapore (Singapore), Rawalpindi, Bahawalpur, Islamabad and Karachi (Pakistan), Dhaka (Bangladesh), and Kolkata (India).

These centers are well placed to generate, add value to or play roles as fulcra for BRI corridor flows. However, for the centers to play such roles they will need to take some deliberate actions and make appropriate investments specially to foster value by adding logistics services, and through them participation in value chains moving through the corridors.

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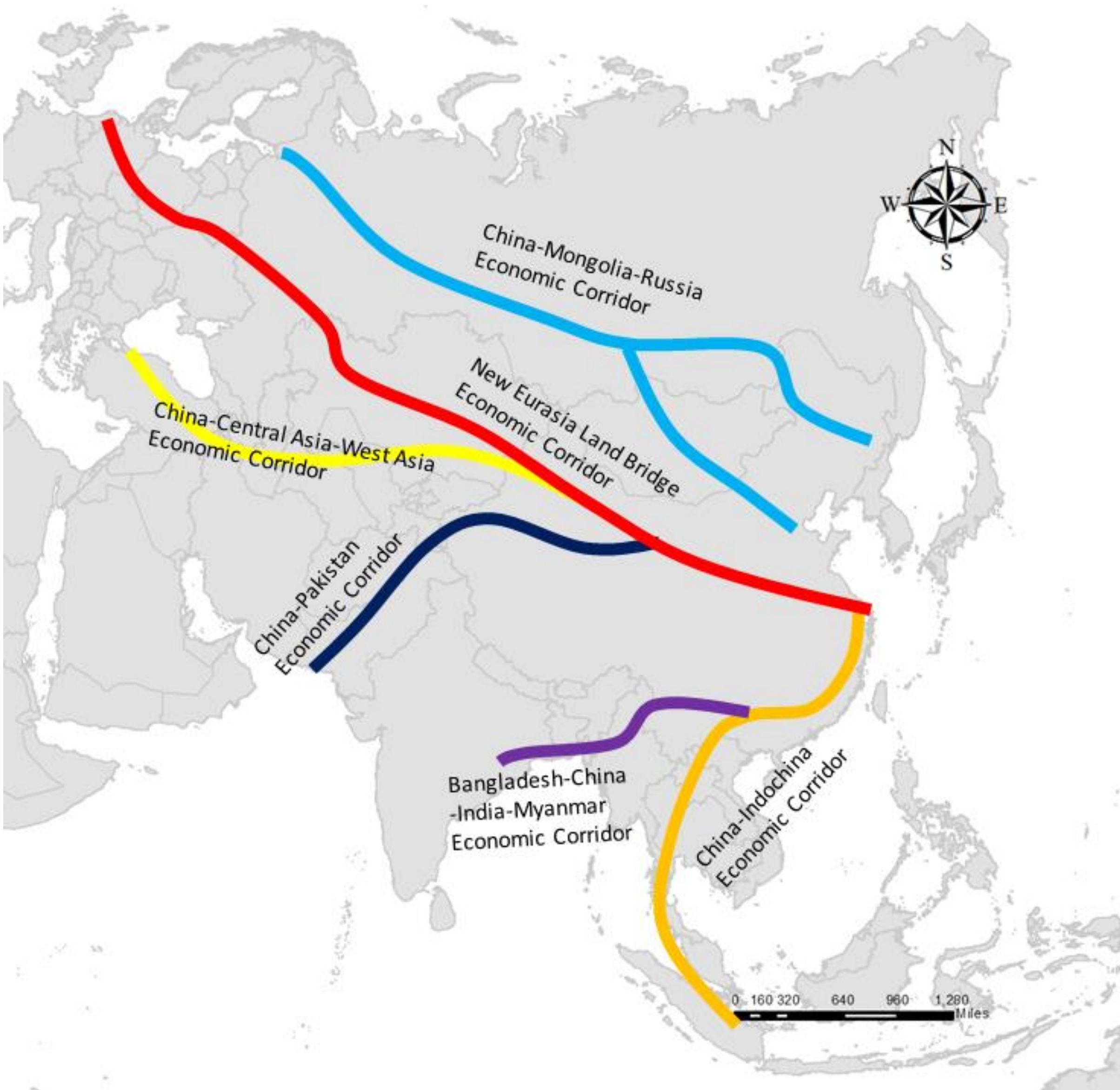
Introduction

The twofold purpose of this paper is to (1) chart and analyze the networks between major and intermediate economic centers along the different 'Belt and Road' (BRI) corridors, and (2) use this as the input to a model that allows for the design of some policy recommendations for the future development of these corridors.

The BRI identifies a number of priority overland corridors, which can be defined as coordinated bundles of transport and logistics infrastructures and services that facilitate interaction between major centers of economic activity (Kunaka and Carruthers, 2014). One of the orthodoxies in urban-economic geography states that the development of transportation networks commonly leads to the creation or deepening of corridors of economic centers through the spatial concentration of flows along what become privileged axes. The most well-known corridor development model has been developed by Taaffe et al. (1963) to explain the stepwise evolution from a non-integrated set of small trade centers to an integrated regional transport system linking major economic centers. This 'mature' system is unlikely to change unless there are significant policy, economic or technological developments that allow for an efficient exploitation of economies of scale and scope in centers along the corridor. The ultimate objective of the BRI Initiative is to develop such an archetypical regional transport system (albeit on an unprecedented scale) because it will make economic centers in different countries more attractive by providing productivity benefits. However, it is the 'place' of an economic center along the corridor – its linkages with other centers – that will co-determine how it benefits from the BRI. For instance, when a city is positioned between otherwise relatively poorly connected cities in the network, it can intermediate flows and thus specifically benefit from its network position. Against this background, this study of the connectivity of economic centers along the 'Belt and Road' Initiative aims to advance our understanding of 'corridor connectivity' along the BRI, as well as propose a model that allows for drafting some policy recommendations.

This study will first appraise the theoretical importance of undertaking connectivity analysis by reviewing the state-of-the-art of research on urban-economic prominence. This takes the form of a discussion of agglomeration and network externalities[i], with a particular focus on the latter. Appreciating network externalities implies adopting topological concepts of space in the analysis of production, productivity and innovation. Such a topological understanding of space emphasizes the uneven ability across economic centers to connect to other economic centers. Importantly, it is often argued that the enhanced connectivity potential offered by successive information, communication, and transportation-technological revolutions render network externalities relatively more prevalent (Castells, 1996). This calls for a systematic analysis of how strong, how, and where cities are connected, and we therefore construct a composite corridor network consisting of links between major and intermediate in BRI countries in general and along the proposed corridors in particular. This composite network model consists of a series of proxy measures of the possibility for the exchange of people, ideas, and knowledge between economic centers. The empirical focus is on a combination of the major economic/political centers in BRI countries and the major centers along the six corridors that have been identified to link to the BRI, i.e. (1) the China-Mongolia-Russia Economic Corridor, (2) the New Eurasian Land Bridge, (3) the China-Central Asia-Western Asia Corridor, the (4) China-Indochina Peninsula, (5) the China-Pakistan Economic Corridor, and (6) the Bangladesh-China-India-Myanmar Corridor.

Figure 1. Six international economic cooperation corridors within the BRI countries (Drawn based on the authors' own interpretation of the Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road Report, issued by The National Development and Reform Commission (NDRC) of China on 28 March 2015; the alignment of individual corridors is indicative).



China Pakistan Economic Corridor (CPEC)

The China-Pakistan Economic Corridor (CPEC) is the most prominent and ambitious of the BRI corridors. Its development objectives are multifaceted and include infrastructure development; increased people-to-people contact for enhanced academic, cultural, and regional knowledge exchanges; and a higher volume of trade flows and business activity. In principle, the CPEC model should result in a well-connected, integrated and dynamic economic belt extending between China and the coast of Pakistan.

The CPEC is supported by a bilateral trade agreement between China and Pakistan. Most of the investments, estimated at close to $50bn, are being spent on building and modernizing the overland connections between Xinjiang in western China to the Arabian Sea across the Himalayas. They are comprised of a network of roads extending almost 3,000 km, the port of Gwadar in Pakistan, a rail line and an oil pipeline between the two countries. The corridor will also see ancillary investments in solar power and a hydro power station. The CPEC is part of a broader vision to enhance connectivity between China and the South and West Asia countries of India, Iran, Afghanistan, and the Central Asian Republics.

When completed, the corridor should enable China's imports of oil to go through the pipeline and therefore avoid the busy routes through the Straits of Malacca as well as congestion in the coastal provinces of China itself. However, outside these benefits, the corridor is also one of the more controversial ones, as it cuts through disputed territory between India and Pakistan.

China, Mongolia, Russia Economic Corridor

The China, Mongolia, Russia Economic Corridor is the most direct route between north-east China and its economic hubs and markets in Russia and Europe. The corridor builds on several years of efforts by Mongolia and Russia to extend connectivity with China and to their own more remote territories. In fact, the corridor is therefore a convergence of the Eurasian Economic Community that is championed by Russia, the BRI and Mongolia's initiative to enhance connectivity with the two neighbors. For instance, Mongolia in 2013 defined a new initiative to construct roads between the borders with China in the south and Russia in the north, including 1,100 km of electrified rail lines, and an oil and gas pipeline across Mongolia, that altogether will cost US$50 billion (Otgonsuren, 2015). The three governments have agreed to build an economic corridor and strengthen cooperation in transportation infrastructure connectivity, port construction, industrial capacity, investment, trade and economy, cultural exchanges and environmental protection in order to improve economic benefits amongst each of the countries. In 2015 the three governments agreed to rail freight and to establish a Mongolian–Russian–Chinese joint railway transportation and logistics company. Rail transport is key to the CMREC.

New Eurasian Land Based Economic Corridor

The New Eurasia Land Bridge is an international railway line running from Lianyungang in China's Jiangsu province through Alashankou in Xinjiang to Rotterdam in Holland. The China section of the line comprises the Lanzhou-Lianyungang Railway and the Lanzhou-Xinjiang Railway and stretches through eastern, central and western China. After exiting Chinese territory, the new land bridge passes through Kazakhstan, Russia, Belarus and Poland, reaching a number of coastal ports in Europe. Capitalizing on the New Eurasia Land Bridge, China has opened an international freight rail route linking Chongqing to Duisburg (Germany); a direct freight train running between Wuhan and Mělník and Pardubice (Czech Republic); a freight rail route from Chengdu to Lodz (Poland); and a freight rail route from Zhengzhou to Hamburg (Germany). All these new rail routes offer rail-to-rail freight transport, as well as the convenience of "one declaration, one inspection, one cargo release" for any cargo transported. They are borne of a realization that shippers are prepared to pay a premium for faster service, which allows them to respond quickly to changes in market conditions.

China-Central Asia-West Asia

The China-Central Asia West Asia Economic Corridor will run from Xinjiang via Alashankou, on the China Kazakhstan border, to join the existing railway networks of Central Asia and Middle East. The corridor covers the Central Asian countries of Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan and Afghanistan as well as Iran and Turkey. An extension of the line could be added to run to Ukraine via Azerbaijan, Georgia and Russia. That said, individual components of the corridor have already been implemented. For example, the Kamchiq Tunnel, the longest railway tunnel in Central Asia and a critical project along the Angren-Pap railway line in Uzbekistan, is already open, advancing connectivity between China and Central Asia. In September 2016, a rail connection between China and Afghanistan was inaugurated. Once completed, trains can run from eastern China to Iran taking less than half the time of an alternative route by sea via the port of Shanghai.

China Indochina Peninsula Economic Corridor (CICPEC)

The corridor also known as Nanning-Singapore Economic Corridor, aims to connect eight major cities—Singapore, Kuala Lumpur, Bangkok, Phnom Penh, Ho Chi Minh City, Vientiane, Hanoi and the Chinese city of Nanning. From there, additional connectivity nodes would be extended to the major economic hubs of Guangzhou and Hong Kong, thus forming a web connecting ten cities with cumulative population of over 50 million. Essentially, the corridor connects China and the contiguous ASEAN states. ASEAN has one of the more connected transport networks among the developing regions of the world. The network has been developed over time but especially through the Greater Mekong Sub-region initiatives.

Bangladesh-China-India-Myanmar Economic Corridor (BCIMEC)

The proposed BCIMEC will be comprised of expressway and high-speed rail links between the Chinese city of Kunming in Yunnan Province and Kolkata in India via Mandalay in Myanmar and the Bangladeshi capital of Dhaka. In addition to the land bridge the four countries have also agreed to build air and water ways connecting each other as well as power transmission lines and oil pipelines. The corridor will connect a collective market of over 400 million people including West Bengal, India's fourth most populous state.

There is already a discernible trend of Chinese manufacturing firms relocating further inland. These firms are looking at Myanmar and beyond, as well as Indian markets. The road corridor through Myanmar to India and Bangladesh can result in significant distance and time savings (Nittsu Research Institute and Consulting, 2014).

However, beyond the road connectivity, a potential game changer will be the proposed high-speed rail link between the Chinese city of Kunming in Yunnan Province and Kolkata in India via Mandalay in Myanmar and the Bangladeshi capital of Dhaka. Of course, improving railway connectivity faces many challenges and will take time to realize. This is because the existing railways have so far been unreliable and have been losing traffic. For instance, the existing network in Bangladesh is in a bad state and has been losing traffic and money for several years. Differences in gauge within Bangladesh and between Bangladesh and India are also a major constraint to seamless movement of traffic. The network is made up of a mixture of narrow and broad-gauge systems with several interchange points for bilateral traffic. Given the various problems faced with the railways, it is unlikely, at least in the short term, that rail traffic will divert from the Siliguri corridor to the cross-Bangladesh routes. These problems will affect the extent to which any BRI railway will interconnect with the wider networks that already exist in the BCIMEC countries.

A major (empirical) challenge in a geographical analysis of the BRI is that the exact alignment of the above economic cooperation corridors is not precisely defined. However, it is possible to interpret the general arrangement, the countries involved, and the key nodes alongside these corridors from the Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road Report, which was issued by The National Development and Reform Commission (NDRC) of China (Figure 1). For example, the New Eurasian Land Bridge corridor develops around an international rail line that runs from the city of Lianyungang in Jiangsu Province (China) all the way to Rotterdam (the Netherlands). Within China, key nodes on this corridor include Zhengzhou, Xi'an, Lanzhou, and Urumqi, which are provincial capitals in central and western China as well as major rail stations. This international rail line then runs across the territories of Kazakhstan and Russia, before linking up with the rail and other transport systems in Europe. One key assumption of this study is therefore that these corridors aim to link major urban-economic centers along the general alignment.

The composite network model utilizes and combines data on four main types of components that facilitate inter-city flows: road, rail, air, and information technology networks. Our selection of transport modes is firmly centered on passenger transport, and this is for three overlapping reasons:

The BRI has both a logistical and corporeal component: the idea is to enhance the flows of both goods and people alike. So, although much of the BRI policy narrative focuses on the movement of goods, there are much broader policy objectives related to moving people and goods alike.

Inter-city data detailing the movement of goods is not publicly available. Trade flow data is commonly garnered at the level of countries, making analyses at the level of economic centers contingent on the definition of a pre-hoc model allocating flows to pairs of centers. Moreover, especially in the context of very large countries with a broad distribution of economic centers in geographical and hierarchical terms, such an allocation-exercise is fraught with difficulties. Although data on passenger transport is not readily available in a single database, there are publicly available data sources that make it feasible to put together a systematic dataset with information on connections between pairs of centers.

Although flows of passengers and goods may seem to be very different, they are in fact strongly related. Previous research found a direct causal relationship of passenger travel on trade connections in the short run, and a bi-directional relationship in the longer. Thus, connections of passengers and goods are strongly interdependent and co-evolve, so that a detailed analysis of connectivity in passenger networks along corridors explicitly and implicitly informs our understanding of connectivity in logistical networks.

The analyses of the connections of economic centers in our model thus reveal three empirical dimensions of connectivity in BRI: (1) an economic center's major connections including its potential to participate in value chains; (2) the dominant geographical orientation of these connections; and (3) an economic center's role in a network with other nodes that may not be directly interconnected. The main output is a series of measures of the intensity of interactions between centers in the BRI corridors, which in turn allows gauging the position of any center in generating and/or mediating flows within the corridor. Using these measures as the input to a model can then help identifying institutional and governance measures that can be taken to influence a center's position within the corridor.

The remainder of this paper is organized as follows. Section 2 discusses the theoretical rationale for an analysis of the connectivity of economic clusters. Section 3 reviews how a connectivity analysis of economic centers can be implemented. Section 4 outlines our operational approach to the empirical analysis of 'corridor connectivity' along the proposed BRI segments: a network analysis of the composite infrastructure network created by aggregating four different data layers, i.e. rail, road, air, and information technology networks. Section 5 uses the observed networks as the input to network model for the different BRI segments, the parameters of which can help co-determine the interventions that are needed to tackle connectivity bottlenecks, covering infrastructure, policy and regulatory constraints. Section 6 concludes this paper with a summarizing model of BRI city connectivity and an associated discussion of policy implications.

Network Externalities and the Connectivity of Economic Centers

Agglomeration and Network Externalities

The analyses in this paper are concerned with the much broader question of the uneven geographies of economic activity and their influences on the potential impacts of BRI. Received knowledge in economic geography suggests that value creation, productivity, innovation, and knowledge creation are best understood as the result of interactive processes where actors possessing different types of knowledge and competencies come together and exchange information with the aim to solve – technical, organizational, commercial or intellectual – problems (Bathelt et al., 2004; Khanna, 2016).

In geographical terms, such exchange and interaction can be organized and facilitated broadly along two axes. First, there is the potential of spatial proximity offered by urban agglomerations. West et al. (2007), for example, review how and why cities are the predominant engines of innovation and wealth creation. They present compelling empirical evidence for the presence of agglomeration externalities, indicating that the processes relating urbanization to economic development and knowledge creation are generic, being shared by all cities belonging to the same urban system and sustained across different nations and times. Many diverse properties of cities from patent production to personal income are shown to be power law functions of population size with scaling exponents. A large number of studies in economic geography have confirmed the importance of interaction in agglomerations (e.g., Scott, 1988; Scott and Storper, 2014; Meijers et al., 2015). Yet relatively few empirical studies have provided convincing empirical evidence of agglomeration externalities in and by themselves being sufficient to sustain a thriving city, aside from some well-known case studies on creative milieus (see Florida, 2002). Research on regional linkage patterns has provided evidence that even in regions such as the San Francisco Bay area and Baden-Württemberg, which are often portrayed as prototypes of thriving intra-agglomeration networking, transactions internal to the urban region are by no means dominant over external relations (Oakey et al., 1988; Grotz and Braun, 1993). Owen-Smith and Powell (2002) use the term 'pipelines' to refer to the channels used in such often-distant extra-agglomeration interactions. Based on a study of the Boston biotechnology community they conclude that, even though knowledge spillovers may be more efficient within an agglomeration, decisive knowledge flows are often generated through strategic 'network pipelines' of interregional and international reach.

The connectivity of agglomerations, and the access this allows to external markets of ideas and knowledge, is therefore key in understanding the production and reproduction of successful agglomerations[ii]. Or, as Malecki (2000: 341) puts it: "Some places are able to create, attract, and keep economic activity … [particularly] because people in those places 'make connections' with other places." As a consequence, and second, there is the potential of non-agglomeration forms of exchange and interaction as offered by connectivity within a network of cities (Martinus and Sigler, 2017). Meijers et al. (2016), for example, find that – after controlling for all sorts of agglomeration effects – network connectivity positively enhances the presence of metropolitan functions in European cities, confirming the presence and relevance of urban network externalities alongside agglomeration externalities[iii]. A well-developed connectivity is beneficial for economic agents as it allows establishing knowledge- and productivity- enhancing relations to actors in other economic centers. New and valuable knowledge can be created across cities, and the presence of connections to many and/or strategically important cities thus (re)produces competitive advantage; even the world's economically leading city-regions cannot be self-sufficient in terms of state-of-the-art knowledge creation (e.g Saxenian, 1994; Rodríguez-Pose and Fitjar, 2013; Zhang and Kloosterman, 2014). Furthermore, it seems reasonable to assume that there is a self-reinforcing effect in that information and knowledge that one economic agent in an economic center acquires through interaction with others economic centers will spill over to other economic agents through agglomeration externality processes.

Network Analysis of City-Systems

Network externality perspectives tend to focus on the extent to which benefits of one networked entity spill over to the other entities. Katz and Shapiro (1985, p. 424) provided a first formulation of network externalities in which they examine goods where "the utility that a user derives from consumption of the good increases with the number of other agents consuming the good." For example, they discuss telephone and ICT infrastructure where "the utility that a given user derives from the good depends upon the number of other users who are in the same 'network'" (Katz and Shapiro 1985, p. 424). Camagni (1993) and Capello (1996, 2000) have proposed a similar notion of 'network externalities' to understand the urban-economic benefits associated with inter-city interactions. They advance a 'club good' perspective on urban network externalities, emphasizing that benefits accrue on the level of the city production function as connections deliver beneficial 'synergies' and 'complementarities' (Camagni et al. 2012; van Oort et al. 2010).

It is often argued that the technological possibilities offered by consecutive information, communication, and transportation-technological revolutions render urban network externalities relatively more prevalent (e.g., Castells 1989, 2000; Camagni 1993; Batten 1995; Veltz 1996; Camagni et al., 2014; Burger and Meijers, 2016). This calls for a methodical appraisal of what interactive and knowledge-enhancing connections between agglomerations look like. Network analysis offers the opportunity for such a methodical appraisal. In its most basic guise, the concept of a 'network' refers to an observable pattern of 'linkages' between 'nodes', which can together be examined using tools of graph theory. Although interest in 'networks' in geography dates back to at least the 1960s (e.g., Nystuen and Dacey 1961; Haggett and Chorley 1969), there has been a surge in interest in the concept since the 1990s. In particular, references to 'urban networks' have grown dramatically in the scientific literature (Neal 2013), and these networks are currently researched within many social but also natural science disciplines (e.g., Bettencourt and West 2010).

In our research on the BRI, we position ourselves in this line of research by theorizing that urban network externalities derive from the strength and (geographical) nature of agglomerations' connections within telecommunications, road, airline and high-speed rail networks. Urban network externalities can credibly be related to infrastructure, as for example shown by the insight that the (spatially uneven) lowering of costs associated with connections to other agglomerations via myriad infrastructure networks produces an increased utility for the agglomeration (Zook and Brunn 2006). Bel and Fageda (2007), for example, show that the availability of nonstop intercontinental flights is one of the main determinants of the location of large firms' headquarters. This confirms the importance of transport infrastructures and the tacit information exchanges these facilitate between cities for firm location and the embeddedness in value chains.

A key conceptual reason – in addition to the lack of data on inter-city flows of goods – for quasi-exclusively focusing on passenger transport is that knowledge flows between urban economies foremost move through the people communicating through these networks. This results in the emergence of all sorts of asymmetries between cities based on their level of connectivity to other cities in passenger networks (Neal 2011; Pain et al., 2015). In addition, O'Connor (2010) and Ducruet and Notteboom (2012) show that the possibility for freight movements, although very important and central to the BRI as a concept, have a more complex and implicit relation with urban economies than the movement of people. Moreover, collectively, passenger-based transport and communication networks do have the potential to more broadly assess economic centers' participation in value chains. For example, previous research has shown the strong impact of passenger travel on trade based on the importance of face-to-face contact in trade negotiations (Leamer and Storper, 2001). Such arguments are part of a much wider literature showing how spatially uneven declining communication/transport costs and spatially uneven growing communication opportunities impact international trade and operations (see Fink et al., 2005). It has been argued that as trade booms, it becomes more complex and it increasingly incorporates the movement of components along global value chains. As a result, the need to co-ordinate tasks grows, thus strengthening the need for face-to-face contacts (Storper and Venables, 2004). Thus, better and more passenger transport services help overcome the difficulties of coordinating and running increasingly complex value chains, which is consistent with Poole's (2013, p. 24) observation that passenger transport "helps to overcome informational asymmetries in international trade, generating international sales in the form of new export relationships". Similarly, in their article on the travel patterns of professionals in the Irish ICT-cluster, Wickham and Vecchi (2008) show that travel enables firms to build up trust relations with distant customers and suppliers[iv],[v]. Frankel (1997, p.45) discusses the importance of the causal impact of passenger transport on exports in the high-tech capital goods sector: "to begin sales in a foreign country may involve many trips by engineers, marketing people, higher ranking executives to clinch a deal", but at the same time it may involve the movement of "technical support staff to help install the equipment or to service it when it malfunctions." Against this backdrop, it does not come as a surprise that previous research by Van de Vijver et al. (2014) and Tan and Tsui (2017) found a direct causal relationship between passenger travel and trade in the short run, and a bi-directional relationship in periods of 12 months and longer. In our empirical framework, we therefore focus on infrastructure networks that are primarily aimed at moving people rather than goods (although it is hard to make a distinction between both types of networks as trains, roads and planes often carry both), assuming that the former more broadly inform a city's insertion in value chains.

Review of Measures to Assess the Connectivity of Economic Centers

The impact of the deployment of transport infrastructures and the concomitant network externalities strongly depends on the resulting connectivity of an agglomeration (Rietveld and Bruinsma, 2012). Connectivity is much more than the mere stock or quality of available infrastructures; it refers to the directness, the range and geographical diversity, and the density of an agglomeration infrastructure's linkages with all of the other agglomerations in the overall network. For instance, a well-connected node in a rail network does not simply denote the presence of a large railway station but refers to a railway station that has a large number and a wide variety of direct links and short-path indirect connections across the entire network. Given the scientific and policy recognition that connectivity in transportation and communication networks affects an economic center's productivity and economic growth, in this paper we adopt a network analysis perspective.

Network Centrality Analysis

The first set of network analysis measures adopted in this paper gives information about the relative importance of nodes (i.e. agglomerations) in the network: these centrality measures give information on the 'importance' of an agglomeration in the network at large. We use three measures, each providing a specific and complementary perspective on a city's position in the network: degree centrality (DC), betweenness centrality (BC), and closeness centrality (CC). In our analysis, we use normalized versions of these measures (i.e. to make results independent of the number of nodes/edges) for weighted networks (i.e. networks where the edges are valued rather than binary). Second, the basic structure of the network will be explored through the application of a community detection algorithm, which divides a network in 'communities' in such a way that each of the communities is densely connected internally.

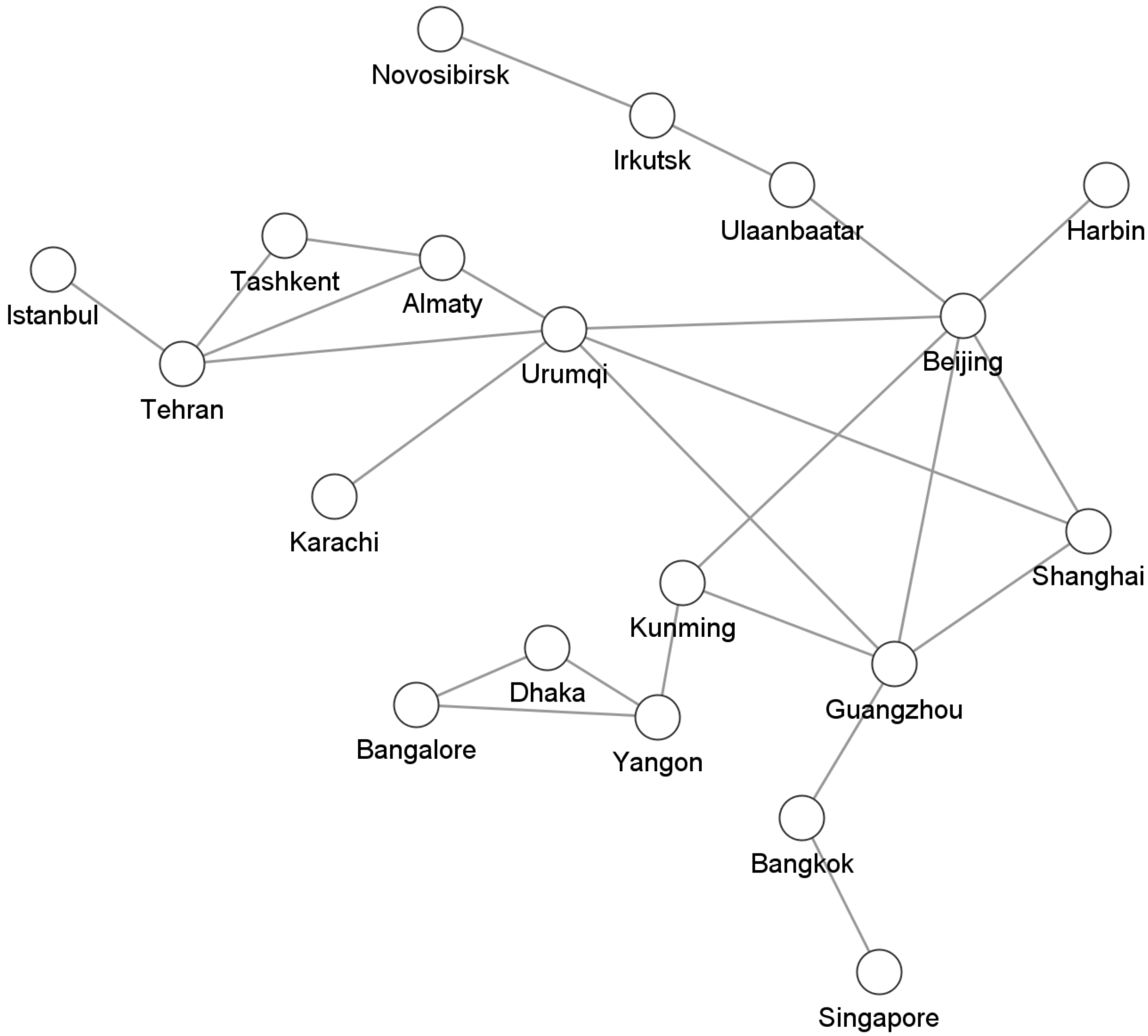
To facilitate the interpretation of this approach, we describe the essence of the measures presented in section 5 by drawing on an intuitive sample network with non-normalized measures and binary connections. This example will be used in what follows to provide concrete results and should be treated as strictly illustrative for explaining the measures. Figure 2 plots this sample network, which is based on the adjacency matrix in Table 1.

Table 1: Sample adjacency matrix.

	BEJ	SHA	GZH	BKK	SIN	DHA	HRB	ULB	KAR	IST	YGN	URM	KMG	ALM	NOV	IRK	TEH	TAS	BNG
BEJ	0	1	1	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0
SHA	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
GZH	1	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
BKK	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SIN	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DHA	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
HRB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ULB	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
KAR	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
IST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
YGN	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	1
URM	1	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0
KMG	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
ALM	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0
NOV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
IRK	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
TEH	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0
TAS	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0
BNG	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0

City codes: ALM: Almaty; BEJ: Beijing; BKK: Bangkok; BNG: Bangalore; DHA: Dhaka; GZH: Guangzhou; HRB: Harbin; IRK: Irkutsk; IST: Istanbul; KAR: Karachi; KMG: Kunming; NOV: Novosibirsk; SHA: Shanghai; TAS: Tashkent; TEH: Tehran; SIN: Singapore; ULB: Ulaanbaatar; URM: Urumqi; YGN: Yangon

Figure 2: Sample corridor network derived from the adjacency matrix



The key to understanding the relevance of using different connectivity measures is that a city can assume an 'important' position in a network for different reasons (see Table 2 for results). First and perhaps most straightforwardly, a city has a strong position in the network if it has a large number of connections. This is measured through degree centrality. From this perspective, Beijing is a well-connected city in the sample network because it has 6 connections; Dhaka is a poorly connected city because it only has 1 connection.

Second, a city has a strong position in the network if it often 'stands' on the shortest route between other pairs of cities that are not directly interconnected. This is measured through betweenness centrality. A city with a large betweenness centrality plays an important role in the network because it brokers exchanges between city-pairs or even entire communities. In the ranking of betweenness centrality, Kunming emerges as the fourth most important node as it 'controls' connections between Yangon and most other cities: all cities other than Dhaka and Bangalore have to go via Kunming to reach Yangon (and the other way around). Thus, although Kunming and Shanghai are equally ‘important’ in terms of degree centrality in this sample network, Kunming does play an important role interconnecting the entire network. Shanghai, in contrast, has a betweenness centrality of 0, as there is not a single city-pair in this network that ‘needs’ this city to quickly interconnect.

Third, a city has a strong position in the network if it is, on average, connected to well-connected cities. This is measured through closeness centrality. In a nutshell, closeness centrality reflects the total length of the shortest paths between a city and all other cities in the network. From this perspective, Shanghai is ‘closely’ connected to the rest of the network, because it has direct connections to other well-connected cities such as Beijing and Urumqi. By contrast, Novosibirsk is ‘remotely’ connected, as it needs to take more ‘steps’ to reach other cities in the network. Although for this particular network degree centrality and closeness centrality are related, there are some distinctions. The difference between Ulaanbaatar and Tashkent is a case in point: both cities have the same degree centrality (2 connections), but Ulaanbaatar has a higher closeness centrality because – in contrast to Tashkent – it has a direct link with Beijing, which has a wide range of direct connections making it on average easier for Ulaanbaatar than for Tashkent to reach the other cities in the network.

It is customary in network analysis to use normalized versions of centrality measures rather than the ‘raw’ versions used for analyzing the sample network (see bottom part of Table 2). This is done to facilitate comparisons between analyses with different numbers of nodes/edges (e.g. for future research using a lower threshold, or to make comparisons with other regions). In addition, in our research we use versions of the centrality measures that take the relative strength of inter-city connections into account (Hanneman and Riddle, 2011).

Table 2: non-normalized and normalized centrality measures for the sample network (DC = degree centrality, BC = betweenness centrality, and CC = closeness centrality).

Rank	City	DC	City	BC	City	CC
1	Beijing	6	Beijing	73	Beijing	36
2	Urumqi	6	Urumqi	69	Guangzhou	38
3	Guangzhou	5	Guangzhou	46	Urumqi	39
4	Tehran	4	Kunming	45	Shanghai	44
5	Almaty	3	Ulaanbaatar	32	Kunming	44
6	Kunming	3	Yangon	32	Ulaanbaatar	49
7	Shanghai	3	Tehran	24	Tehran	51
8	Yangon	3	Bangkok	17	Almaty	52
9	Bangkok	2	Irkutsk	17	Bangkok	53
10	Bangalore	2	Almaty	7.5	Harbin	53
11	Dhaka	2	Bangalore	0	Karachi	56
12	Irkutsk	2	Dhaka	0	Yangon	57
13	Tashkent	2	Harbin	0	Irkutsk	64
14	Ulaanbaatar	2	Istanbul	0	Tashkent	67
15	Harbin	1	Karachi	0	Istanbul	68
16	Istanbul	1	Shanghai	0	Singapore	70
17	Karachi	1	Singapore	0	Bangalore	73
18	Singapore	1	Tashkent	0	Dhaka	73
19	Novosibirsk	1	Novosibirsk	0	Novosibirsk	81

Rank	City	DC	City	BC	City	CC
1	Beijing	1.000	Beijing	0.477	Beijing	0.500
2	Urumqi	1.000	Urumqi	0.451	Guangzhou	0.474
3	Guangzhou	0.833	Guangzhou	0.301	Urumqi	0.462
4	Tehran	0.667	Kunming	0.294	Shanghai	0.409
5	Almaty	0.500	Ulaanbaatar	0.209	Kunming	0.409
6	Kunming	0.500	Yangon	0.209	Ulaanbaatar	0.367
7	Shanghai	0.500	Tehran	0.160	Tehran	0.353
8	Yangon	0.500	Bangkok	0.111	Almaty	0.346
9	Bangkok	0.333	Irkutsk	0.111	Bangkok	0.340
10	Bangalore	0.333	Almaty	0.049	Harbin	0.340
11	Dhaka	0.333	Bangalore	0.000	Karachi	0.321
12	Irkutsk	0.333	Dhaka	0.000	Yangon	0.316
13	Tashkent	0.333	Harbin	0.000	Irkutsk	0.281
14	Ulaanbaatar	0.333	Istanbul	0.000	Tashkent	0.269

15	Harbin	0.167	Karachi	0.000	Istanbul	0.265
16	Istanbul	0.167	Shanghai	0.000	Singapore	0.257
17	Karachi	0.167	Singapore	0.000	Bangalore	0.247
18	Singapore	0.167	Tashkent	0.000	Dhaka	0.247
19	Novosibirsk	0.167	Novosibirsk	0.000	Novosibirsk	0.222

Network Modeling

To explore the strength and remit of the main forces underlying the formation of the urban infrastructure networks in BRI countries, we employ a 'spatial interaction modeling' approach. This model explains the observed flows between cities as a function of these cities' 'importance' on the one hand and the 'distance' between them on the other hand (van Oort et al., 2010). The underlying assumption is straightforward and related to hypotheses that can be drawn from the findings presented in section 5: the connection between two cities is positively related to their size; inversely related to the Euclidean distance between them; and the presence of an international border. Our model can therefore be represented as follows:

$$T_{ij} \sim P_i P_j d_{ij} SC_{ij}$$

Where:
Tij: the connectivity between cities i and j;
Pi and Pj: the population size of cities i and j, respectively;
dij: the logged Euclidean distance between cities i and j;
SCij: a dummy variable that equals 1 if i and j are located in the same country, and 0 if otherwise;

The model can be transformed and estimated via ordinary regressions. The modeling exercise thus entails finding the combination of model parameters generating a network that most closely resembles the structure of the observed composite network. Annex A provides an overview of the model parameters for the continental network and the different corridors.

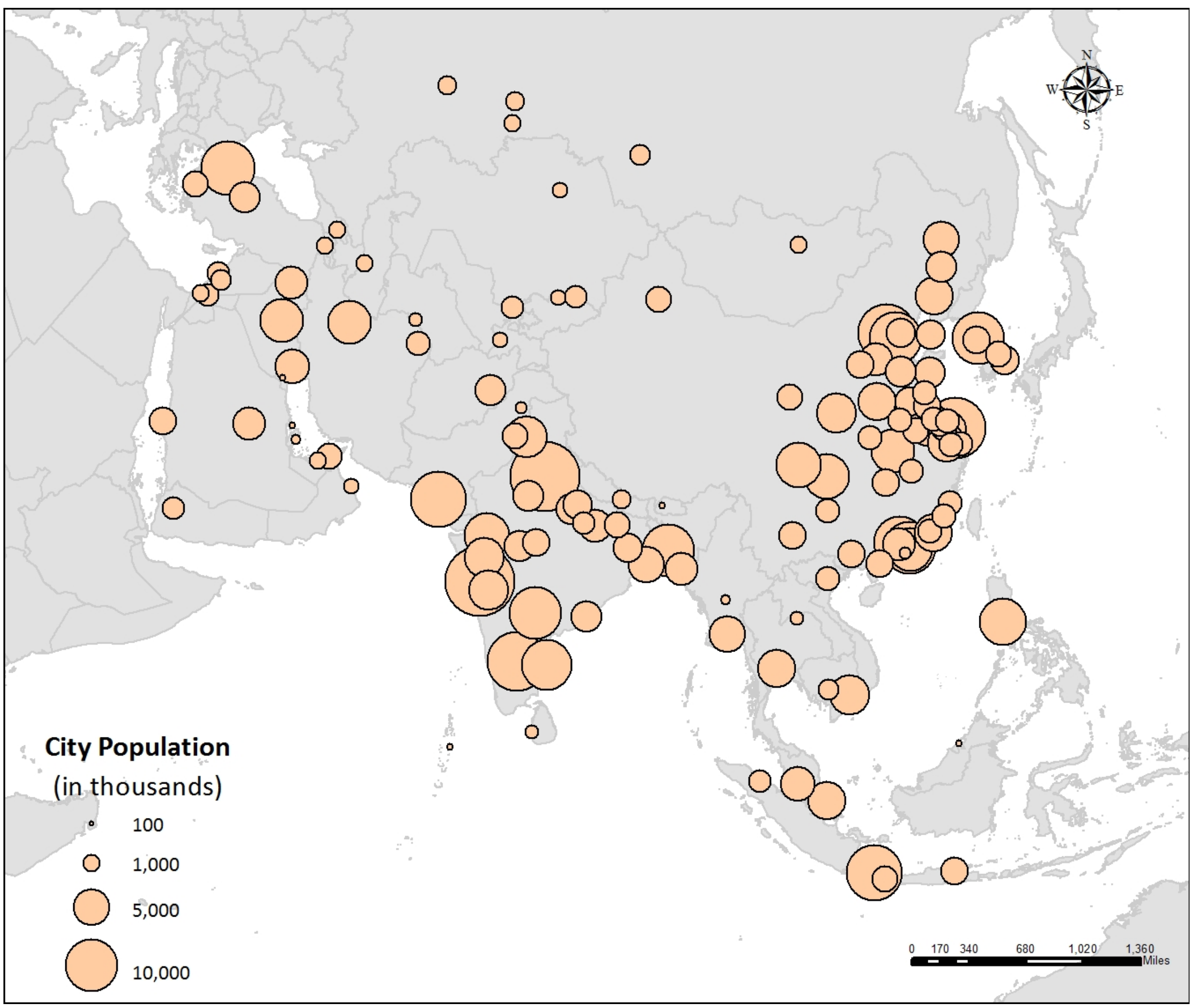
Although the predictive power of the models for the different corridors varies, overall, they confirm the intuitive description developed in the previous sections: all of the variables are statistically significant. However, importantly, standardized coefficients show that it is above all being located in the same country that explains the strength of inter-city connections. This conforms the community detection results network partitioning suggesting that the BRI should focus more on inter-regional connectivity.

Scope of the BRI Corridor Connectivity Model

Selection of Cities

The BRI corridor connectivity model is constructed and analyzed at two levels: an overall analysis to examine the overall connectivity patterns at the continental level, and more refined analysis of connectivity within individual economic cooperation corridors. We use the list of BRI countries provided on the Initiative's official website. While the Belt and Road Initiative includes countries outside Asia, the analysis will be confined to BRI countries in Asia. This is partly because infrastructure is well endowed in much of Europe and the focus of infrastructure investment within the BRI framework (e.g., the works of the Asian Infrastructure Investment Bank) tends to be on Asia. For the continental level analysis, all cities with a population of more than 2 million inhabitants in BRI countries for the year 2015 are included, in addition to the capital cities to ensure that all Asian political centers are represented (Figure 3).

Figure 3: The 134 cities included in the continental connectivity analysis (node size varies with a city's population size).



For corridor-level analysis, we first identify cities that are located in or close to individual corridors (Figure 1). Although the exact alignment of corridors is not defined, we assume that the corridors will aim to link major economic centers along the general alignment that is offered. To cater for minor variations in alignment within countries, we (1) utilize data on known main road and rail links to identify broader geographic units (e.g., provinces, regions, and states) that locate along the known main BRI routes; (2) consider cities that locate in the broader geographic units identified in the previous step; and (3) apply a population threshold to identify major urban centers. More specifically, for cities associated with individual corridors, all Chinese cities with a population of more than 1 million inhabitants and all non-Chinese cities with at least half a million residents are included. In addition, we ensure that all capital cities and cities that are specifically mentioned as 'strategic nodes' in the Vision and Actions on Jointly Building the Silk Road Economic Belt and 21st Century Maritime Silk Road are included. Cities selected for analyses of (1) the China-Mongolia-Russia Economic Corridor, (2) the New Eurasian Land Bridge, (3) the China-Central Asia-Western Asia Corridor, the (4) China-Indochina Peninsula, (5) the China-Pakistan Economic Corridor, and (6) the Bangladesh-China-India-Myanmar Corridor are shown in Figures 4-9. The full list of cities for each of the corridors is provided in Appendix 1.

Figure 4: Cities included in the analysis of the China-Mongolia-Russia Economic Corridor (node size varies with a city's population size).

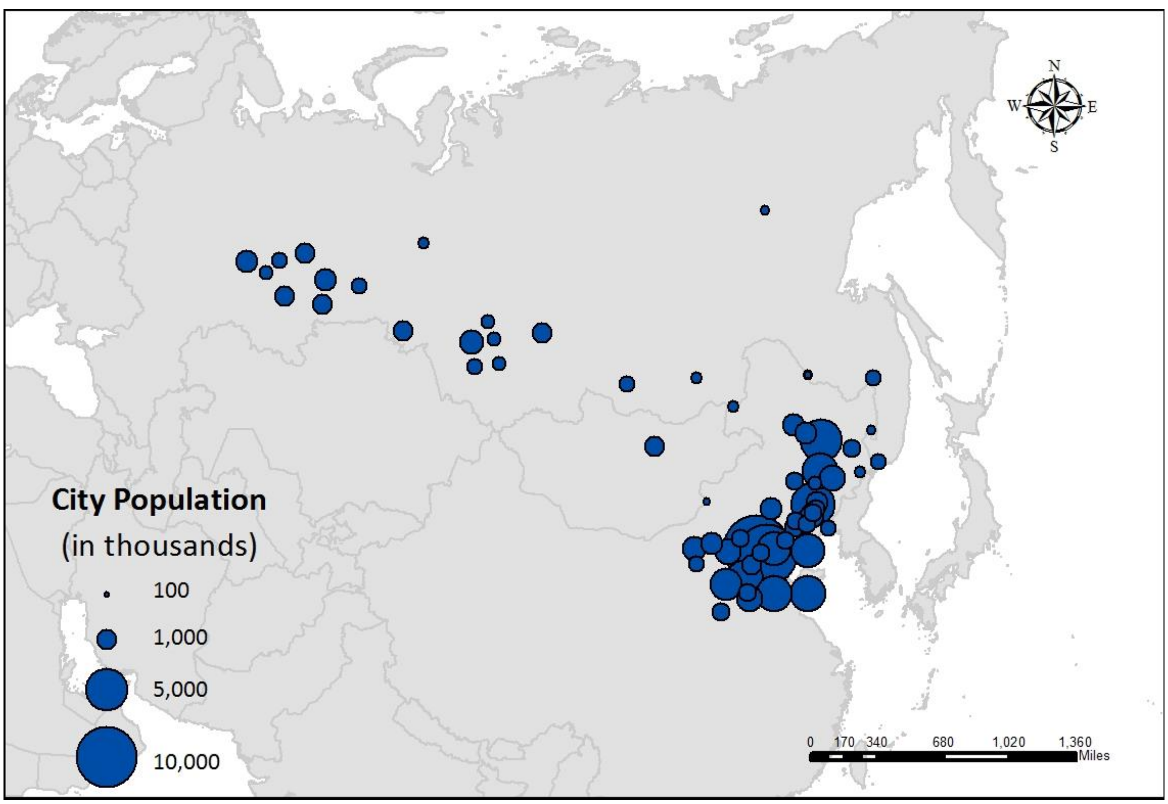


Figure 5: Cities included in the analysis of the New Eurasian Land Bridge Corridor

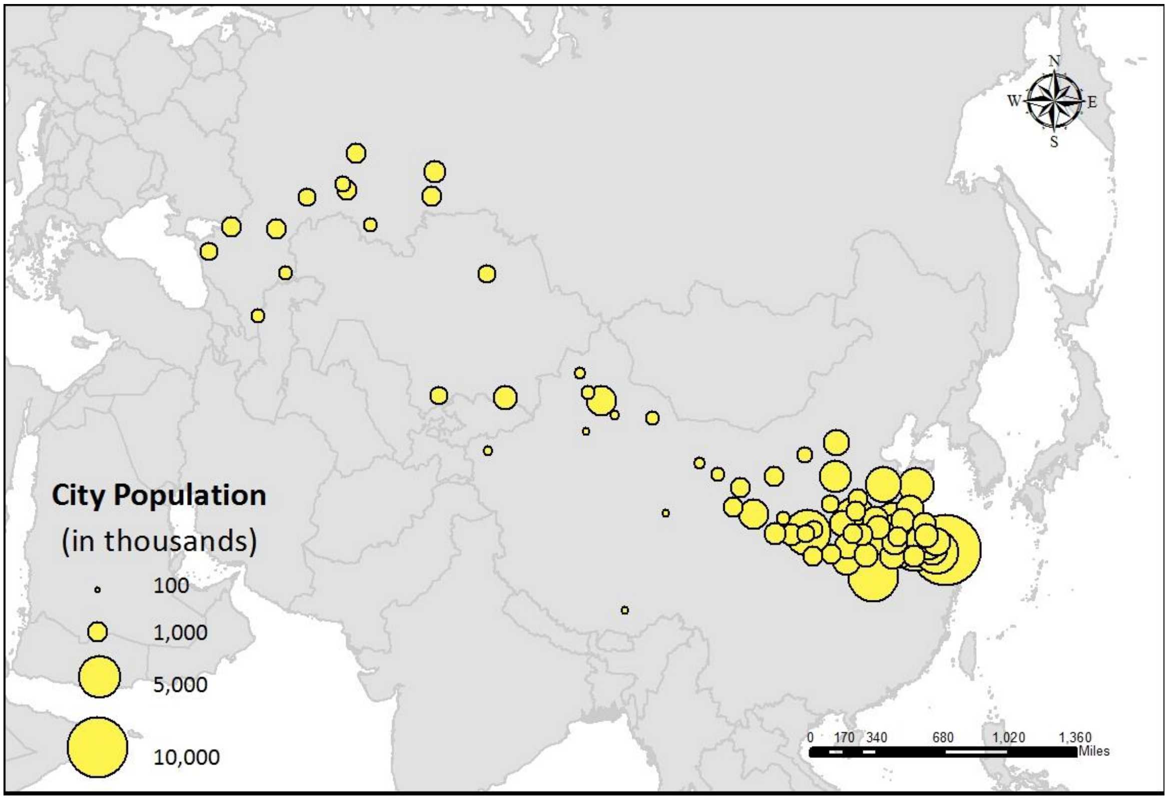


Figure 6: Cities included in the analysis of the China-Central Asia-Western Asia Corridor (node size varies with a city's population size).

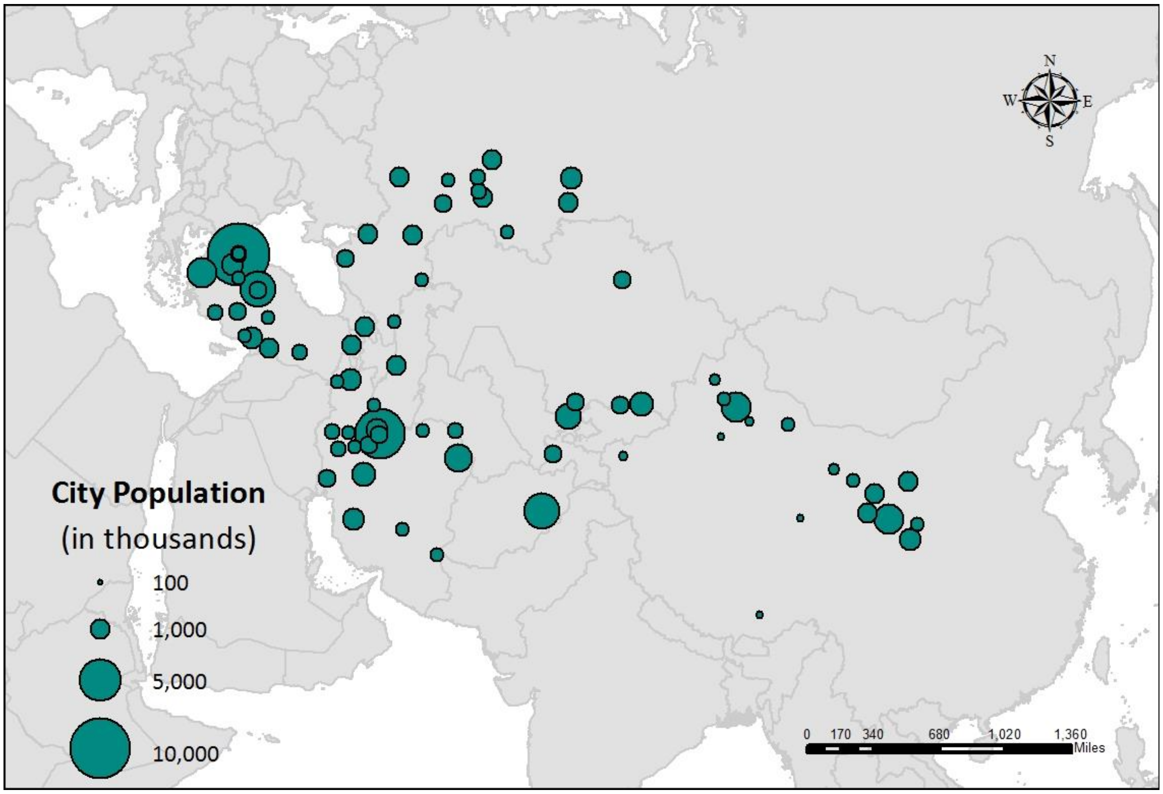


Figure 7: Cities included in the analysis of the China-Indochina Peninsula Corridor (node size varies with a city's population size).

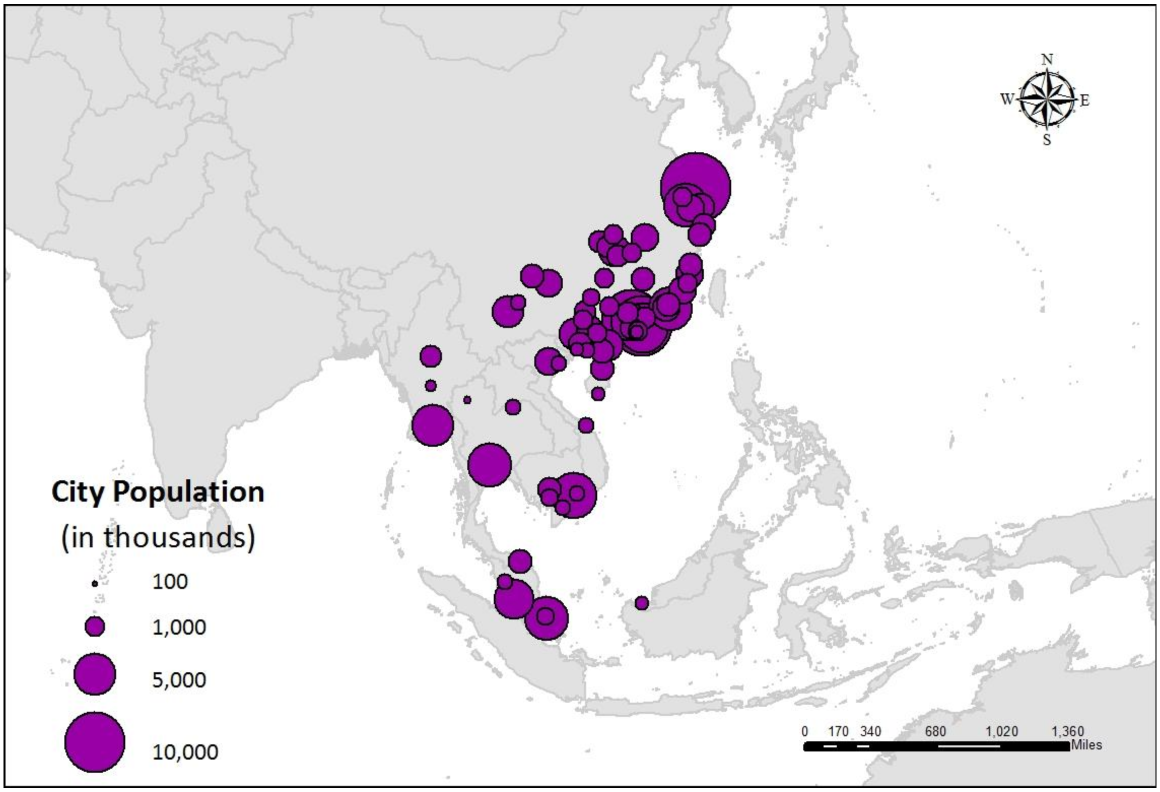


Figure 8: Cities included in the analysis of the China-Pakistan Economic Corridor (node size varies with a city's population size).

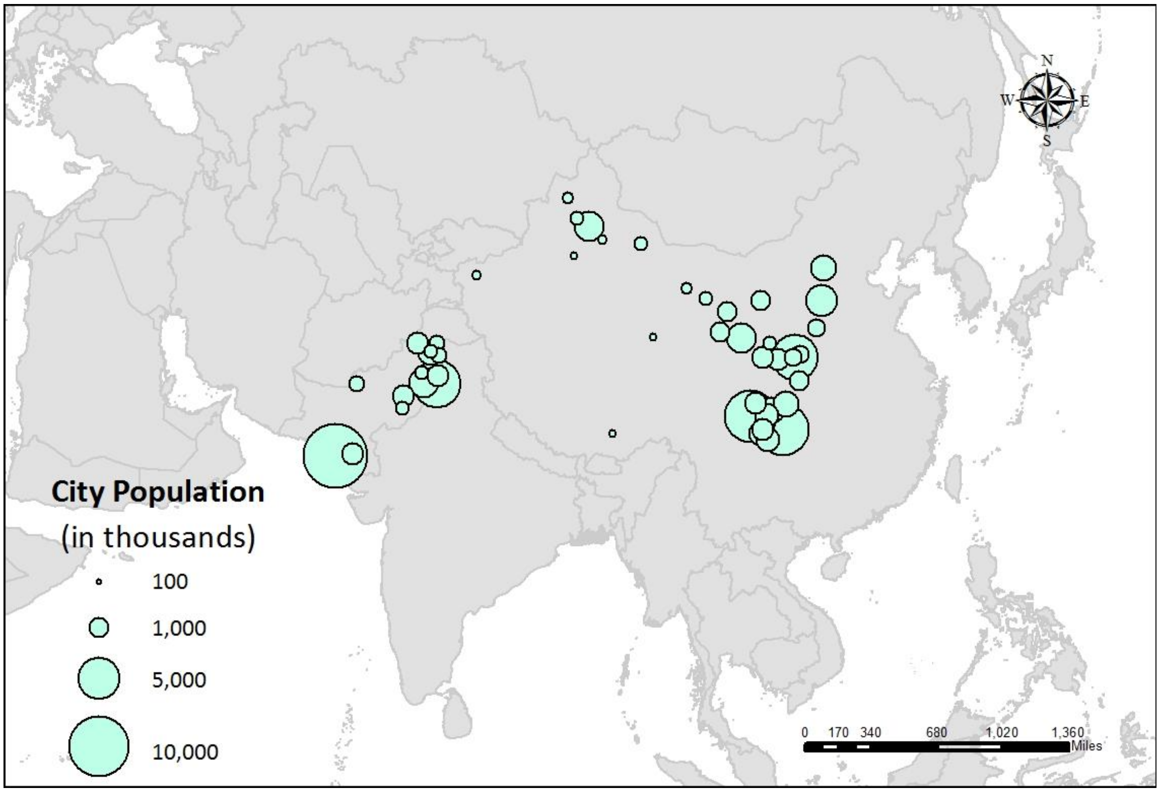
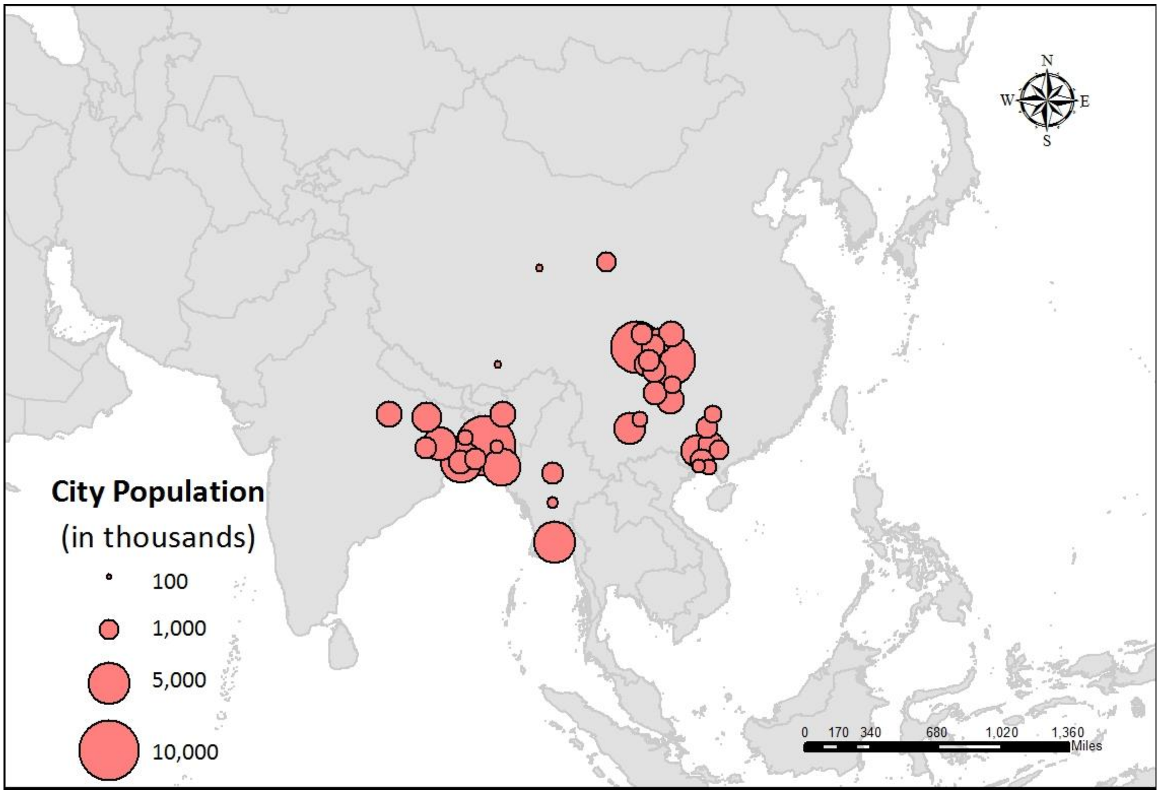


Figure 9: Cities included in the analysis of the Bangladesh-China-India-Myanmar Corridor (node size varies with a city's population size).



Collection and Pre-Processing of Network Data

We illustrate our approach with the continental-level model, but analyses of individual economic corridors were performed in the same manner. Urban connectivity in BRI countries is analyzed for a total 134 cities. We construct a composite infrastructure network that consists of an aggregation of four different layers, i.e. rail, road, air, and information technology networks. Each of these layers will comprise 134x133/2 = 8911 edges that are undirected and valued: this implies that the connection from city i to city j equals that from city j to city i, while edges represent the relative strength of an inter-city connection. A detailed overview of the data sources used in this study can be found in Appendix 2. Each of the data layers is normalized, after which the sub-networks are combined into a composite network that is further transformed to make it fit for network analysis[vi].

The Airline Network Layer

The airline network layer was constructed around the number of direct weekly flights offered during the last week of June 2017[vii]. Data were obtained through Google's web crawling service (see Figure 10) and crosschecked with the SkyScanner passenger flight search engine. The strongest connection in this layer is Mumbai-Delhi, followed by Jakarta-Surabaya and Shanghai-Beijing.

Figure 10: Google's overview of weekly direct flights between Shanghai and Beijing

48+ flights per day, 2h 15m duration

Shanghai, China (all airports) to Beijing, China (all airports)

7:00 am	9:20 am	China Eastern 5137	- M T W T F -	SHA-PEK
7:55 am	10:10 am	Air China 1858	S M T W T F S	SHA-PEK
8:00 am	10:15 am	China Eastern 5101	- M T W T F S	SHA-PEK
8:05 am	10:30 am	CUA 5988	S M T W T F S	PVG-NAY
8:20 am	10:35 am	Hainan 7604	S M T W T F S	SHA-PEK
8:30 am	10:45 am	China Eastern 5151	S M T W T F S	SHA-PEK
8:55 am	11:10 am	Air China 1590	- M T W T F S	SHA-PEK
9:00 am	11:20 am	China Eastern 5103	S M T W T F S	SHA-PEK
9:00 am	11:25 am	China Eastern 5129	S M T W T F S	PVG-PEK
9:30 am	11:55 am	China Eastern 5153	- M T W T F S	SHA-PEK
10:00 am	12:15 pm	China Eastern 5105	S M T W T F S	SHA-PEK
10:55 am	1:10 pm	Air China 1832	S M T W T F S	SHA-PEK
11:00 am	1:20 pm	China Eastern 5107	S M T W T F S	SHA-PEK
11:15 am	1:25 pm	Hainan 7606	S M T W T F S	SHA-PEK
11:45 am	2:10 pm	China Southern 3952	S M T W T F S	SHA-PEK
11:55 am	2:10 pm	Air China 1502	S M T W T F S	SHA-PEK
11:55 am	2:10 pm	Xiamen 8177	S M T W T F S	SHA-PEK

The Information Technology Network Layer

The Internet subnetwork will be based on data garnered in the context of the DIMES project. DIMES is a distributed scientific research project that aims to study the structure and topology of the Internet, and results in what is by far the best data source around for mapping day-to-day Internet geographies (Tranos and Nijkamp, 2013). The data are based on 'traceroute' measurements made daily by a global network of more than 10,000 agents in 2016 (for a description of the DIMES project, see Shavitt and Shir, 2005). DIMES volunteers derive the raw connectivity data through geo-locating Internet Protocol (IP) links: although 'Internet flows' are often thought to be 'immaterial', this is an infrastructural measure because IP links represent physical data links between city-pairs (these can be e-mails, file downloads, etc.). In this layer, each IP link represents a connection, whereby edges are geo-coded at the level of the cities as defined in our framework. The strongest connection in this layer is Shanghai-Beijing, followed by Hefei-Beijing and Shenyang-Beijing.

The Road and Train Network Layers

The road and train network layer were constructed around the number of direct weekly busses and trains offered during the last week of June 2017. Data were gathered from a variety of sources, such as trains.china.org.cn for China, cambodiatrains.info for Cambodia, pakrail.com for Pakistan, and russiantrains.com for Russia. For transnational links such as Beijing-Ulaanbaatar-Moscow, we used a range of secondary sources. The strongest connection in the road network layer is Guangzhou-Foshan, followed by Istanbul-Izmir and Guangzhou-Shenzhen. The strongest connection in the rail network layer is Shanghai-Suzhou, followed by Nanjing-Shanghai and Nanjing-Suzhou.

Transformations and Construction of the Composite Network

Information from each of the four layers is combined into a single connectivity measure. We first logged measures in each of the layers to alleviate the skewness in the distributions. We then applied a min/max transformation to the logged figures in order to standardize the distributions, so that all four networks layers have an edge distribution ranging from 0 (minimum connectivity) and 1 (maximum connectivity)[viii]. And finally, the values of the different connections in the composite network were computed by taking the average score of the logged and normalized values in each of the different layers. The strongest connection in the composite network layer is Shanghai-Beijing, followed by Seoul-Busan and Nanjing-Beijing.

BRI Connectivity Results

In this section, we discuss the results of the connectivity models for both the continental network and the 6 corridors. For each of the 7 networks, we include (1) a map in which node size for cities varies with degree centrality and different colors are used for the different communities and (2) a table with the 10 most connected cities for each of the three centrality measures.

Continental Network

The continental network can be seen as the broader framework against which BRI connectivity corridors unfold. It is not a corridor per se but shows how cities in this world-regions are connected in general.

There are 7 communities in the continental network, and these have a modularity of 0.36. In addition to tightly connected Chinese, Indian and Indonesian communities, there is also a community for western Asia (mainly cities on the Arab Peninsula, but with sizable geographical outreach to cities in Sri Lanka, Afghanistan/Pakistan, and even Bangladesh), the northern part of the Middle East, Southeast Asia (but with geographical outreach to South Korea and Taipei), and central Asia (including Russian cities). The strong imprint of territorial states on urban connectivity shows from the presence of the three ‘national clusters’ for the three most populous countries in the region (China, India, and Indonesia). There is a more general ‘geographical’ impact on the topology of the network in that nearby cities tend to be in the same community, but this effect of distance is not all-encompassing and also confounded by the effect of national borders. Examples of the former include the stronger connections of South Korean cities/Taipei with Southeast Asian cities than with Chinese cities, as well as the relatively stronger connections between a city such as Dhaka with the likes of Dubai and Abu Dhabi than with nearby Indian cities. An example of the latter includes the observation that Medan, the fourth most populous city of Indonesia is more strongly connected with other Indonesian cities than with nearby cities such as Singapore and Kula Lumpur. This impact of borders and geographical proximity will re-emerge in the remainder of the results and in the modelling exercise but note that there are always notable exceptions and complex interactions between Euclidean distance and national borders.

Beijing emerges as the most connected city in the continental network. It leads the ranking for degree and betweenness centrality, as well as ranking third in terms of closeness centrality (Table 3). However, the most interesting and meaningful result here is that the three rankings tell very different, yet complementary stories about connectivity in the region. The degree centrality ranking is dominated by Chinese cities; indeed, there is not a single non-Chinese city in the top 10 of the degree centrality ranking. This can be attributed to the combination of China’s large (urban) population and its well-developed internal transport infrastructures, which imply that – in absolute volumes – Chinese cities are, and always will be irrespective of the territorial framework, strongly inter-connected. However, the connectivity map in Figure 11 shows that these connections are indeed above all confined to other Chinese cities, and this becomes clear in the other two rankings which clearly suggest that having many connections does not automatically translate into a privileged position in the overall urban network. Indeed, only 3 major Chinese cities show up in the betweenness centrality ranking, while the closeness centrality ranking is a combination of Chinese cities with a sizable number of connections (as measured by degree centrality) and a range of cities that are, on average, few steps away from the other cities in the continental network (as measured by closeness centrality). Thus, although Seoul and Bangkok do not really stand out in terms of their absolute volume of connections in comparison to Chinese cities, they are topologically on average much closer to the other cities across the continent than the vast majority of Chinese cities. Meanwhile, Shanghai is conspicuously absent from the betweenness centrality ranking: it is well connected from the perspective of the volume and distribution of its connections but does not act as a major ‘connector’ for other cities. Instead, it is Guangzhou that – alongside Beijing – emerges as the main Mainland Chinese gateway for connectivity, most notably between cities in the Southeast Asian community and the Chinese community. And finally, the well-known gateway role of Singapore and Hong Kong is made explicit here in substantive and geographical terms: they rank second and third in terms of betweenness centrality, respectively, and clearly play a central role in connecting India with Southeast Asia and Southeast Asia with China, respectively.

Figure 11: Composite network for the continental analysis (node size varies with a city's degree centrality; color codes indicate community affiliation).

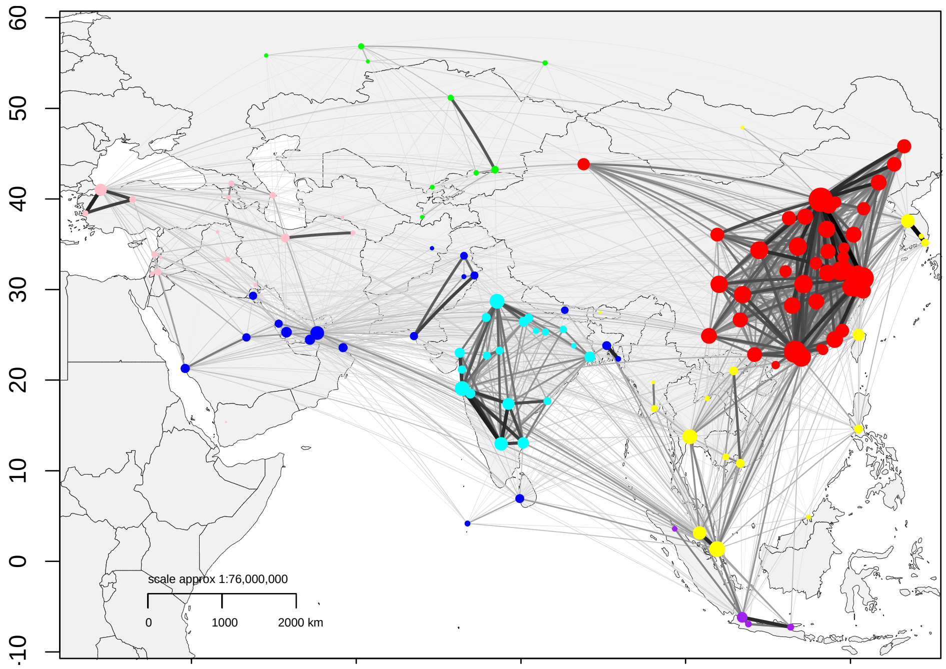


Table 3: Top 10 of most central cities (as measured by three centrality measures) in the continental analysis.

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Beijing	Beijing	Hong Kong
2	Shanghai	Singapore	Singapore
3	Guangzhou	Hong Kong	Beijing
4	Nanjing	Guangzhou	Guangzhou
5	Shenzhen	Dubai	Shanghai
6	Hangzhou	Mumbai	Seoul
7	Wuhan	Istanbul	Bangkok
8	Zhengzhou	Delhi	Nanjing
9	Xi'an	Seoul	Zhengzhou
10	Chengdu	Jakarta	Shenzhen

Connectivity Analysis for the China-Mongolia-Russia Economic Corridor

There are three communities in the China-Mongolia-Russia Economic Corridor network, with a modularity of 0.27: a Russian community, a Central Chinese/Mongolian community, and an Eastern Chinese community. Although the modularity scores are lower than for many other corridors, there is a lack of trans-border integration in connectivity. Nowhere is this is more clear than in cities located on or very near to the border (such as Manzhouli/Hulunbuir on the Chinese side, and Khbaravosk on the Russian side of the Chinese-Russian border): these cities are clearly and firmly connected to their 'national' community, with the borders being almost de facto dead-ends in land-based travel and with little or no transnational air transport links to compensate.

The degree centrality ranking is dominated by Chinese cities from both communities (Table 4). This can be attributed to the larger number of (large) cities on the Chinese side in combination with its well-developed internal transport infrastructure. As the Chinese cities make up the bulk of our empirical framework, the closeness centrality ranking is almost a carbon copy of the degree centrality ranking. However, there are notable exceptions such as Baotou, which in spite of its small degree centrality is very close to the network at large because its limited connectivity is with well-connected Chinese cities so that it is close to the network at large. The betweenness centrality ranking paints a more diverse and complex picture, with Russian cities such as Novosibirsk and Irkutsk playing an important role in mediating connections in the China-Mongolia-Russia Economic Corridor, and the northern Chinese city of Hohhot playing an intermediating role in connecting cities such as Manzhouli/Hulunbuir and Baotou to this corridor: without the linkages between the latter cities and Baotou, these cities would be virtually cut off from this corridor. From an international perspective, Novosibirsk and Irkutsk in Russia are the key nodes in brokering connections between China and the remainder of this corridor.

Figure 12: Composite network for the China-Mongolia-Russia Economic Corridor (node size varies with a city's degree centrality; color codes indicate community affiliation).

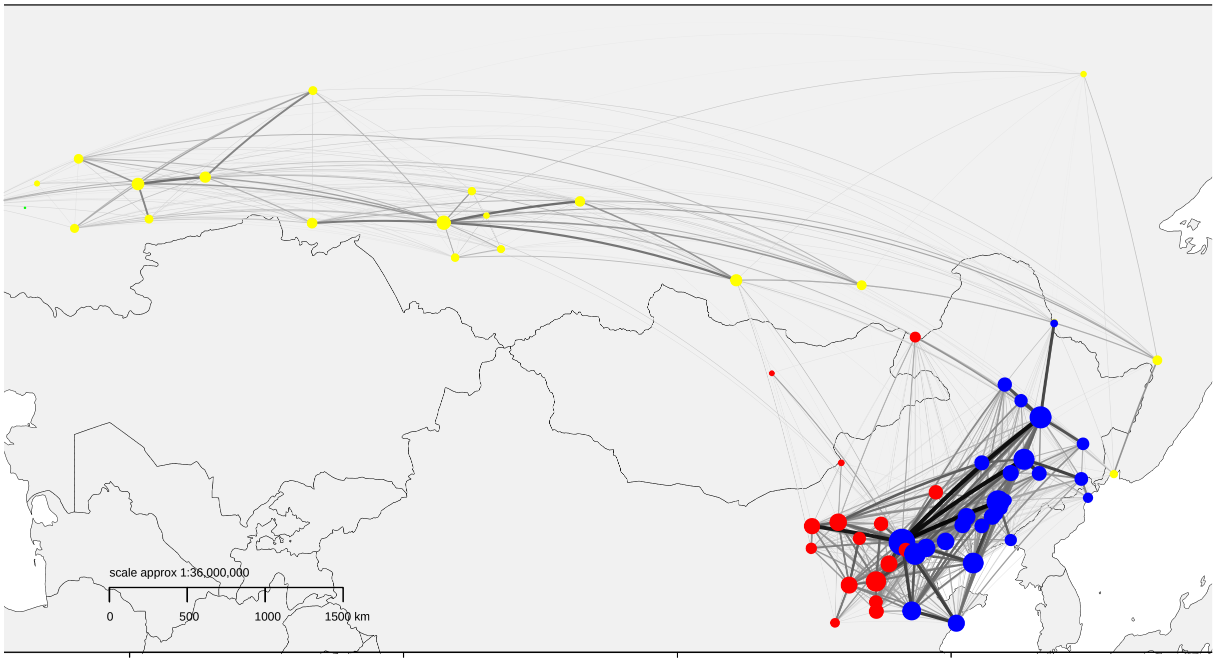


Table 4: Top 10 of most central cities (as measured by three centrality measures) in the China-Mongolia-Russia Economic Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Beijing	Beijing	Beijing
2	Shenyang	Novosibirsk	Shenyang
3	Harbin	Shenyang	Harbin
4	Tianjin	Irkutsk	Tianjin
5	Changchun	Harbin	Changchun
6	Dalian	Changchun	Baotou
7	Shijiazhuang	Yekaterinburg	Dalian
8	Jinan	Hohhot	Jinan
9	Tangshan	Tyumen	Shijiazhuang
10	Jinzhou	Shijiazhuang	Qingdao

New Eurasian Land Bridge

There are four communities in the New Eurasian Land Bridge Corridor network, with a modularity of 0.23: three Chinese communities (West, Central, and East) and a community with the Russian and Kazakh cities located along this corridor. The low modularity score is due to the fact that Chinese cities themselves are divided among three communities: although these communities form coherent subnetworks, there are nonetheless myriad connections between cities in these communities. Again, there is a general lack of trans-border integration with few connections between Chinese cities on the one hand and Russian and Kazakh cities on the other hand. In spite of the very strong connections among Kazakh cities, linkages with Russian cities appear strong enough for them to form a cohesive sub-network, which probably reflects path dependence of network integration under the Former Soviet Union umbrella.

The degree centrality ranking is dominated by Chinese cities from all three communities (Table 5). This can, again, be attributed to the larger number of (sizeable) cities on the Chinese side in combination with its well-developed internal transport infrastructure. As the Chinese cities make up the bulk of our empirical framework, the closeness centrality ranking strongly resembles the degree centrality ranking, albeit with the notable introduction of Lanzhou and above all Urumqi (on which more below). Zhengzhou, Shanghai, and Xian are by far the most connected cities. Shanghai has the largest number of connections, while Zhengzhou and Xian combine strong connections with a bridging role between the Chinese sub-networks as visible in their betweenness centrality surpassing that of Shanghai. This bridging role of specific cities is very apparent in the New Eurasian Land Bridge Corridor, with in addition to Zhengzhou and Xian a betweenness-central role for three duos of cities: Yekaterinburg/Krasnodar in Russia, Almaty/Astana in Kazakhstan, and Urumqui/Lanzhou in China. These cities literally knit the network together: without the bridging role of these cities, the New Eurasian Land Bridge Corridor network would disintegrate. Although the origins of the betweenness centrality of these three pairs of cities can be interpreted in a similar way, by far the starkest example is Urumqi: although not featuring in the top 10 of degree centrality, it has the highest betweenness centrality and ranks fourth in closeness centrality. Urumqi is the largest city in China’s western interior and Central Asia more generally. As one of the most remote cities from any sea in the world, it now capitalizes on its central location in Asia in that has developed strong landside and airside connections: with major Chinese cities, but also – and unusually for Chinese cities beyond the likes of Beijing, Shanghai, Hong Kong and Guangzhou – across borders. For example, Urumqi is a hub for China Southern Airlines (one of China’s largest carriers) and Xinjiang Province’s main rail hub with a high-speed rail line connecting the city to Lanzhou. However, at least as importantly, some of its connectivity has a regional-international component (e.g. a daily flight to Astana in Kazakhstan), which explains why Urumqi has evolved into the critical gateway city in this New Eurasian Land Bridge Corridor.

From an international perspective, Almaty, Astana, Urumqi, Krasnodar and Yekaterinburg are the key nodes in brokering connections between China and the remainder of this corridor.

Figure 13: Composite network for the New Eurasian Land Bridge Corridor (node size varies with a city's degree centrality; color codes indicate community affiliation).

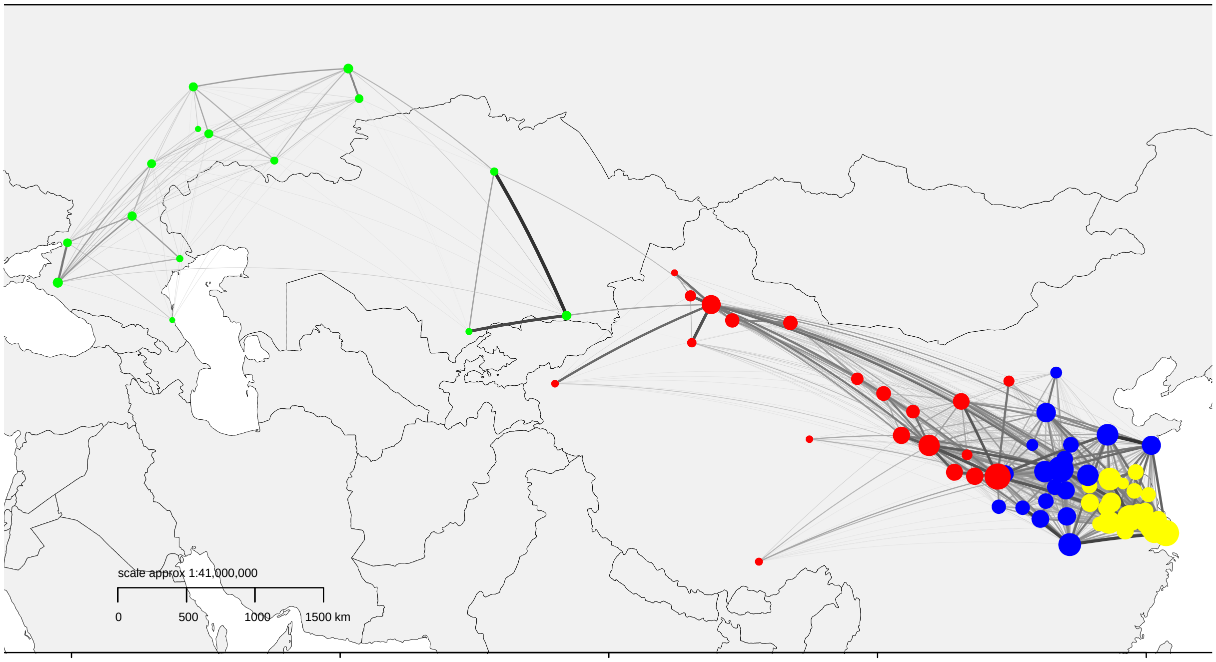


Table 5: Top 10 of most central cities (as measured by three centrality measures) in the New Eurasian Land Bridge Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Shanghai	Urumqi	Zhengzhou
2	Zhengzhou	Almaty	Shanghai
3	Xian	Xian	Xian
4	Nanjing	Zhengzhou	Urumqi
5	Hefei	Shanghai	Nanjing
6	Wuhan	Krasnodar	Lanzhou
7	Xuzhou	Astana	Wuhan
8	Suzhou(JS)	Nanjing	Hefei
9	Jinan	Yekaterinburg	Jinan
10	Luoyang	Lanzhou	Suzhou(JS)

China-Central Asia-Western Asia Corridor

There are four communities in the China-Central Asia-Western Asia Corridor network, with a very high modularity of 0;66: a Turkish community, an Iranian community, a Western Chinese community, and a Central Asian community that brings together post-Soviet cities. The high modularity score reveals that these four sub-networks are hardly connected. Moreover, many of these communities are de facto national. Only the Central Asian community, which again reflects path dependence of network integration under the Former Soviet Union, is the major exception to the general lack of trans-border network integration in this corridor. Another exception is Kabul's membership of the Turkish community. However, this finding should not be over-interpreted, as it reflects above all the very poor connectivity of Kabul in general: whatever little connectivity it has is with Istanbul, and results in a network position in the Turkish community centered on Istanbul.

The degree centrality ranking is a roll call of the most connected cities in each of the four communities, with Tehran, Istanbul, Urumqi and Yekaterinburg as leading cities in these communities (Table 6). As the Central Asian and Iranian sub-network are somewhat more dispersed and sparsely connected, the remainder of the top 10 for degree centrality consists of Turkish and Chinese cities. The figure clearly shows that the Asia-Western Asia Corridor network is very poorly inter-connected. This gives a central role to Almaty (and to a lesser degree Astana), which ranks markedly higher on between centrality as it acts as the gateway between the Turkish, Chinese, and Central Asian community. Yekaterinburg and Samara play similar roles, albeit somewhat less prominently and only between the Turkish and Central Asian community, leading to sizable but somewhat lower betweenness centrality scores. Because Astana and Almaty are, alongside Istanbul and Ankara, the only cities with more or less substantial connections with cities across the network, they also score high on closeness centrality: these are the only four cities that can be reached relatively easy from the remainder of the network (or, alternatively, can be used as a starting point to reach the remainder of the network relatively easy). Tehran is at the apex of the betweenness centrality ranking because it connects the otherwise largely unconnected Iranian community to the rest of the Asia-Western Asia Corridor network – no other city is as dominant in its sub-network. Notice the slightly different position of Urumqi in this network when compared to its role in the New Eurasian Land Bridge Corridor: it again has a high betweenness centrality (3rd) in this network, but this time it does not have a high closeness centrality (not in the top 10) as it nonetheless takes a relatively large number of connections to reach the remainder of the cities in this corridor.

From an international perspective, Tehran, Istanbul, Urumqi and Almaty are the key nodes in brokering connections along this corridor. At the same time, Kabul is clearly in need of further development of connectivity with cities along this corridor.

Figure 14: Composite network for the China-Central Asia-Western Asia Corridor (node size varies with a city's degree centrality; color codes indicate community affiliation).

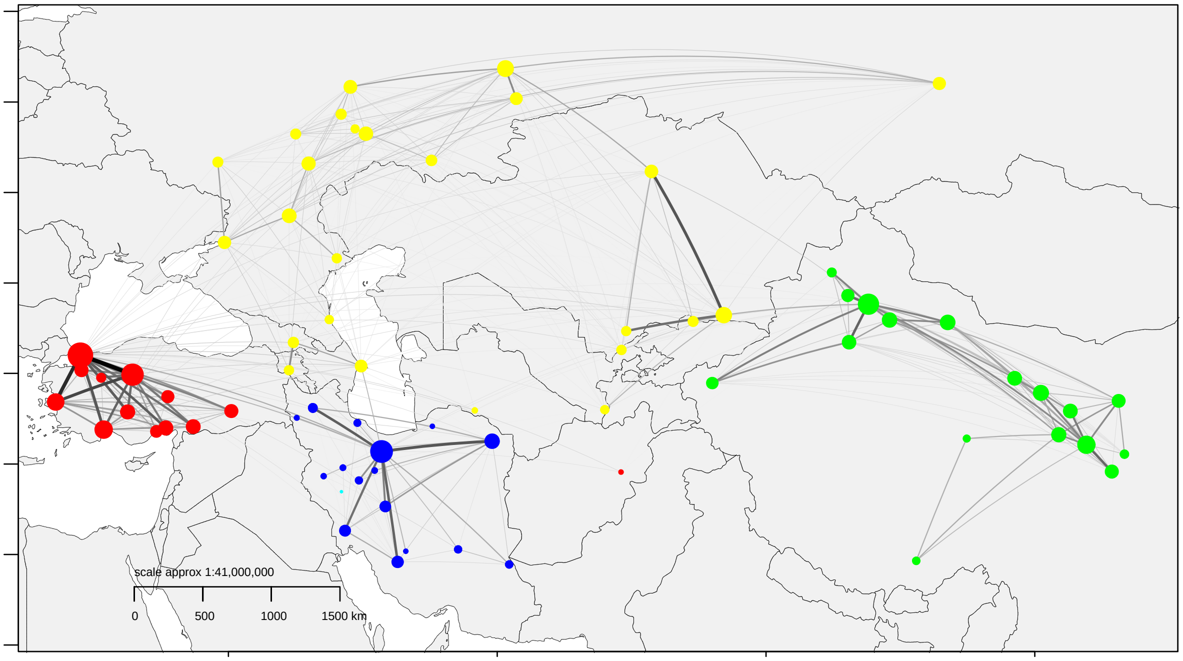


Table 6: Top 10 of most central cities (as measured by three centrality measures) in the China-Central Asia-Western Asia Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Istanbul	Tehran	Istanbul
2	Tehran	Istanbul	Almaty
3	Ankara	Urumqi	Ankara
4	Urumqi	Almaty	Antalya
5	Antalya	Yekaterinburg	Izmir
6	Lanzhou	Astana	Tehran
7	Izmir	Antalya	Astana
8	Yekaterinburg	Lanzhou	Adana
9	Almaty	Samara	Konya
10	Zhangye	Xining	Bishkek

China-Indochina Peninsula Corridor

There are three communities in the China-Indochina Peninsula Corridor network, which has a modularity of 0.23: two Chinese communities and one community bringing together all of the remaining cities. The low modularity score and Figure 15 reveal that, in comparison to the corridors discussed up till now, Southeast Asia is a region whose cities are fairly well connected across borders. There are transnational connections across the board, even for some less prominent cities, thus producing a single community rather than several 'national communities' as per the previous corridors. Another difference with the previous analyses is that the Chinese sub-networks do not neatly reflect regionalization-through-proximity. There is a rough West/East divide to the communities, but there are major exceptions with the most westerly cities of Kunming and Qujing being more strongly connected to cities in the Yangtze River Delta economic belt than with more proximate Chinese cities. The relative geographical isolation of Kunming and Qujing results in relatively underdeveloped – at least in the Chinese context – landside connections with the rest of the Chinese cities. Combined with sizable air transport connections with major cities such as Shanghai and Nanjing, this leads Kunming and Qujing to be 'closer' (in topological terms) to the leading cities of western China in the context of this corridor.

The degree centrality ranking is dominated by Chinese cities from both communities (Table 7). This can, again, be attributed to the larger number of (large) cities on the Chinese side in combination with its well-developed internal transport infrastructure. Given that this corridor is one of the most inter-connected networks, this degree centrality ranking is roughly replicated in the closeness centrality ranking (with the major exception of Hong Kong, on which more below): given a relative comprehensive urban network connectivity along the corridor (especially in comparison with the other corridors), having many connections almost automatically translates into being close to the rest of the network. The betweenness centrality ranking is more diverse, with cities with relatively strong connections with both Southeast Asian and Chinese cities at the apex. At least in this corridor, Guangzhou is clearly reclaiming its historical position as a gateway into, and out of China alongside Hong Kong. The latter city is the only erratically positioned city, with relatively weak connections overall but with a very strong intermediating role and being very close to the entire China-Indochina Peninsula Corridor network.

From an international perspective, Yangon, Kuala Lumpur, Bangkok, Hanoi, Singapore and Guangzhou are the key nodes in brokering connections along this corridor.

Figure 15: Composite network for the China-Indochina Peninsula Corridor (node size varies with a city's degree centrality; color codes indicate community affiliation).

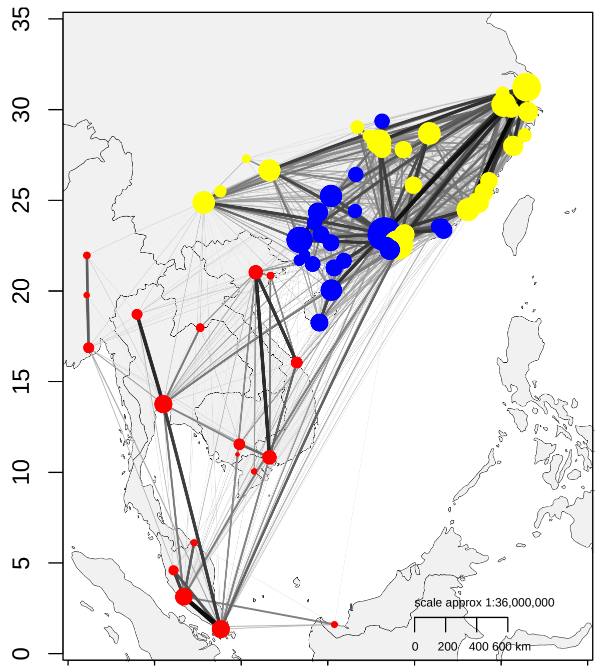


Table 7: Top 10 of most central cities (as measured by three centrality measures) in the China-Indochina Peninsula Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Guangzhou	Guangzhou	Guangzhou
2	Shenzhen	Hong Kong	Shanghai
3	Shanghai	Shanghai	Shenzhen
4	Nanning	Singapore	Hong Kong
5	Hangzhou	Hanoi	Nanning
6	Changsha	Bangkok	Hangzhou
7	Xiamen	Kuala Lumpur	Changsha
8	Nanchang	Yangon	Xiamen
9	Kunming	Nanning	Dongguan
10	Guilin	Kunming	Kunming

China-Pakistan Economic Corridor

There are four communities in the China-Pakistan Corridor network, with a modularity of 0.37: three Chinese communities and one community with cities located in Pakistan. Figure 16 suggests a fairly straightforward regionalization among the three Chinese communities, with especially the westernmost community being circumscribed by its relative geographical isolation. The average modularity score can be traced back to the almost complete isolation of the Pakistan community on the one hand (leading to very high modularity), and the fact that three Chinese communities are nonetheless inter-connected on the other hand (leading to low modularity).

The degree centrality ranking is dominated by Chinese cities from all three communities (Table 8). Only Karachi, the city in Pakistan with the largest number of connections, makes it into the top 10. This can, again, be attributed to the larger number of (large) cities on the Chinese side in combination with its well-developed internal transport infrastructure. The betweenness centrality ranking, in contrast, is very different with Rawalpindi and Urumqi towering over the rest of the cities. In fact, this is the only Sino-Pakistan inter-city connection to speak of, and this ‘weak connection’ has a key strength in that it turns the China-Pakistan Corridor network into an actual network: if this connection were to be cut, the communities would form separate networks. The remaining cities in the betweenness centrality ranking play far less important roles and are ranked in the top 10 because of strong connections with either Urumqi and Rawalpindi alongside connections with cities that are not connected to Urumqi and Rawalpindi. The closeness degree ranking largely reflects the degree centrality ranking, albeit with due acknowledgement of Urumqi’s unique closeness to all cities in this China-Pakistan Economic Corridor because of its strong connections with major Chinese cities on the one hand and its connections to Pakistan via Rawalpindi on the other hand.

From an international perspective, Rawalpindi, Bahawalpur, Islamabad, Karachi, Chengdu and Urumqi are the key nodes in brokering connections along this corridor.

Figure 16: Composite network for the China-Pakistan Economic Corridor (node size varies with a city's population size).

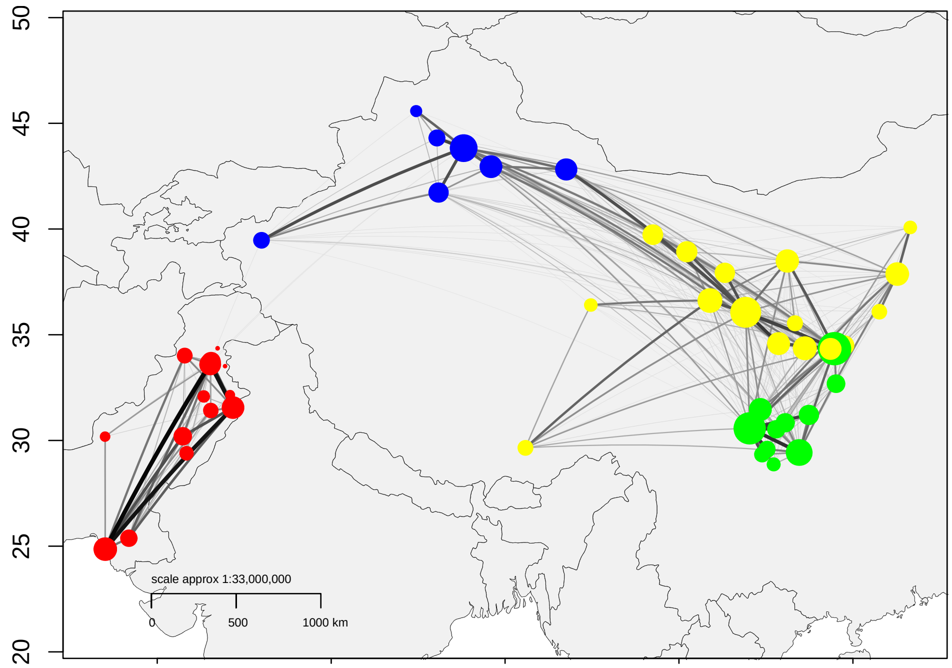


Table 8: Top 10 of most central cities (as measured by three centrality measures) in the China-Pakistan Economic Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Xian	Urumqi	Urumqi
2	Chengdu	Rawalpindi	Xian
3	Lanzhou	Chengdu	Lanzhou
4	Urumqi	Xian	Chengdu
5	Chongqing	Lanzhou	Xining
6	Xining	Karachi	Chongqing
7	Baoji	Xining	Yinchuan
8	Taiyuan	Taiyuan	Hami
9	Karachi	Bahawalpur	Kashgar
10	Yinchuan	Islamabad	Taiyuan

Bangladesh-China-India-Myanmar Corridor

There are five communities in the Bangladesh-China-India-Myanmar Corridor network, with a modularity of 0.40: three Chinese communities, a community with cities located in India and Bangladesh, and a Myanmar community. The Chinese communities are clearly regionalized, with a Tibetan community centered on Lhasa and Yulin, a central community focused on Kunming and Chengdu, and a more easterly community centered on Nanning and Liuzhou. In contrast to the continental network, from the perspective of this corridor, cities in Bangladesh and Indian are relatively closely connected. Nonetheless, the modularity is quite high as this is the network where Chinese communities are least inter-connected, while the India/Bangladesh and Myanmar communities are poorly integrated with the rest of the network.

The degree centrality ranking is dominated by Chinese cities, especially cities in the more central community centered on Chengdu, Kunming, Nanning and Chongqing (Table 9). This can, again, be attributed to the larger number of (large) cities on the Chinese side in combination with its well-developed internal transport infrastructure. The closeness centrality ranking broadly replicates the degree centrality ranking, albeit that Kunming is ranked higher because of its connections to cities such as Lhasa, Dhaka, and Yangon. These connections are relatively feeble, but they are instrumental in inter-connecting the Bangladesh-China-India-Myanmar Corridor, and give Kunming a gateway function (as evidenced by its top rank in the betweenness centrality ranking) and a position that is not only topographically but also topologically close to the remainder of the cities in the network (as evidenced by its top rank in the closeness centrality ranking). Dhaka also has a relatively sizable betweenness centrality (especially in comparison to its degree centrality) because the city connects the other major cities in Bangladesh to the Chinese communities.

Although this is the corridor that would be most difficult to connect from an international perspective, Lhasa, Dhaka, Yangon, Kunming and Chengdu could be the key nodes in brokering connections along this corridor.

Figure 17: Composite network for the Bangladesh-China-India-Myanmar Corridor (node size varies with a city's population size).

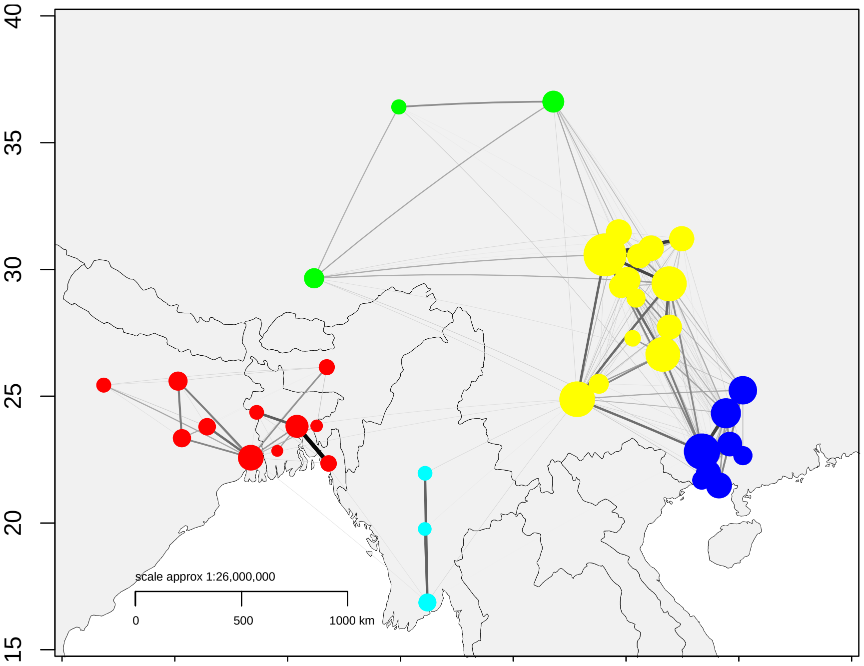


Table 9: Top 10 of most central cities (as measured by three centrality measures) in the Bangladesh-China-India-Myanmar Corridor

Rank	Degree centrality	Betweenness centrality	Closeness centrality
1	Chengdu	Kunming	Kunming
2	Nanning	Chengdu	Chengdu
3	Kunming	Kolkata	Nanning
4	Chongqing	Nanning	Chongqing
5	Guiyang	Dhaka	Guiyang
6	Liuzhou	Yangon	Qujing
7	Guilin	Patna	Dazhou
8	Neijiang	Dhanbad	Mianyang
9	Beihai	Guiyang	Nanchong
10	Mianyang	Xining	Suining

Communities and BRI Corridors

Following the analysis and results for specific corridors, it was apparent that there were clusters of economic centers that have better connections with each other than with other centers. Social, infrastructural and information networks often combine organization and randomness. In this context, we explore the presence of community structures. A ‘community structure’ refers to the occurrence of organization in the sense that there are groups of nodes (i.e. communities) that are, on average, more densely interconnected than with the other nodes in the network. Conceptually similar to ‘standard’ cluster analysis for multivariate datasets, a community detection algorithm reveals these communities and presents them through mutually exclusive partitions of nodes[ix]. In the sample network, a community detection algorithm would discern five communities (Figure 18): a ‘Chinese community’ which includes not only the densely interconnected Chinese cities but also Karachi because of its only link with Urumqi; a ‘Southeast Asian community’ of Bangkok and Singapore; a ‘Central and West Asian community’ of Almaty, Tehran, Tashkent, and Istanbul; a ‘South Asian’ community that represents the group of Bangalore, Dhaka, and Yangon; and a ‘North Asian’ community that links Mongolian and Russian cities in the sample network. Note that although connections are often strong between proximate cities (Tobler, 1970), a community detection algorithm groups cities based on their connections rather than their geographical proximity. For example, although the city of Urumqi is physically closer to Almaty than to Beijing, it is a member of the ‘Chinese community’ in our toy network due to its strong connections with other Chinese cities. Similarly, Karachi is grouped with other Chinese cities, as its sole link in the toy network is with Urumqi.

There are a number of different community detection algorithms in the literature, whereby the selection of a particular algorithm often depends on finding the approach that has the ‘ideal’ balance between the computational effort/speed required and the quality of the partitions. The latter is measured through the so-called ‘modularity’ of the partition, which measures the density of connections inside communities as compared to links between communities. Here we apply the ‘Girvan-Newman network partitioning’ for finding communities (Newman, 2006), which uses the ‘edge betweenness’ of connections to detect communities. Similar to betweenness centrality at the nodal level (see 3.1), edge betweenness measures the number of shortest paths between pairs of nodes that run along it. If there is more than one shortest path between a pair of nodes, each path is assigned equal weight such that the total weight of all of the paths is equal to unity. If a network contains communities that are only loosely connected by a few inter-community edges, then all shortest paths between different communities must go along one of these few edges. Thus, the edges connecting communities will have high edge betweenness, and by removing these edges the communities are separated from one another and so the underlying community structure of the network is iteratively revealed. The Girvan-Newman network partitioning algorithm’s steps for community detection are therefore:

The betweenness of all existing edges in the network is calculated.

The edge with the highest betweenness is removed.

The betweenness of all edges affected by the removal is recalculated.

Steps 2 and 3 are in principle repeated until no edges remain, producing a dendrogram as the outcome of the algorithm. However, the output with the highest level of ‘modularity’ can be seen as an ‘ideal’ portioning of the network, producing the community structure of the network.

In addition to the topological and geographical layout of the communities produced by the Girvan-Newman algorithm, two other interesting features of the results are (1) the degree to which communities are indeed 'self-contained' sub-networks and (2) how these poorly connected communities are nonetheless interconnected.

The first feature is captured by assessing the modularity of the partitioned network: networks with higher levels of modularity have dense connections between the nodes within communities but sparse connections between nodes in different communities; networks with lower modularity have dense connections between the nodes within communities but there are also some connections between nodes in different communities.

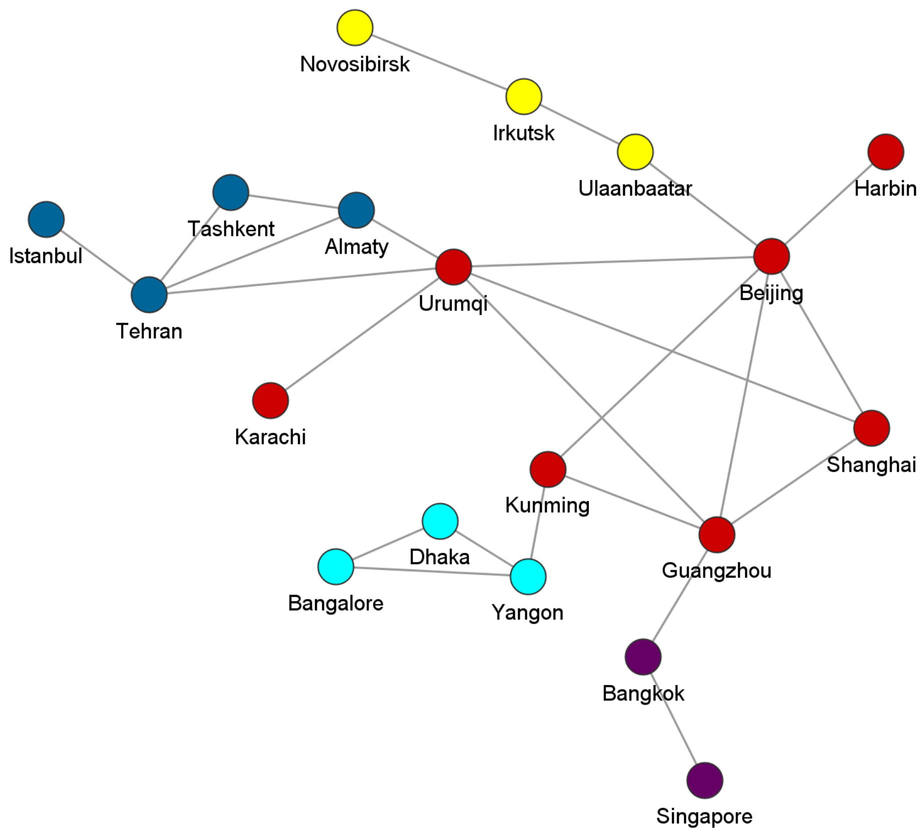
The second feature focuses on how cities in disparate communities are nonetheless being interconnected. As networks with low modularity are poorly interconnected, this assigns great importance to the few inter-community connections that do exist, as these essentially hold (parts of) the network together. In figure 18, Yangon-Kunming is an inter-community connection that has strategic importance as without it the 'Chinese' and the 'South Asian' community would not be connected at all and the 'South Asian community' would even not be connected to the remainder of the network at all. Even if the strength of this connection would be small in absolute terms in a valued network, it would be of great strategic importance. In the literature on social networks, this crucial importance of what otherwise would be regarded to be a 'minor connection' is captured through the concept of the 'strength of weak ties' (Granovetter, 1973): an apparently weak connection playing a very important role in the networks as it currently exists. Identifying these particular 'weak ties' has major policy implications in our study, as these are crucial connections in terms of integrating the network and communities within the network.

Applying the above analysis, we were able to identify regional agreements that seem to be a factor behind the emergence of different communities or clusters of centers. The main mechanisms and agreements along each corridor are the following (the details of which countries are parties to the same agreements with China are shown in Annex B):

China – Central Asia – West Asia: Shanghai Cooperation Organization, Transports Internationaux Routiers (TIR).
BCIM: Asia Highway Network, Trans-Asian Railway, Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation.
China Pakistan: bilateral agreements.
New Eurasia Landbridge: Shanghai Cooperation Organization, EU Partnership Cooperation Agreements.
China – Mongolia – Russia: Shanghai Cooperation Organization.
China – IndoChina: China – ASEAN Free Trade Agreement, Regional Comprehensive Economic Partnership.

Based on the analysis there are a few platforms around which the countries can discuss and co-define the BRI corridor networks. The Shanghai Cooperation Organization seems to be the one that brings together the largest number of participating countries and is the most influential in shaping the evolving connectivity map along the different corridors.

Figure 18: Community structures in the sample network (node color reflects the community membership of individual cities).



Policy Implications of BRI Corridor Connectivity

Given the scientific recognition and the policy perception that connectivity in transportation and communication networks affects an economic center's productivity and economic growth, a thorough understanding of the concept and empirics of 'connectivity' is of major importance. Against this backdrop, the purpose of this paper has been to describe and network-analyze the connections between major and intermediate economic centers along the different 'Belt and Road Initiative' corridors. Based on our earlier review of the economic geography literature, it is clear that the processes of exchange and interaction that are at the root of economic growth and innovation can be organized and facilitated along two geographical axes. First, there is the potential of spatial proximity offered by urban agglomerations: agglomeration externalities. Second, there is the potential offered by connectivity between agglomerations: network externalities. Although the research presented here is specifically concerned with the latter form of externalities, we can control for the effect of agglomeration externalities in the production of network externalities by statistically controlling for this effect alongside other effects.

Policy ambitions and initiatives to build, support and develop agglomerations with similar and related levels of economic activity have been abundant in recent years. Many of these efforts are directed towards encouraging and developing mechanisms at the level of the agglomeration. However, the focus of this research has been radically different, as are its policy implications. Most agglomeration externalities are non-excludable (Johansson and Quigley 2003): by being located in the city, by simply 'being there' (cf. Gertler 1995), economic agents can reap the advantages. However, network externalities often have a club good character (i.e. they are excludable; see Capello, 1996); there is an uneven potential for participation of economic agents as reflected in their uneven connectivities. When cast in Bathelt et al's (2004, pp. 40–41) metaphorical language of 'local buzz and global pipelines': the local 'buzz' is ubiquitously accessible to all locally-present economic agents, but cities' participation in the 'global pipelines' requires some sort of conscious effort. This vantage point is discursively reinforced by the fact that many transportation system expansion or improvement projects are justified on their ability to enhance the economy[x] (Banister and Berechman, 2001; Acharya, 2007; Gilbert, and Banik, 2008, Hurlin, 2006; Kuroda et al., 2008; Cidell, 2014; Chen and Vickerman, 2017). Indeed, policy-makers, government leaders and planners frequently cite economic growth as a key motivation and justification for major transportation investments, based on the real or perceived potential of investments in cyber-infrastructure, highways, rail tracks, airports, and intermodal facilities for developing inter-regional and international business markets or expanding labor and delivery markets.

Of course, the development of connections with other agglomerations is sometimes based on mere market demand (e.g. airline connections), and as such does not always require targeted policy intervention. Yet, as this paper has shown, the remit of connectivity is much more complex and encompassing than the straightforward development of connections between city-pairs. The processes behind the establishment and maintenance of connectivity must be predesigned and planned in advance, and this often requires specific investments. Successfully fostering network externalities is a complex and costly process and requires the development of a shared institutional context that enables joint problem-solving, learning and governance. This involves intense efforts to develop joint action frames, governance structures, institution-building and policy frameworks, as the BRI itself so vividly shows.

Based on our analysis, the following broad conclusions can be drawn for the BRI corridors and economic centers that they link:

The impacts of BRI corridors will depend on the degree of integration of the connected regions. The results of the community detection modelling show distinct clusters of relatively highly connected centers within regions and also within countries. It is apparent that centers in China are highly interconnected. As such improvements to any one link will have magnified impacts through network effects. The same applies also in some of the other regions that are connected by the priority corridors. This applies in particular to the ASEAN region (and the European Union). Intra-regional connectivity in these regions is already high such that focus should be on building the “bridges” between China on the one hand and the EU or ASEAN countries on the other. In addition, focus should be on the services that run on the existing infrastructure. This can already be seen in the case of the railway services between China and Europe which were in essence designed by the private sector, in this case DHL. Once the core networks are in place this enables the private sector to provide services depending on the needs of markets and their dynamics.

A focus on connecting services at an international level requires a focus on third party or open access to infrastructure, measures to allow uninterrupted or seamless services, and appropriate frameworks for the regulation of competition between service providers. A well-known impediment to the cross-border provision of services in the context of international corridors such as those under BRI is the lack of interoperable systems – for instance differences vehicle weight limits in road transport or break of gauge in railways or lack of cross-border payment systems. While technical solutions can always be designed to overcome these hindrances, they tend to increase costs and build-in inefficiencies. As such, it becomes critical to have both institutions to address the weaknesses and appropriate regulatory regimes to ensure the markets are contested.

On the other hand, in regions that have poor intra-regional connectivity, the development of core infrastructure should be paramount. Such infrastructure should assume the classical definition of corridors. There needs to be basic infrastructure that has high capacity and connects the major economic centers. The CPEC and BCIM corridors are examples of corridors of such a form. In the first scenario, focus should be on developing core infrastructure as well as services. In addition, it will be important to also invest in productive capacity along the corridors. To some extent, the approach that has been adopted for CPEC reflects this comprehensive approach, to build connectivity infrastructure and services as well as promote production and productivity through industrial zones.

In the case of the development of brownfield BRI corridors the lessons from other economic corridors is very pertinent. Sequeira, Hartmann and Kunaka (2015) identify five pre-requisites for a successful corridor, namely (i) combining both public and private investments to improve infrastructure, (ii) establishing appropriate institutional arrangements to promote and facilitate coordination, (iii) an emphasis on operational efficiency of the logistics services; (iv) established economic potential (endogenous factors) and (v) a convergence with political interests between the countries or territories to be connected. While it is often rare for all conditions to be satisfied, it is always crucial to be aware of the compromises that are being made and what needs to be done to mitigate the attendant risks.

Borders have a strong influence on BRI corridor connectivity. The community detection analysis shows that borders between trade areas or between countries have important effects on network connectivity. In practice this manifests through border controls and the time and cost it takes to pass through the borders, in other words the “thickness” of the borders. A comparison between the BCIM and China-Indochina corridors illustrates this well. The BCIM corridor at present exists largely on paper and still is a disparate group of economies with limited intra-regional trade. On the other hand, ASEAN shows a much higher degree of integration with many regional supply chains, several of which extend over the wider East Asia and Pacific region, anchored by China and Japan.

Given the large-scale design of BRI the border management and trade facilitation issues are best addressed using international standards that establish minimum levels of performance. The WTO TFA is the most appropriate framework. Many of the BRI participating countries are either WTO members or currently in the process of accession. The OECD estimates that the potential transaction cost reduction from full and effective implementation of the TFA is 16.5% of total costs for low income countries, 17.4% for lower middle income countries and 14.6% for upper middle income countries. The requirements to implement the WTO TFA in BRI countries are the subject of a separate and complementary paper.

The development of the BRI corridors should prioritize existing weak links. The concept of the 'strength of weak ties' is fundamental to how the BRI corridors will impact regional and global connectivity. There is ample empirical evidence that an entity (person, firm, country) can enhance its network by focusing more on its weak connections. Strengthening weak connections to other networks brings benefits to the connected entities. In the context of BRI, identifying these particular 'weak ties' should guide the prioritization of investment needs, and with it the negotiation of trade and other agreements, and improving the regulatory and policy frameworks for the provision of services. The analysis has identified the main links along each corridor that are important to the transmission and facilitation of flows within each corridor. A next step would be to determine the condition and capacity of those links and design holistic solutions covering physical infrastructure, regulation of services and coordination arrangements for cross border components.

Select economic centers along BRI corridors can leverage their positions to maximize benefits of BRI. In China there are as many as 18 provinces that are officially part of the BRI with several others making submissions to be officially recognized. However, the analyses in this paper suggests that only a few provinces (six) are real gateways to the BRI network of overland corridors. In addition, there are specific centers (seven) in these provinces that can generate and/or mediate trade or people to people flows. These are Baotou (Inner Mongolia), Zhengzhou (Henan), Xian (Shaanxi), Lanzhou (Gansu), Urumqi (Xinjiang Uyghur), Kunming (Yunnan), and Qujing (Yunnan). These centers have high degrees of centrality that enable them to intermediate flows between China and BRI partners and will ultimately be key to the success of the initiative, at least in China.

Similar to the above, along each corridor there are centers in the BRI partner countries that are well placed or connected to benefit most from BRI. Based on the analysis, the centers along each corridor are the following:
China-Mongolia-Russia Economic Corridor: - Novosibirsk and Irkutsk in Russia
New Eurasian Land Bridge Corridor: - Yekaterinburg, Krasnodar, Almaty, Astana
China-Central Asia-Western Asia Corridor: - Tehran, Istanbul, Kabul
China-Indochina Peninsula Corridor: - Yangon, Kuala Lumpur, Bangkok, Hanoi, Singapore
China-Pakistan Economic Corridor: - Rawalpindi, Bahawalpur, Islamabad, Karachi
Bangladesh-China-India-Myanmar Corridor: - probably the most dysfunctional and weakest of the corridors but Lhasa, Dhaka, Yangon could be important fulcra.

These centers are well placed to generate, add value to or play roles as fulcrums for BRI corridor flows. However, for the centers to play such roles they will need to take some deliberate actions and make appropriate investments specially to foster value by adding logistics services, and through them participation in value chains moving through the corridors. Logistics clustering is growing both as a spatial phenomenon and as a tool for modern supply chain organization and management. The evidence of impacts of clustering and agglomeration is striking, and China has already built or is planning to build close to 800 logistics clusters. While clusters are relevant in nearly all markets, they are particularly appealing in countries and regions with thin volumes where a concentration of activities may bring about productivity, efficiency or innovation gains. In principle, co-locating or clustering of services or industries brings economies of scale and scope, while organizationally it can help firms deepen labor markets, generate complementary demand and offer specialized services. Centers along BRI corridors will therefore need to invest to take advantage of the development of the corridors. This will then engender a self-reinforcing process where the centers benefit from improved connectivity which in turn will enhance overall connectivity.

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Annex A: Network modeling

To explore the strength and remit of the main forces underlying the formation of the urban infrastructure networks in BRI countries, we employ a 'spatial interaction modeling' approach. This model explains the observed flows between cities as a function of these cities' 'importance' on the one hand and the 'distance' between them on the other hand (van Oort et al., 2010). The underlying assumption is straightforward and related to hypotheses that can be drawn from the findings presented in section 5: the connection between two cities is positively related to their size; inversely related to the Euclidean distance between them; and the presence of an international border. Our model can therefore be represented as follows:

$$T_{ij} \sim P_i P_j d_{ij} SC_{ij}$$

Where:
Tij: the connectivity between cities i and j;
Pi and Pj: the population size of cities i and j, respectively;
dij: the logged Euclidean distance between cities i and j;
SCij a dummy variable that equals 1 if i and j are located in the same country, and 0 if otherwise[xi].

The model can be transformed and estimated via ordinary regressions. The modeling exercise thus entails finding the combination of model parameters generating a network that most closely resembles the structure of the observed composite network. Table 10 provides an overview of the model parameters for the continental network and the different corridors. Although the predictive power of the models for the different corridors varies, overall, they confirm the straightforward and intuitive description developed in the paper: the R-square value ranges from >40% to >60%, with all parameters across all models being statistically significant at the p <.01 level. However, importantly, standardized coefficients show that it is above all being located in the same country that explains the strength of inter-city connections. This conforms the community detection results showing network largely playing out at the national level and suggests that the BRI should indeed focus more on inter-regional connectivity.

In addition to the model parameters being interesting in and of themselves, regression analysis also allows looking for divergences from the regression model: inter-city connections that are either significantly stronger or weaker than predicted by the model. To this end, Table 10 also lists, for each corridor, the 5 largest positive and largest negative residuals, and this for both the intra- and inter-country case. Overall findings can be summarized as follows:
(1) Stronger-than-expected connections within countries ten to between key economic centers (e.g. Mumbai-Bangalore and Beijing-Shanghai).
(2) Weaker-than-expected connections within countries tend to be between secondary, proximately located centers that are poorly connected because of topographic/physiographic reasons (e.g. it takes five hours and there are relatively few buses between Piangling and Tianshui , in spite of these sizable cities only being 250kms apart) and between peripheral and core cities in the most developed regions of India and china (e.g. Maoming-Hong Kong).
(3) Stronger-than-expected connections between countries are between key economic centers with strong air transport connections (e.g. Singapore-Kuala Lumpur and Hong Kong-Singapore).

(4) Weaker-than-expected connections between countries are above all between major economic centers in Central and Western Asia that are proximate but not well connected because of geographical and political constraints (e.g. Karachi-Ahedabad and Hanoi- Huiyang).

Continental

VARIABLES	
Ln(popi)	0.00838***
	(0.000438)
Ln(popj)	0.00838***
	(0.000438)
Ln(distanceij)	-0.0342***
	(0.00114)
SameCountryij	0.129***
	(0.00692)
Constant	0.199***
	(0.00966)
Observations	16,512
R-squared	0.583

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

China-Mongolia-Russia Economic Corridor

VARIABLES	
Ln(popi)	0.0348***
	(0.00147)
Ln(popj)	0.0348***
	(0.00147)
Ln(distanceij)	-0.0533***
	(0.00204)
SameCountryij	0.0722***
	(0.00375)
Constant	0.106***
	(0.0202)
Observations	4,160
R-squared	0.614

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

New Eurasian Land Bridge Corridor

VARIABLES	
Ln(popi)	0.0286***
	(0.00131)
Ln(popj)	0.0286***
	(0.00131)
Ln(distanceij)	-0.0544***
	(0.00146)
SameCountryij	0.0727***
	(0.00737)
Constant	0.183***
	(0.0191)
Observations	5,550
R-squared	0.589

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

China-Central Asia-Western Asia Corridor

VARIABLES	
Ln(popi)	0.0177***
	(0.00145)
Ln(popj)	0.0177***
	(0.00145)
Ln(distanceij)	-0.0148***
	(0.00168)
SameCountryij	0.0784***
	(0.00478)
Constant	-0.0390**
	(0.0163)
Observations	5,256
R-squared	0.435

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

China-Indochina Peninsula Corridor

VARIABLES	
Ln(popi)	0.0349***
	(0.00173)
Ln(popj)	0.0349***
	(0.00173)
Ln(distanceij)	-0.0482***
	(0.00214)
SameCountryij	0.211***
	(0.0194)
Constant	0.0253
	(0.0187)
Observations	4,970
R-squared	0.448

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

China-Pakistan Economic Corridor

VARIABLES	
Ln(popi)	0.0228***
	(0.00222)
Ln(popj)	0.0228***
	(0.00222)
Ln(distanceij)	-0.0526***
	(0.00370)
SameCountryij	0.0418***
	(0.0143)
Constant	0.197***
	(0.0357)
Observations	2,256
R-squared	0.440

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Bangladesh-China-India-Myanmar Corridor

VARIABLES	
Ln(popi)	0.0203***
	(0.00263)
Ln(popj)	0.0203***
	(0.00263)
Ln(distanceij)	-0.0541***
	(0.00462)
SameCountryij	0.0945***
	(0.0173)
Constant	0.190***
	(0.0402)
Observations	1,560
R-squared	0.486

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Annex B: Main Regional Agreements Along Each Corridor

China – Central Asia – West Asia

Kazakhstan	Kyrgyzstan	Tajikistan	Uzbekistan	Turkmenistan	Afghanistan	Iran	Turkey	
BIT 1992/1999 48 Other SCO CAREC WTO TIR	BIT 1992/1999 32 other SCO CAREC WTO TIR	BIT 1993/1999 35 Other SCO CAREC WTO TIR	BIT 1992/2011 50 Other SCO CAREC TIR	BIT 1992/1999 27 Other ECO CAREC TIR	Joint declar'n 2012 SCO Observer CAREC WTO TIR	BIT 2000/2005 65 Other SCO CAREC Obs TIR	BIT 1990/1994/2005 94 Other SCO Dialogue WTO TIR	China
	CIS FTA TIFA ECO	CIS FTA TIFA ECO	CIS FTA TIFA ECO	CIS FTA TIFA ECO	ECO	ECO	ECO	Kazakhstan ECO
						BIT	BIT	Kyrgyzstan
					BTA	BTA		Tajikistan
								Uzbekistan
								Turkmenistan
							BTA	Afghanistan
								Iran

Notes:
SCO = Shanghai Cooperation Organization;
ECO = Economic Cooperation Organization
CIS FTA = CIS Free Trade Area
TIFA = USA Central Asia Trade and Investment Framework Agreement
China joined the WTO on Dec 11, 2001

BCIM

Bangladesh	India	Myanmar	
ESCAP Asia Highway Network Trans-Asian Railway WTO	BIT 2006 ESCAP Asia Highway Network Trans-Asian Railway East Asia Summit BRICS NDB WTO TIR	BIT 2001 ESCAP Asia Highway Network Trans-Asian Railway East Asia Summit WTO TIR	China
	BIMSTEC SAARC SAFTA	BIMSTEC	Bangladesh
		Trilateral Highway Mekong Ganga Cooperation	India

China – Pakistan Economic Corridor

Pakistan	
BIT 1989/90 WTO membership China – Pakistan FTA 2007 2013 Framework agreement on CPEC More than 43 Bilateral agreements and MoUs TIR WTO	China

Eurasian Landbridge

Kazakhstan	Russia	Belarus	EU	
BIT 1992/94 SCO WTO TIR	BIT 2006/09 SCO WTO TIR	BIT 1993/95 SCO WTO TIR	BITs (=>23 EU states) WTO TIR EU-China Summit EU-China Economic Cooperation Agreement Smart and Secure Lanes Project	China
	EEU OSCE CIS	EEU OSCE CIS	Enhanced PCA	Kazakhstan
		EEU OSCE CIS Treat of Russia – Belarus Union	PCA	Russia
			PCA	Belarus

PCA = Partnership and Cooperation Agreement

China – Mongolia - Russia

Russia	Mongolia	
BIT 2006/9 SCO EPA – 32 projects BRICS NDB WTO TIR APEC	BIT 1991/93 SCO Obs EPA – 32 projects WTO TIR ASEAN Obs ESCAP	China
		Russia

EPA = Economic Partnership Agreement
SCO = Shanghai Cooperation Organization

China – Indochina

Singapore	Malaysia	Cambodia	Thailand	Laos	Vietnam	
BIT 1985/86 China ASEAN FTA Chiang Mai Initiative WTO RCEP Singapore – China FTA	BIT 1988/90 China ASEAN FTA Chiang Mai Initiative WTO RCEP	BIT 1996/2000 China ASEAN FTA Chiang Mai Initiative WTO RCEP	BIT 1985 China ASEAN FTA Chiang Mai Initiative WTO RCEP Thailand – China FTA	BIT 1993 China ASEAN FTA Chiang Mai Initiative WTO RCEP	BIT 1992/93 China ASEAN FTA Chiang Mai Initiative WTO RCEP	China
						Singapore
						Malaysia
						Cambodia
				Laos – Thailand Preferential Trade Agreement		Thailand
						Laos
						Vietnam

[i] In this background paper, we will use the notion 'externalities' when referring to spillover effects. According to Olsen (2002), the central misunderstanding between economic geography and geographical economics regarding 'externalities' can be traced back to scope of the analysis. This can be either the perspective of the individual firm or the wider geographical environment in which firms are situated. The associated difference between 'internal' and 'external' agglomeration effects has been widely recognized in the literature (Parr, 2002), and can be understood as the difference between 'agglomeration economies' and 'agglomeration externalities'. Since this analysis is primarily concerned with environmental-level effects that accrue across economic agents, we adopt the

definitional yardstick that ‘externalities or spillovers occur if an innovation or growth improvement implemented by a certain enterprise increases the performance of other enterprises without the latter benefiting enterprise having to pay (full) compensation’ (Burger et al. 2009, p. 140).

[ii] This chimes, of course, well with Jane Jacobs’ (1969, p. 35) famous observation that a city never exists alone, but always as a group of cities interaction with each other. As a consequence, the creation of new urban knowledge might be best viewed as a result of a combination of intra- and extra-agglomeration interactions.

[iii] This neat distinction between agglomeration and network externalities, which conform to intra-urban interactions and inter-urban interactions, respectively, is of course too simple for a number of reasons. In addition to the complexities associated with defining cities in densely urbanized regions with peri-urban characteristics (discussed in the body of the text), there are also theoretical frameworks that appear to explicitly link both concepts in single notion of urban-economic ‘importance’. For example, Walter Christaller’s (1966) central place theory posits the presence of a ‘transport principle’ alongside the more well-known ‘market principle’. This transport principle suggests that being located along corridors connecting major centres positively influences the ‘importance’ of a centre. We have chosen not to explicitly incorporate this line of thinking in our framework because in Christaller’s theory ‘importance’ does not equate agglomeration in the sense we use it here. Rather, ‘importance’ in Christaller’s theory derives solely from the presence of central place functions such as hospitals, schools, etc., and as such does not deal with other forms of economic activity. From this perspective, it can be said that Christaller-ean theories do not make explicit statements about the ‘economic importance’ of cities along transport corridors, and we will therefore not adopt this line of thinking in our framework.

[iv] The effect of travel on trade may vary, however, as the effect “is stronger for differentiated products and for higher-skilled travelers, reflecting the information-intensive nature of differentiated products and that higher-skilled travelers are better able to transfer information about trading opportunities” (Poole, 2013, p.24).

[v] Meanwhile, growing volumes of trade and the associated rise in deal-making, follow-up, etc. may in turn lead to heightened demand for air travel (see Ishutkina and Hansman, 2009). Cristea (2011), for instance, finds robust evidence that in the US the demand for air travel is directly related to export: an increase in the volume of exports has been shown to raise the local demand for business air travel. Simultaneously, she shows that that close communication between trade partners, via face-to-face-interactions, is essential for successful trade transactions, because these meetings have the potential to both improve the transaction and add value to the exported products.

[vi] Although our report is cast in the language of a ‘connectivity’ analysis, in practice our analytical framework consists of a mixed connectivity/accessibility setup. The sometimes-subtle difference between both concepts can be summarized as follows: in infrastructural terms, connectivity refers to the *actual* interaction between cities, while accessibility refers to the *potential capacity or ease* with which other cities can be reached. For instance, when assessing how actors in two cities ‘relate’ to one another via ‘the Internet’, a measure of actual interactions via e-mail, webpage visits, file transfers, etc. would be a connectivity measure, while the aggregate quality of the available backbone networks would be an accessibility measure. The distinction between both concepts is sometimes

blurry: the number of weekly flights between two cities can clearly be seen as a measure of both connectivity and accessibility; large values point to a large potential of connections *and* large de facto relations.

[vii] For some destinations there may be some seasonal fluctuation in the number of flights, in particular holiday destinations during high season. This would imply that using a different reference week may slightly impact the results, but it is unlikely that this would have a major bearing on our results.

[viii] For the road network, the formula is actually 1-(original-min)/(max-min) as low values in the raw data represent strong connectivity. After this transformation, larger values also represent stronger connectivity (in line with the other three sub-networks)

[ix] Note that not all networks need to display a community structure. Random graphs and the Barabási–Albert model, for instance, do not display a community structure.

[x] However, at the same time, empirical evidence has been inconsistent. Although past research has provided broad support for a positive relationship between enhancing transportation infrastructures and economic development, the ranges of estimates of the effects of infrastructure have varied widely (EDR, 2009). This is because generative effects depend on numerous contextual and intervening factors (e.g. Button, 1998; Brueckner, 2003; Ishutkina and Hansman, 2009), but also more implicitly because some distributive effects may remain hidden (e.g. Meijers et al., 2012). An additional problem is that in analyses of the effects of transport infrastructures, spatial economic development – however conceived – is an endogenous variable, i.e. it influences the distribution of transport infrastructures in its own right (see however, Michaels, 2008; Faber, 2009; Donaldson, 2010). And finally, there are of course potential ecological and social costs associated with the development of transport infrastructures.

[xi] Note that we also experimented with an additional ‘China dummy’ variable to control for (possible) extra strong connections between Chinese cities. However, this parameter was either not significant or only marginally improved the explanatory power of the models, and we therefore opted not include it here as we report our results.