Regional integration in the Horn of Africa through the lens of inter-city connectivity

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ABSTRACT

Urban challenges are increasingly framed in the context of broader objectives of socio-economic development and macro-regional evolutions. Cities and the myriad networks in which they are embedded have thus been placed at the center of regional integration agendas. This paper benchmarks contemporary regional integration levels in the Horn of Africa by examining its cities’ connectivities in transport networks. To this end, we specify a composite network consisting of air/train/road connectivity and analyze cities’ eigenvector and betweenness centralities within these networks. We find that the importance of national spaces for inter-city connectivity is much more evident in the Horn of Africa than in other parts of the world, which is also visible in the peripheralization of cities in borderlands. We argue that the region’s connectivity needs to be understood from a multiscalar and multimodal perspective and provide a baseline against which the impact of future interventions aimed at enhancing city connectivity/regional integration can be examined.

1. Introduction

In recent decades, the World Bank’s urban policies have become increasingly geared towards developing contexts. Jones and Ward (1994) noted that changes in the World Bank’s policy paradigms were often discursive rather than formative, but lauded the increasing attention for situating urban development assistance in the context of broader socio-economic development objectives and macro-regional evolutions. In the Horn of Africa, arguably one of the least researched areas in the world in general and in terms of its cities in particular (Kanai et al., 2018), a major recent evolution has been the increased importance of regional integration. For example, in late 2019, five countries in the Horn of Africa – Djibouti, Somalia, Kenya, Ethiopia, and Eritrea – launched the Horn of Africa Initiative, highlighting the importance of regional partnerships and stressing the importance of cooperation and concerted action to address common challenges.

Continuing the trend first observed by Jones and Ward (1994), World Bank-led policy research on the Horn of Africa (HoA) Initiative frames urban challenges in the context of broader objectives of socio-economic development and macro-regional evolutions. A crucial component has been to position cities and the myriad networks in which they are embedded at the center of the regional integration agenda. For example, poor inter-city connectivity across national borders has emerged as one of the main signals of weak regional integration. As a result, regional dialogue in the HoA Initiative is placing a premium on interventions that enhance regional inter-city connectivity because of the broad range of socio-economic benefits allegedly associated with it. For example, there is ample empirical evidence that the goods, services, and knowledge provided by well-connected urban contexts are more abundant, more diverse, and lower in cost (Cattaneo et al., 2021). Furthermore, well-connected cities also provide more direct access to medical services and education and have the potential to promote social interaction between people with different ethnic, national, and linguistic backgrounds (Weiss et al., 2020).

Against this backdrop, in this paper, we report on a World Bank-funded policy research project that attempts to provide a baseline of...
the level of regional integration in the HoA. Using a network-analytical framework, we benchmark contemporary levels of regional connectivity of HoA cities by measuring and interpreting the topological position of cities in transport networks. In doing so, we contribute to the literature in three complementary ways. First, the paper has an empirical objective: we extend urban research on what continues to be one of the least-researched regions of the world (Kanai et al., 2018), and this in spite of fast-paced urban developments in the HoA (Güneralp et al., 2018). Second, the paper has a methodological objective: we explore how the lack of comparable and up-to-date urban data on the HoA can be overcome by drawing on a combination of emerging data sources (Carr-Hill, 2013). Third, the paper also has a policy objective: by benchmarking the regional connectivity of HoA cities, we provide a baseline against which the impact of future interventions aimed at enhancing city connectivity/regional integration can be examined, both on its own terms and in terms of broader objectives of socio-economic development within the region at large. Although given ongoing tensions in Tigray much of the thinking and discourse on HoA regional integration needs to be (re)cast and critically (re)examined, we hope our approach, framework, and results remain of relevance in the years to come.

The remainder of this paper is organized as follows; Section 2 outlines the rationale for an analysis of inter-city connectivity and its linkages to address the broader topic of regional integration in the HoA; Section 3 discusses our analytical framework; Section 4 provides an overview of our results; Section 5 extends the discussion of results by reviewing some of the main implications, after which the paper is concluded in Section 6 with an overview of our main findings and some avenues for further research.

2. Conceptual framework: intercity connectivity and regional integration in the HoA

Research on the impacts of city connectivity can be framed within broader scientific debates on the impacts of transport infrastructure provision on socio-economic processes in general and its role in promoting regional integration by causing, reinforcing, or tackling spatial inequality in particular. It is widely accepted that transport infrastructures have the potential to impact the development of cities as well as the welfare of their population (e.g., Limão & Venables, 2001; Yin et al., 2015; Glaeser et al., 2016). This extensively documented impact is discursively reinforced by policy narratives: many transport expansion or improvement projects are justified because of their alleged ability to bolster socio-economic development in the broadest sense (Banister & Berechman, 2001; Button & Yuan, 2013; Zhao et al., 2017). The notion of urban connectivity is, however, much more specific than mere transport provision. Camagni (1993) and later Capello (2000) extended the concept of ‘network externalities’, initially coined in economics (Katz & Shapiro, 1985), into ‘city network externalities’ to refer to the benefits associated with inter-city connections. They advance a club good perspective on city network externalities (van Meeteren et al., 2016), emphasizing the benefits accruing on the level of the urban production function because connections deliver beneficial synergies and complementarities (Camagni et al., 2013).

In its most basic guise, city connectivity refers to the pattern of linkages between cities that can be examined using graph theory tools. Although interest in ‘city networks’ dates back to at least the 1960s (e.g., Nystuen & Dacey, 1961), there has been a surge in interest in this field since the early 2000s (Neal et al., 2021). Crucially, city connectivity entails much more than a city’s stock of transport infrastructures: it refers to the directness, diversity, topology, and density of a city’s connections with other cities. For example, the presence of a sizable airport alone does not make a city a well-connected node, as this also depends on the nature and variety of its direct connections and several other connectivity characteristics. In addition, a city’s connectivity may change because of changes that are not directly related to that city: creating additional air transport connectivity in a proximate city with which it has good road connectivity may also change a city’s connectivity.

It is clear that HoA cities are very unequally connected in transport networks (e.g., Rammelt and Leung (2017)). For example, the Kenyan city of El Wak and the Ethiopian city of Tepi are separated by a Euclidean distance of about 780 km. However, given the lack of well-developed transport corridors, this entails 1250 km of driving that takes 24 h at best. Furthermore, there are no clear-cut options to significantly shorten this connection (for example, by air), making it hard to conceive meaningful interactions between both urban economies. Overall, regional, national, and international connectivity is clearly concentrated in the HoA’s major cities, especially its capital cities. Meanwhile, relatively smaller and/or peripherally located cities are often poorly connected to these major nodes and transport corridors. Furthermore, regional integration in the HoA is in many ways uneven. On the one hand, HoA was one of the pioneering African regions experimenting with regional cooperation in the 1990s. On the other hand, the results of such experiments were mixed, with often more conflict than cooperation emerging (El-Affendi, 2009). One of the many reasons for the uneven regional integration is that some of the territories in HoA states consist of de facto ungoverned spaces, undermining the establishment of an overarching governance structure within the region (Kabandula & Shaw, 2018).

Most previous research on HoA integration has been based on qualitative analysis, often drawing on ethnographic methods applied to case studies (e.g., Harbeson (1978); Feyissa et al. (2010); Mengistae and Bereket (2012)). Here, we complement this research with a large-scale analysis of transport network data. In particular, we formalize the notion of the unequal connectivity of cities in the region based on a network analysis of HoA cities’ connectivity in the ensemble of regional transport networks. The following section outlines the analytical framework of our study.

3. Analytical framework

3.1. Selection of cities

One of the recurring challenges in urban research is the formal and consistent identification of cities (Parr, 2007). Measures of cities often rely on national definitions, which vary considerably and limit comparability and integrated analysis. Over the past years, there have been several efforts to develop harmonized indicators. One of the most consistent frameworks in this context is the Degree of Urbanization (DoU), which is based on the Global Human Settlement Layer developed

1Although this paper 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. 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 accessibility of and large de facto connections.
in the context of a European Union-initiated project (https://ghsl.jrc.ec.europa.eu/degrba.php). This entails developing a spatial raster dataset depicting the global distribution of population, after which population densities are used as the input to an algorithm assigning territories to different classes based on spatial contiguities of similar raster cells. ‘Cities’ are identified as contiguous sets of grid cells with a density of at least 1,500 inhabitants per km$^2$ that collectively have a population of at least 50,000. Gaps within this collection of grid cells are filled, after which the edges are smoothed.

A total of 84 centers in the Horn of Africa are identified as ‘cities’ in the DoU classification, two of which are cross-border cities (i.e., Mandera at the Kenya/Somalia border and Moyale at the Kenya/Ethiopia border). With the exceptions of Djibouti (Djibouti) and Asmara (Eritrea), all cities are located in Kenya, Ethiopia, and Somalia. To make the analysis regionally more inclusive, additional cities with a population below 50,000 were selected for Djibouti (4) and Eritrea (5) using population data from the City Population database (http://www.citypopulation.de). This produces 92 cities, with at least five cities in each country (Fig. 1).

### 3.2. Data sources and specification of connections

Our analysis is based on a combination of three transport networks: road, air, and train. In recent literature, such a combination has been widely applied to develop a comprehensive view of inter-city connectivity (e.g., Zhu et al., 2018; Zhu et al., 2019). Although air transport and train networks are increasingly important connectivity providers within the region at large, the connectivity they provide is presently restricted to specific parts of the population and specific HoA cities and corridors: most inter-city connections in the HoA are provided via road. Furthermore, the road network is also a major potential ‘feeder’ of air transport connectivity, especially for cities located in the relative vicinity of major air transport hubs (e.g., Athi River near Nairobi and Debre Zeit near Addis Ababa): depending on the distance and road quality, these cities can also draw on the air transport connectivity nominally associated with their capital cities. More recently, Bertazzini (2021) highlighted the importance of the road network built across the HoA region, as it could have a long-term impact on the region’s spatial distribution of economic activities. In light of this, we specify a network that combines all three networks but assigns a larger weight to the road network.

Road connectivity is based on measures of driving time (in minutes) and distance (in kilometers) for the fastest routes given by Google Maps between all 92*(92-1)/2 = 4,186 pairs of cities. In reality, many potential factors may affect the actual driving time within the HoA. One of the most prominent factors is perhaps border-crossings. The exact spent on each border-crossing trip in HoA is highly idiosyncratic – sometimes it takes no extra time; sometimes it can take several hours if not days. Nevertheless, for modeling purposes, we have to add a universal ‘penalty’ of extra travel time to all international connections to reflect this nature, which is also a common practice in transport studies (e.g., Zhu et al., 2018; Zhu et al., 2019). We added a conservative 20-min penalty to all international connections to account for time lost at border-crossings, which may nonetheless underestimate the time to cross borders in the region but is aligned with ongoing efforts (e.g., at Moyale) to smoothen the process. Road connectivity is, however, much subtler than mere potential average speed: it is also defined by the distance that needs to be covered (reflecting time and potentially capital ‘lost’ when making the connection) and population size effects (reflecting the magnitude of the benefits offered by a high-quality connection). We therefore specify a road connectivity measure that draws on a spatial interaction approach (Fotheringham, 1983; Wu et al., 2021): it jointly considers the population sizes of the cities and the road quality. As to not overestimate the effects of larger population sizes and shorter driving distances and times, we use logarithms, producing the following road connectivity measure:

$$\text{Road}_{a,b} = \frac{\log(\text{Pop}_a) + \log(\text{Pop}_b)}{\log(\text{Distance}_{a,b}) + \log(\text{TravelTime}_{a,b})}$$  \hspace{1cm} (1)

The strongest national connections are between (very) proximate cities, e.g., between Dese and Tita in Ethiopia and between Nairobi and Ndenderu in Kenya. Note, however, that as per Equation (1), road connectivity is not a mere matter of distance. For example, although being located in relative proximity, Ndenderu and Athi River in Kenya are not that strongly connected because it takes on average 73 min to cover the 46 km separating these medium-size cities in light of the congestion around Nairobi.

Air connectivity is measured by recording the number of weekly direct flights. This information was derived from Google searches, after which it was cross-referenced with secondary online data sources such as Skyscanner (globally one of the largest metasearch travel engines) and details of operations at the different airports. Using the logarithm of weekly flights as not to inflate the importance of the few sizable air transport links in the HoA produces the following air connectivity measure:

$$\text{Air}_{a,b} = \log(\# \text{ of weekly direct flights}_{a,b} + 1)$$  \hspace{1cm} (2)

Finally, train connectivity is measured by recording the number of weekly trains, drawing on national railway enterprise websites, most notably for Kenya (e.g., https://metickets.krc.co.ke/) and Ethiopia (e.g., http://www.erc.gov.et/). Results were cross-referenced with online searches of operations in specific cities. Again, using the logarithm of weekly trains produces our train connectivity measure:

$$\text{Train}_{a,b} = \log(\# \text{ of weekly direct trains}_{a,b} + 1)$$  \hspace{1cm} (3)

The strongest air connections are Nairobi-Mombasa and Nairobi-Kisumu, with a total of 169 and 85 weekly direct flights, respectively. This is followed by a range of connections between Addis Ababa and major cities in northern and eastern Ethiopia (Bahir Dar, Dire Dawa, Jijiga, Gondar, and Mekelle). The strongest international connection is between Nairobi and Addis Ababa, with 38 weekly direct flights. The most substantial train connection is again Nairobi-Mombasa, with a total of 21 weekly trains. Although most of the – presently scarce – railway corridors in the HoA are national, there is an international corridor: the Addis Ababa–Djibouti Railway, a new standard gauge international railway that serves as one of the backbones of the new Ethiopian National Railway Network. It also connects Nazret and Dire Dawa (Ethiopia) and Ali Sabieh (Djibouti) on a near-daily basis and provides landlocked Ethiopia with access to the Gulf of Aden and the Red Sea via Djibouti.

### 3.3. Network analysis

#### 3.3.1. Network specification

This specification of the inter-city connections outlined in the previous sub-section produces three networks: a fully connected road network (Fig. 2a), a sparse air transport network (Fig. 2b), and an even sparser train network (Fig. 2c). The three networks are aggregated in two steps.

First, the three sub-networks are combined into a composite network (Fig. 2d). To this end, we standardize all three measures given by Equations (1)-(3) by applying a min-max normalization, producing distributions between 0 (minimum connectivity) and 1 (maximum connectivity). These normalized connectivity scores are then combined into an overall connectivity score between each pair of cities by combining the three scores. The road connectivity network is assigned

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2 We conducted a suite of robustness checks by specifying the time lost at border-crossings as 10 min, 20 min, 30 min, 40 min, 1 h, 1.5 h, and 2 h. The pairwise correlation coefficients of the total travel time from any two treatments are higher than 0.999.
the most significant weight because of its great importance and full connectedness (see Fig. 2a). Within the air transport and train networks, the former was given a larger weight than the latter, given more pairs of cities connected via flights than trains (see Fig. 2b vs. Fig. 2c). Therefore, we operationalized the following weight assignment as 3/6 for road, 2/6 for air, and 1/6 for train in Eq. (4):

\[
\text{Connectivity}_{a-b} = \frac{\text{Road}_{a-b}}{2} + \frac{\text{Air}_{a-b}}{3} + \frac{\text{Train}_{a-b}}{6}
\]  

(4)

Second, we remove non-significant connections. In principle, the network specified in Equation (1) (Fig. 2a) and subsequently Equation (4) (Fig. 2d) is fully connected: the distribution produced by Equation (1) has a theoretical minimum of 0, but in practice infinitesimally converges upon 0. The latter values are associated with relatively small cities divided by extremely long driving distances and/or times: it is always possible to connect any pair of cities no matter how feasible this turns out to be. To remove these conceptually meaningless connections, we imposed a threshold. To decide on the cutoff point, starting with the poorest connection (between Barentu in Eritrea and Ukunda in Kenya), we eliminated connections stepwise. After each elimination, we calculated the Pearson correlation coefficient between the original, fully connected network and the newly derived network to assess how strongly they resemble each other. Ultimately, we decided on a cutoff point of Connectivity_{a-b} = 0.08. This produces a network with a very sizable correlation of 0.91 with the original network but only retains 248 of the 4,278 (6%) original city pairs. Each city has at least one connection and is therefore connected to the network at large. The

Fig. 1. ‘Cities’ in the HoA based on the Degree of Urbanization methodology (https://ghsl.jrc.ec.europa.eu/degurba.php, and http://www.citypopulation.de for cities in Eritrea and Djibouti beyond the capital). City codes can be found in Appendix 1.
Fig. 2. Inter-city transport networks in the HoA: (a) Road, (b) Air, (c) Train, and (d) Composite. The relative strength of connections is shown through both shades and thickness utilizing quartiles (Q1 = the first quantile; Q2 = the second quantile; Q3 = the third quantile; Q4 = the fourth quantile).
resulting network is shown in Fig. 3: this much-sparser network closely resembles the original network structure (Fig. 2d) but with a density that allows for a more meaningful analysis of its topology and structure.

3.3.2. Formal network analysis of connectivity matrix

Network analysis offers the opportunity for a systematic appraisal of connectivity in city networks (Derudder, 2021; Zhang et al., 2019). In our research, we implement two complementary centrality measures that inform our understanding of the position of individual cities within the HoA’s infrastructure networks: eigenvector centrality (EC) and betweenness centrality (BC). As two of those most classic centrality measures, both EC and BC have been widely applied in transport studies and applied geography (e.g., Cheung et al., 2020; Wang et al., 2020). The application of centrality measures implies adopting a graph-theoretical conceptualization in which a node is a ‘vertex,’ and a connection is an ‘edge’. The formal mathematical specification of this is that a network \( G(\mathcal{V},\mathcal{E}) \) is constructed with each of the \( N = |\mathcal{V}| \) nodes representing a city, with the connections between them being encoded in the set of links \( \mathcal{E} \). This network is fully described by the non-negative adjacency matrix \( W = \{ w_{ij} \} \). An element \( w_{ij} \) of \( W \) is different from zero if there is a connection between two cities \( i \) and \( j \), while \( i \neq j \).

EC accounts for the strategic nature of a node’s connections: it foregrounds cities that are on average well connected to well-connected cities. Instead of using the simplest, but not necessarily very informative, centrality measure – degree centrality (DC), which is a ‘local’ measure accounting for the total strength of a node’s connections – EC is a ‘global measure’ looking specifically beyond first-order neighbors. EC can be cast as a generalization of DC in that it is given by:

\[
EC(i) = u_{i1}
\]

with \( u_{i1} \) representing the \( i \)th component of \( u_1 \), the eigenvector associated with the eigenvalue \( \lambda_1 \) of \( A \), so that it satisfies:

\[
A u_1 = \lambda_1 u_1
\]

In this case \( A \equiv \{ a_{ij} \} \) is the adjacency matrix of \( G \), whose non-zero elements denote the presence of a connection between cities \( i \) and \( j \). In our research, EC will above all foreground major transport hubs (e.g., Addis Ababa) and smaller cities located near them. In addition, it also identifies the privileged position of cities located along major transport corridors because of the externalities associated with having access to multiple nodes that are in turn also inter-connected. In contrast, cities that have above all connections with poorly connected cities will have small EC.

BC, in turn, accounts for a node serving as the most efficient gateway for otherwise unconnected nodes. For each city \( i \in \mathcal{V} \), BC can be computed from \( W \) as follows:

\[
BC(i) = \sum_{a \neq b \in \mathcal{V}} \frac{\sigma_{ab}(i)}{\sigma_{ab}}
\]

where \( \sigma_{ab} \) is the total number of shortest paths between nodes \( a \) and \( \beta \), and \( \sigma_{ab}(i) \) is the number of those paths that pass through \( i \). In our research, BC will foreground cities with several near-exclusive connections that cities can use to make otherwise unfeasible connections. In doing so, these cities serve the most efficient gateways for accessing the remainder of the city network. Like EC, this is a ‘global’ measure in that it looks beyond nodes’ first-order neighbors. More concretely, cities combining air transport connections with strong road connections to otherwise not very well-connected cities will have large BC. However, BC can be more subtle, with cities along long road corridors acting as the most efficient gateway for entire network parts that would otherwise be unconnected (Neal, 2014). This also implies that cities with limited connections can have sizable BC if one of their connections links other cities to the remainder of the network. BC is typically much more skewed than EC, as only a limited number of nodes often perform this role.

4. Results: city connectivity in the HoA

We organize the discussion of our results in two sub-sections. First, we focus on the overall regional integration in the HoA through the lens of inter-city connections. Second, we present the results of the centrality analysis, zooming in on the most significant patterns.

4.1. Regional integration in the HoA

The most obvious starting point is a discussion of the HoA’s strongest connections. Table 1 shows the ten strongest connections at large (top part) and the ten strongest international connections (bottom part). The national imprint of city connectivity patterns is immediately apparent in that there is no overlap between both rankings: the ten strongest connections at large are all intra-national, with the strongest international connection (Addis Ababa-Djibouti) ranked 13th overall.

Nairobi-Mombasa is the most connected city-dyad in the HoA: it has both the strongest air and train connections alongside a moderate level of road connectivity via the (often-congested) A109. The importance of road connectivity as put forward in our analytical framework shows from the second strongest connection not being a multimodal connection between major cities, but rather a road connection between two

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Fig. 3. Inter-city transport networks in the HoA after network parsing. The relative strength of connections is shown through both shades and thickness through quartiles (Q1 = the first quantile; Q2 = the second quantile; Q3 = the third quantile; Q4 = the fourth quantile).
smaller yet adjacent settlements: Dese and Tita in Ethiopia are only 10 km separated from each other along Ethiopia’s A2 highway. The remainder of the top 10 combines both patterns, i.e., either city connected by multiple modes or nearby cities connected via major roads.

The most important international connections are a combination of city-dyads connected by relatively strong air linkages (Nairobi-Addis Ababa and Mogadishu-Addis Ababa) and a range of city-dyads in the corridor running from Addis Ababa to Djibouti. In this west-east corridor, a number of cities are linked by more than one mode: Addis Ababa-Djibouti and Djibouti-Dire Dawa by all three modes, and Djibouti-Nazret, Dire Dawa-Ali Sabieh, Nazret-Ali Sabieh, and Addis Ababa-Djibouti and Dire Dawa-Djibouti by all three modes, and

Table 1

| City a         | Country | City b         | Country | Connectivity_{a,b} |
|---------------|---------|---------------|---------|--------------------|
| Mombasa       | Kenya   | Nairobi       | Kenya   | 0.588              |
| Dese          | Ethiopia| Tita          | Ethiopia| 0.500              |
| Addis Ababa   | Ethiopia| Dire Dawa     | Ethiopia| 0.477              |
| Nairobi       | Kenya   | Ruiri         | Kenya   | 0.424              |
| Nairobi       | Kenya   | Ndenderu      | Kenya   | 0.381              |
| Kismu         | Kenya   | Nairobi       | Kenya   | 0.378              |
| Nairobi       | Kenya   | Athi River    | Kenya   | 0.376              |
| Mombasa       | Kenya   | Ukunda        | Kenya   | 0.374              |
| Addis Ababa   | Ethiopia| Bahir Dar     | Ethiopia| 0.368              |
| Debre Zeyit   | Ethiopia| Dukem         | Ethiopia| 0.336              |

(b) International connections

| City a         | Country | City b         | Country | Connectivity_{a,b} |
|---------------|---------|---------------|---------|--------------------|
| Dhibouti      | Djibouti| Addis Ababa   | Ethiopia| 0.309              |
| Addis Ababa   | Ethiopia| Nairobi       | Kenya   | 0.299              |
| Dhibouti      | Djibouti| Dire Dawa     | Ethiopia| 0.298              |
| Addis Ababa   | Ethiopia| Hargeysa      | Somalia | 0.264              |
| Addis Ababa   | Ethiopia| Moqdisho      | Somalia | 0.262              |
| Nairobi       | Kenya   | Moqdisho      | Somalia | 0.231              |
| Addis Ababa   | Ethiopia| Mombasa       | Kenya   | 0.223              |
| Dhibouti      | Djibouti| Moqdisho      | Somalia | 0.204              |
| Ali Sabieh    | Djibouti| Dire Dawa     | Ethiopia| 0.183              |
| Asmera        | Eritrea | Addis Ababa   | Ethiopia| 0.181              |

Fig. 4 shows all international connections where Connectivity_{a,b} > 0. When read alongside the bottom half of Table 1, the map accentuates that the strongest international connections are between capital cities or between cities along the broadly defined Addis Ababa-Djibouti corridor. Some of the strongest connections, for example, Addis Ababa-Burco and Nazret-Hargeisa, connect central Ethiopia to Djibouti and northern Somalia. This west-east corridor fans out east of Awash and Dire Dawa, respectively. In Awash, the A1 highway branches off to Djibouti in a northeasterly direction, while there is also road and train connectivity further to the east in the direction of Dire Dawa. In Dire Dawa, the train connection branches off to Djibouti in a northerly direction, with road connectivity continuing east into Somalia. East of Dire Dawa, connectivity is less strong and more fragmented; however, it combines air transport connections such as Addis Ababa-Hargeisa and moderates yet viable road connections between Dire Dawa and Jijiga in Ethiopia on the one hand and Hargeisa and Berbera in Somalia on the other hand. The relative strength of connectivity along this broadly defined east-west corridor compared to a possible north-south corridor between Addis Ababa and Nairobi via Moyale can in large part be explained by the importance of access to ports for landlocked Ethiopia.

Although fewer international road connections are running from north to south, there are some connections between Asmara on the one hand and northern Ethiopian cities on the other hand (Bahir Dar, Tita, and Gonder). Proposed road upgrades and negotiations on a rail corridor connecting northern Ethiopia via Mekelle and Asmara to Massawa’s port could strengthen this potential. The strongest north-south connection is that between Addis Ababa and Nairobi, reflecting the size of both cities and – by the standards of the HoA – reasonable connectivity along the A2 (Kenya) and A7 (Ethiopia) via Moyale. On the one hand, this shows that previous road upgrades have paid off: when not factoring in the Moyale border-crossing time, our data suggest a possible average speed of up to 1.3 km/min. Besides, the opening up of a border facility at Moyale easing the flow of goods and people allows capitalizing on this potential. This shows that upgrades to road connectivity also require upgrades to border services and facilities, which in the Nairobi-Addis Ababa link has been well understood. Another long-distance transborder connection is between Nairobi and Kismayo along the A3, an important artery from Nairobi to the east that is in relatively good condition for most of the way.

The weakest connections – defined here as the shortest distances without a viable road link – are found in the borderlands between Ethiopia, Djibouti, and Eritrea. Table 2 shows the shortest distances where Connectivity_{a,b} = 0. This is, to some degree, a physical-geographical artifact with the Gulf of Tadjourah acting as a barrier. However, it nonetheless shows that the connectivity between Ethiopia and Djibouti is presently not extended into southern Eritrea. In the face of poor intra-Eritrea connections between Assab and the major centers in northern Eritrea, Assab is presently isolated on all possible fronts, 3

\[ 3 \text{ The planned rail link between Awash and Weldiya will further strengthen the road-based connectivity along this corridor.} \]
Table 2
10 international connections with shortest Euclidean distance but connectivity = 0.

| City a | Country (city a) | City b | Country (city b) | Euclidean distance (km) |
|--------|------------------|--------|------------------|------------------------|
| Tadjoura | Djibouti | Assab | Eritrea | 136.8 |
| El Wak | Kenya | Mandera | Somalia | 161.4 |
| Djibouti | Djibouti | Assab | Eritrea | 164.6 |
| Arte | Djibouti | Assab | Eritrea | 165.9 |
| Mendefera | Eritrea | Mekele | Ethiopia | 170.3 |
| Dikhil | Djibouti | Dire | Ethiopia | 177.4 |
| Dolo | Ethiopia | El Wak | Kenya | 197.9 |
| Ali Sabieh | Djibouti | Jigga | Ethiopia | 200.2 |
| Dikhil | Djibouti | Jigga | Ethiopia | 200.7 |
| Dikhil | Djibouti | Harer | Ethiopia | 201.2 |

Despite its potential importance as a port. To build a resilient and stronger network in this part of the HoA, a complementary strategy is needed. This will involve extending connections from Assab into Djibouti and Ethiopia, a national policy strengthening connectivity across the Eritrean coastline into Massawa and Asmara, and connecting this to the links coming in from northern Ethiopia. Given that connectivity in this part of the HoA will have a strong logistics dimension, this should ideally involve road and rail connections connected to wider networks that exist or are in the making.

Although transport connectivity is co-defined by distance decay and national functional spaces even in the economically most integrated regions, the lack of regional integration in the HoA is manifest. For example, unlike transnational infrastructure connectivity in Europe and across Asia (especially in the context of the Belt and Road Initiative), HoA connectivity can first and foremost be described as a collection of ‘national spaces’. This can be seen in Table 3, which shows the average values of Connectivity_{ij} for country-pairs. Intra-country connectivities (0.034530) are 29 times larger than the average value of inter-country connectivities (0.001211), which cannot be solely explained by distance decay alone. In short, the lack of regional economic integration results in, and also results from, the lack of connectivity between the HoA’s major cities. Indeed, the five largest values are uniformly for intra-country connections, with Djibouti being unsurprisingly given its small size compared with other countries and features the strongest connections. The connections between the Djibouti-Ethiopia-Somalia triad form a second block, with most connections emanating from the border-crossing connections by road and train in the Djibouti-Dire Dawa-Hargeisa triangle. Given the strategic importance of the Djibouti, Berbera, and Bossaso ports for landlocked Ethiopia, further developing connectivity in this corridor will prove important.

There are minor connections between Djibouti and Eritrea, Ethiopia and Eritrea, Kenya and Somalia, and Kenya and Ethiopia. The small value for the connectivity between Kenya and Ethiopia is an artifact of both countries’ size, with no major connections between Ethiopia’s north and Kenya’s south. However, the low average connectivities between cities in the region’s two largest economies are notable. Indeed, beyond (1) the flights between Addis Ababa on the one hand and Nairobi and Mombasa on the other hand and (2) the Addis Ababa-Nairobi road link via Moyale, there are as good as no viable connections between both countries. Finally, there are no connections between Djibouti and Kenya, Eritrea and Kenya, and Somalia and Eritrea.

4.2. Centralities

The centrality analysis allows translating the structural ensemble of inter-city connections into evaluations of the role of individual cities. Figs. 5 and 6 map the distribution of eigenvector and betweenness centrality, respectively.

The cities with the largest values for eigenvector centrality (EC) are a combination of, first, the HoA’s capital cities/main economic centers and, second, cities with a privileged position along major transport corridors. First, Addis Ababa and Nairobi have a much larger EC than the other capital cities in the HoA. This reflects both the size of their national economies and the diverse ways both cities are connected with many cities. Despite having less EC than Addis Ababa and Nairobi, the importance of capital cities shows from Djibouti (13th), Mogadishu

Table 3
Average connectivities at the level of countries.

| Country 1 | Country 2 | Average connectivity |
|-----------|-----------|----------------------|
| Djibouti | Djibouti | 0.067987 |
| Kenya | Kenya | 0.044773 |
| Eritrea | Eritrea | 0.026542 |
| Ethiopia | Ethiopia | 0.022497 |
| Somalia | Somalia | 0.010849 |
| Djibouti | Djibouti | 0.005470 |
| Djibouti | Somalia | 0.002908 |
| Ethiopia | Somalia | 0.001699 |
| Kenya | Somalia | 0.000787 |
| Eritrea | Ethiopia | 0.000684 |
| Ethiopia | Kenya | 0.000565 |
| Djibouti | Eritrea | 0.000000 |
| Djibouti | Kenya | 0.000000 |
| Eritrea | Kenya | 0.000000 |
| Eritrea | Somalia | 0.000000 |

Fig. 5. Eigenvector centrality (EC) of HoA cities. The relative size of EC is shown through both shades and thickness through quartiles (Q1 = the first quantile; Q2 = the second quantile; Q3 = the third quantile; Q4 = the fourth quantile).
Betweenness centrality (BC) of HoA cities. The relative size of BC is shown through both shades and thickness through quantiles (Q1 = the first quantile; Q2 = the second quantile; Q3 = the third quantile; Q4 = the fourth quantile).

(19th), and Asmara (44th), which are by far the most connected cities in their respective countries. Second, EC map foregrounds cities located along major transport corridors: this allows them to connect with cities with sizable air transport connectivity and/or with many other cities located along these corridors. Prominent examples are cities with strong connections with Addis Ababa: Nazret (2nd) and Dire Dawa (7th) by rail and road, and Debret Zeyit (also known as Bishoftu, 4th) and Dukem (10th) along the expressway to Addis. A similar interpretation holds for Ali Sabieh (23rd) in Djibouti. The EC perspective also emphasizes the strategic importance of having a major direct air service to the HoA’s major gateways, bringing other key centers in closer reach.

Weak EC connectivities are associated with peripheral cities in their national context: Ceerigaabo in Somalia, Assab in Eritrea, Tadjourah in Djibouti, Tepi in Ethiopia, and El Wak in Kenya are clear examples here. These are invariably cities without a commercial airport, are not located along major road corridors, often lack well-developed inter-city road infrastructure at large, and are relatively far removed from other cities. Even though these cities often function as major trading centers for their respective regions, their very modest connectivities within the HoA reflect and reproduce patterns of peripheralization. The culmination of these patterns can be found in border cities, most prominently in the Kenyan-Ethiopian-Somalainian border regions: Dolo (Ethiopia/Somalia), Mandera (Kenya/Ethiopia/Somalia), and Moyale (Kenya/Ethiopia) are among the weakest connected nodes in terms of EC, even if in the case of the latter city there have been ongoing efforts to better connect the city as part of the Addis Ababa-Nairobi link.

The lowest values are for Somaliadi and Eritrean cities, reflecting a combination of the lack of non-road-based transport infrastructure, average or sometimes even poor road infrastructure, and – above all, in Somalia – large distances between the different cities. An obvious example is Beledweyne, located in central Somalia. Although it is relatively a large city, it is only connected to the HoA’s broader transport networks via road. It has no formal connections into Ethiopia, with the Ferfer border post being defunct. Although located along the north-south road axis connecting Mogadishu with northern Somalia via Garowe, these are the only viable connections that cover large distances at limited speeds. A broadly similar situation can be observed in Eritrea, although the somewhat denser cluster of cities around Asmara pushes these cities’ EC somewhat up in the ranking. Nonetheless, for a city such as Barentu, located in western Eritrea, the situation is comparable to that of Beledweyne in Somalia: it has no possible connections into Ethiopia and only low-speed road connections with Mendefera, Keren, and Asmara in Eritrea.

The importance of air connectivity, no matter how small, shows from the example of Boosaaso in Somalia, which is ranked 61st. Although it is one of the least important cities in the HoA in terms of its overall level of connections, its direct link with Mogadishu allows for potentially faster access to the other major cities in the HoA could be expected on the strength of its connections alone. This logic also applies to road connectivity, with Moyale’s links in Kenya along the A2 highway to Nairobi, bringing it somewhat ‘closer’ to other major cities in the HoA compared with other peripheral cities such as El Wak, Ceerigaabo, Mandera, and Dolo.

As expected, the distribution of BC is much more skewed, with only 28 cities having a value > 0. The BC ranking brings the regional dominance of Addis Ababa and Nairobi even more to the fore. Both cities act as the HoA’s regional gateways to complement their broader international gateway function (Bassens et al., 2012). Despite not having that many connections, Asmara (4th) and Mogadishu (8th) are now ranked much higher, reflecting their crucial role in connecting other cities in their country to the rest of the HoA network, most crucially via the air links they offer. Awasa in Ethiopia (ranked 3rd) also emerges as a major gateway. It connects secondary Ethiopian cities located in the south to the rest of the network via its strategic location along the A8 highway (the Cairo-Cape Town link) and its direct air connection with Addis Ababa. Finally, several HoA cities that are (relatively) weakly connected appear on the BC map. Examples are Kisumu (Kenya, 5th), Hargeisa (Somalia, 7th), and Robe (Ethiopia, 14th). What sets these cities apart from Bahir Dar and Gondar in Ethiopia is that they can also be ‘used’ by other cities to connect to the HoA network at large.

5. Discussion: policy perspectives on connectivity for the HoA

The previous section gave a straightforward overview of our results. In this section, we review some of the broader implications of the different tables and maps. Three sets of implications stand out.

First, the importance of national spaces for inter-city connectivity is perhaps much more evident in the HoA than in other parts of the world (Githaiga et al., 2019; Zhang, 2020; Brenton et al., 2021). There are several reasons for this, ranging from the development context to evolving geopolitical and geoeconomic tensions. As a result, connectivity provision has often followed a logic that promotes national cohesion rather than regional integration. This is very clear in Ethiopia, where connectivity provision has been oriented centrally located in Addis Ababa. Although a degree of national coordination is reasonable and even desirable, the relative lack of regional integration in the HoA in terms of inter-urban connectivity is striking. In addition to the plans being drawn up in the HoA Initiative context, several exceptions are already in place. Prime examples include the rail and road connectivity on the west-east corridor running from Addis Ababa on the one hand to...
Djibouti and cities in northwestern Somalia on the other hand, as well as the Addis Ababa-Nairobi road link via Moyale. Future regional patterns of connectivity could include connections between landlocked Ethiopia and a range of Red Sea ports, the Liboi-Kismayo Road facilitating connectivity between Nairobi and southern Somalia, and aligning upgrades to Eritrean infrastructure with connections into northern Ethiopia. Importantly, each of these examples clearly shows that national and regional initiatives are not at odds with each other: targeted national city connectivity provision interventions can have regional effects, and vice versa.

Second, these thick borders also result in the peripheralization of borderlands. The debilitating effect of national borders on intra-regional connectivity in the HoA is nowhere more manifest than in its border cities, which tend to suffer from national development policies ‘borderland blindness’ (cf. Tremolieres & Walther, 2019). Border cities find themselves at the bottom of the centrality rankings because they suffer from the combined effects of limited infrastructure provision (often only road connectivity) and long distances to other cities via poor roads. The market town of Mandera (in the border region between Kenya, Ethiopia, and Somalia) and Dolo (at the Ethiopia-Somalia border) are arguably the most striking examples. However, there is a broader logic here, with peripheral cities often being deprived of connectivity (e.g., El Wak in Kenya, Tepi in Ethiopia, Assab in Eritrea, Tadjourah in Djibouti, and Beledweyne in Somalia). This is a relevant observation in its own right. However, there is a further debilitating effect here because border cities benefit the most from connectivity investments to promote regional integration: they are often veritable trans-border agglomerations with a high potential for social and commercial exchanges. For example, Dolo is an Ethiopian market town at the Somali border extended with refugee camps created around 2010. According to UNHCR registration data (United Nations High Commissioner for Refugees (UNHCR), 2021), these camps now host around 220,000, almost exclusively Somali refugees, so that refugees outnumber the host population. The lack of health facilities at the Somali side of the border and regional tensions in Somalia does not preclude that, according to a recent report by the University of Oxford Refugee Studies Centre (2020), Dolo can only be fully understood as part of a cross-border economy, interconnected to the national economy of Somalia. However, the current state of infrastructure does not reflect this as the nearest tarmac road is more than 300 km in every direction. Thus, and as shown by the example of Moyale, a second observation is that enhancing regional connectivity crucially depends on facilitating, regulating, and further developing existing exchanges across borders.

Third, connectivity needs to be understood from a multiscalar and multimodal perspective. This is very evident in ongoing discussions on the opening up of new ports such as Assab in southern Eritrea as gateways for the HoA at large, of crucial importance for landlocked Ethiopia in particular. Port competitiveness is increasingly tied to developing trade corridors, integrating the port in a multimodal transportation network to improve market access, fluidity of trade, and the integration of emerging industrial networks. From this perspective, a port is an interface between maritime trade, economic activities of ports, and inland terminals that provide intermodal structures and connections with the vast hinterlands (Merk & Noteboom, 2015). Conversely, the amplification capacity of transport corridors may allow the expansion of trade via the port. These bonds of mutual causality are key to understanding connectivity to port cities: the quality and capacity of hinterland connections, road, rail, and possibly sea links, are essential to any expansion of hinterland trade. In the HoA, this crucially requires coordination between national, bilateral, regional-wide, and border city connectivity plans. The case of the border region between Eritrea, Ethiopia, and Djibouti serves to illustrate: to fully unleash the potential of the strategic Eritrean port city of Assab will require (1) action on the Eritrean side (better connections by road and rail to Asmara), (2) coordination between Eritrea, Ethiopia and Djibouti to (re)open cross-border road connections and possibly develop rail links, and (3) integration with plans for expanding the Ethiopian railway system.

6. Conclusions

There is often friction associated with covering vast distances between cities. Investment in trade and transport corridors seek to reduce this friction: it can ensure increased inter-city connectivity, facilitating the mobility of goods, people, capital, and ideas, and subsequently further unleashing the economic and societal potential within cities/regions. In this paper, we have formalized such an approach through a benchmark analysis of the position of HoA cities in regional transport networks.

Overall, and unsurprisingly given the broader development context, inter-city connectivity in the HoA is not as well-developed as in other regions. For example, even though Addis Ababa and Nairobi are reasonably well connected, road connectivity between both cities falls short of their rising economic and demographic potential (and that of southern Ethiopia and northern Kenya more generally). For example, it is anticipated that 22 h and 25 min are needed to cover the 1,556 km between both cities, which is much higher than the time needed to connect major economic centers in other parts of the world that are also separated by a border and a similar distance, e.g., Paris-Warsaw (15 h and 47 min), Vancouver-San Francisco (14 h and 43 min), and Bangkok-Kuala Lumpur (17 h and 59 min). Although the road upgrades and the efforts at the Moyale border crossing often serve as an exemplar, there is clear scope for further improvements, especially when considering that Moyale is the only authorized/formal gateway between both countries.

The creation or deepening of transport corridors in the HoA implies the stepwise evolution from a set of poorly connected cities to a much more integrated, region-wide network connecting all cities in the HoA. The spatial concentration of flows in cities along these axes turns them into privileged sites in the broader region. One of the key objectives of the Horn of Africa (HoA) infrastructure investments is to develop such an integrated regional transport system anchored in its cities. Importantly, enhancing regional connectivity depends on facilitating, regulating, and further developing existing exchanges across borders.

Nevertheless, analyzing specific sets of cities within a regional urban system often suffers from oversimplified explanations (e.g., Muller, 1977). Such analyses should consider both functional and locational variations among the centers or the changing conditions of regional development. Future research could use the baseline developed in this paper to better theorize and understand the functional and locational variations across the HoA. Further research could also explore the potential of multimodal and topological resilience of port access from a network perspective, opening up the discussion beyond the HoA, given that Port Sudan provides an alternative for landlocked Ethiopia.

Notes

The boundaries, colors, denominations, and other information shown on any map in this paper do not imply any judgment on the part of the authors concerning the legal status of any territory or the endorsement or acceptance of such boundaries.

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Appendix 1. City code of all cities in the Horn of Africa (Fig. 1)

| Code | City         | Country | Code | City         | Country | Code | City         | Country |
|------|--------------|---------|------|--------------|---------|------|--------------|---------|
| 1    | Djibouti     | Djibouti| 32   | Hagere Hiwet | Ethiopia| 63   | Mera         | Kenya   |
| 2    | Ali sabieh   | Djibouti| 33   | Harer        | Ethiopia| 64   | Mombasa      | Kenya   |
| 3    | Dikhil       | Djibouti| 34   | Hosaina      | Ethiopia| 65   | Nairobi      | Kenya   |
| 4    | Tadjoura     | Djibouti| 35   | Jijiga       | Ethiopia| 66   | Naivasha     | Kenya   |
| 5    | Arta         | Djibouti| 36   | Jima         | Ethiopia| 67   | Nakuru       | Kenya   |
| 6    | Asmara       | Eritrea | 37   | Kebir Dehar  | Ethiopia| 68   | Nyeri        | Kenya   |
| 7    | Keren        | Eritrea | 38   | K'alto       | Ethiopia| 69   | Ruiru        | Kenya   |
| 8    | Massawa      | Eritrea | 39   | Mekele       | Ethiopia| 70   | Thika        | Kenya   |
| 9    | Assab        | Eritrea | 40   | Mek'i        | Ethiopia| 71   | El Wak       | Kenya   |
| 10   | Mendefera    | Eritrea | 41   | Metu         | Ethiopia| 72   | Ukunda       | Kenya   |
| 11   | Barentu      | Eritrea | 42   | Mojo         | Ethiopia| 73   | Uthane       | Kenya   |
| 12   | Adis Ababa   | Ethiopia| 43   | Nazret       | Ethiopia| 74   | Athi River   | Kenya   |
| 13   | Agaro        | Ethiopia| 44   | Nekekeme     | Ethiopia| 75   | Nolenderu    | Kenya   |
| 14   | Arba Minch   | Ethiopia| 45   | Robe         | Ethiopia| 76   | Moyale       | Kenya & Ethiopia |
| 15   | Ars Negele   | Ethiopia| 46   | Shashemene   | Ethiopia| 77   | Mandera      | Kenya & Somalia |
| 16   | Asela        | Ethiopia| 47   | Sodo         | Ethiopia| 78   | Busia        | Kenya   |
| 17   | Assa         | Ethiopia| 48   | Tepi         | Ethiopia| 79   | Muqdisho     | Somalia |
| 18   | Awasa        | Ethiopia| 49   | Weldiya      | Ethiopia| 80   | Berbera      | Somalia |
| 19   | Bahir Dar    | Ethiopia| 50   | Welkite      | Ethiopia| 81   | Ceeregaabo   | Somalia |
| 20   | Bedele       | Ethiopia| 51   | Ziway        | Ethiopia| 82   | Boosaasoa    | Somalia |
| 21   | Butajira     | Ethiopia| 52   | Tita         | Ethiopia| 83   | Hargeysa     | Somalia |
| 22   | Debre Birhan | Ethiopia| 53   | Baco         | Ethiopia| 84   | Burro        | Somalia |
| 23   | Debre Zeyit  | Ethiopia| 54   | Sululta      | Ethiopia| 85   | Qardho       | Somalia |
| 24   | Dese         | Ethiopia| 55   | Dukem        | Ethiopia| 86   | Laacanaood   | Somalia |
| 25   | Dila         | Ethiopia| 56   | Bungoma      | Kenya    | 87   | Garowe       | Somalia |
| 26   | Dire Dawa    | Ethiopia| 57   | Eldoret      | Kenya    | 88   | Gaalkacyo    | Somalia |
| 27   | Dolo         | Ethiopia| 58   | Garsha       | Kenya    | 89   | Beledweyne   | Somalia |
| 28   | Genet        | Ethiopia| 59   | Kiliif       | Kenya    | 90   | Baydhabo     | Somalia |
| 29   | Ginir        | Ethiopia| 60   | Kisisi       | Kenya    | 91   | Merca        | Somalia |
| 30   | Giyon        | Ethiopia| 61   | Kismu        | Kenya    | 92   | Kismaayo     | Somalia |
| 31   | Gonder       | Ethiopia| 62   | Kikale       | Kenya    | 93   |             |         |
Neal, Z., Derudder, B., & Liu, X. (2021). Using urban networks to gain new insight into old questions: Community, economy, bureaucracy. *Journal of Urban Affairs, 43*(1), 2-15.

Nystuen, J. D., & Dacey, M. F. (1961). A graph theory interpretation of nodal regions. *Papers - Regional Science Association, 7*(1), 29-42.

Oxford Refugee Studies Centre. (2020). https://www.rsc.ox.ac.uk/files/about/rsc-annual-report-2019-2020_web.pdf.

Parr, J. B. (2007). Spatial definitions of the city: Four perspectives. *Urban Studies, 44*(2), 381-392.

Rammelt, C. F., & Leung, M. W. (2017). Tracing the causal loops through local perceptions of rural road impacts in Ethiopia. *World Development, 95*, 1-14.

Remolières, M., & Walther, O. J. (2019). Accessibility and infrastructure in border cities. In OECD West African working papers (Vol. 23)Paris: OECD.

United Nations High commissioner for refugees (UNHCR). (2021). https://www.unhcr.org/data.html.

Wang, M., Chen, Z., Mu, L., & Zhang, X. (2020). Road network structure and ride-sharing accessibility: A network science perspective. *Computers, Environment and Urban Systems, 80*, Article 101430.

Weiss, D. J., Nelson, A., Vargas-Ruiz, C. A., Gligorïc, K., Bavadekar, S., Gabrilovich, E., Bertozzi-Villa, A., Rozier, J., Gibson, H. S., Shekel, T., Kamath, C., Lieber, A., Schulman, K., Shao, Y., Qarkaxhija, V., Nandi, A. K., Reddie, S. H., Rumisha, S., Amratia, P., … Gething, P. W. (2020). Global maps of travel time to healthcare facilities. *Nature Medicine, 26*(12), 1835-1838.

Wu, Z., Smith, D., & Wang, M. (2021). Simulating the urban spatial structure with spatial interaction: A case study of urban polycentricity under different scenarios. *Computers, Environment and Urban Systems, 89*, Article 101677.

Yin, M., Bertolini, L., & Duan, J. (2015). The effects of the high-speed railway on urban development: International experience and potential implications for China. *Progress in Planning, 98*(2), 1-52.

Zhang, C. (2020). Regional transformation of the horn of Africa: Implications for BRI implementation. *China Quarterly of International Strategic Studies, 6*(3), 287-309.

Zhang, L., Du, H., Zhao, Y., De Maney, P., Deseine, B., & Zhang, X. (2019). Drawing topological properties from a multi-layered network: The case of an air transport network in “the Belt and Road” region. *Habitat International, 93*, 102044.

Zhu, Z., Zhang, A., & Zhang, Y. (2018). Connectivity of intercity passenger transportation in China: A multimodal and network approach. *Journal of Transport Geography, 71*, 263-276.

Zhu, Z., Zhang, A., & Zhang, Y. (2019). Measuring multimodal connections and connectivity radiations of transport infrastructure in China. *Transportmetrica: Transportation Science, 15*(2), 1762-1790.