HORN OF AFRICA REGIONAL ECONOMIC MEMORANDUM BACKGROUND PAPER 5

A Framework for Enhancing Intra-regional Connectivity in the Horn of Africa

- Charles Kunaka & Ben Derudder

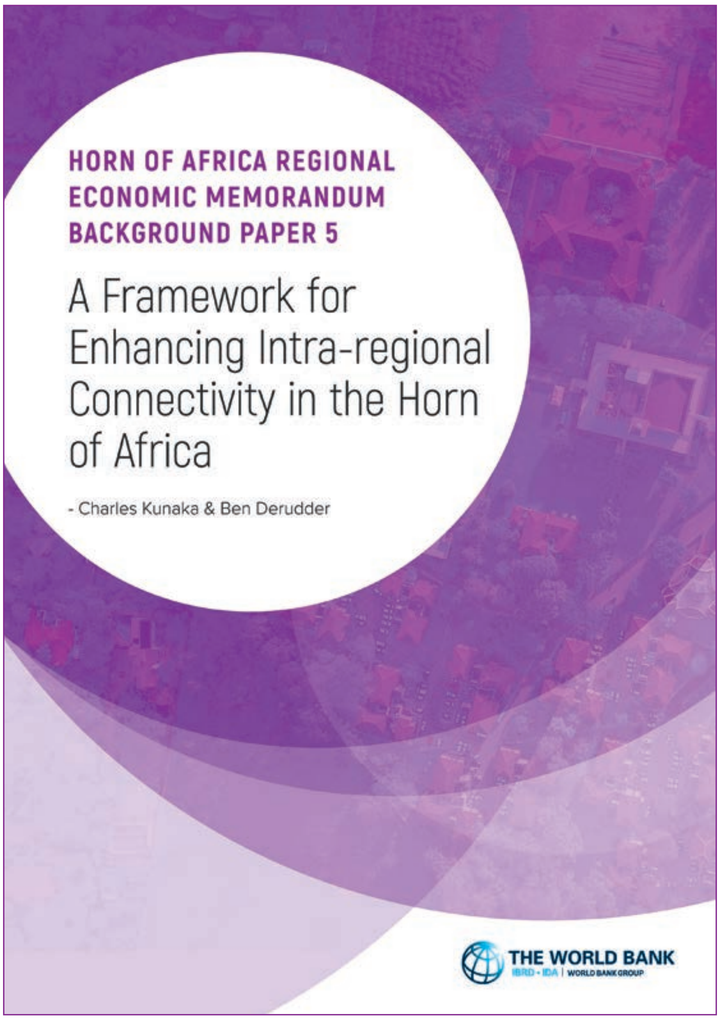
THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP

Photos: Shutterstock and Unsplash.

HORN OF AFRICA REGIONAL ECONOMIC MEMORANDUM BACKGROUND PAPER 5

Enhancing Intra-regional Connectivity in the Horn of Africa

- Charles Kunaka & Ben Derudder



CONTENTS

1 Background ... *1*

2 Why intercity connectivity is key to regional integration ... *3*

3 Analytical framework ... *7*

3.1 Identifying the key nodes for connectivity in the HoA ... *7*

3.2 Data sources and specification of connections ... *9*

3.3 Analytical framework ... *12*

A. Network specification ... *12*

B. Formal network analysis of connectivity matrix ... *13*

4 Results: city connectivity in the HoA ... *17*

4.1 Inter-city connections in the HoA ... *17*

4.2 City centrality in the HoA ... *21*

4.3 Regional integration in the HoA ... *26*

5 Policy perspectives of connectivity for the HoA ... *31*

References ... *35*

SECTION 1
Background

The Horn of Africa (HoA) Initiative places the development of regional corridors at the centre of the regional integration agenda. Poor intra-regional connectivity has emerged as one of the main signals of weak regional integration as well as an impediment to increased trade within the region. Regional dialogue in the HoA places a premium on measures to enhance interconnectivity and remove hurdles to the flow of trade and transport. Enhancing connectivity should enhance access to broad factor and product markets and make connected economic centers in different countries more attractive by providing productivity benefits. From a corridor development perspective, the place of an economic centre, its location and role, its linkages with other centers in a network will determine how it benefits from the HoA initiative.

A classical definition of a corridor is that it is "is a coordinated bundle of transport and logistics infrastructure and services that facilitates trade and transport flows between major centers of economic activity" (Kunaka, Carruthers, 2014). For instance, depending on an economic center's position in a connected corridor network, it can intermediate flows of components and goods between other centers and benefit from its position. As such, this paper is intended to focus dialogue on how to best envision the network of corridors in the Horn. Some of the policy questions it aims to answer are: (a) which regional links would have the most impact on overall regional connectivity: (b) how critical are national transport networks to connectivity outcomes in the region; and (c) what would be the best strategy for improving the integration of lagging regions, many of them in the borderlands of the Horn of Africa. The paper is based on the hypothesis that improving connectivity between the major economic centers in the HoA offers significant prospects for enhancing regional trade and transport connectivity.

The chapter is connected to the range of broader policy discussions on the nexus of access to goods, services, and knowledge provided by cities as a key driver of integration and socio-economic development: cities that are well connected in trade and transport networks can serve both as markets for local products and as hubs for regional and international trade and knowledge exchange. There is ample empirical evidence about the goods, services, and knowledge provided by well-connected urban contexts being more abundant, more diverse, and lower in cost. 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. Overall, as a city's connectivity increases, the average distance/time/cost/difficulty to gain access to/from other urban and regional economies decreases, thus creating more opportunities for interaction and the associated economic benefits.

In the Horn of Africa, distance is arguably the most decisive factor driving regional connectivity. In the region's most sparsely urbanized regions, cities are separated by significant distances which impose considerable constraints on inter-city connectivity. However, rather than distance per se, previous research has shown that it is above all the relative presence or absence of inter-city transport infrastructures that explicates inter-city connectivity (Derudder et al., 2018). For example, the Kenyan city of El Wak and the Ethiopian city of Tepi are separated by an Euclidean distance of about 780 km. However, given the lack of well-developed transport corridors this entails 1250 km of driving that takes 24 hours 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. Although this is of course an extreme example, it provides a stark illustration of the connectivity conundrum in parts of the Horn of Africa.

It is clear that HoA cities are very unequally connected. A first consideration is that different types of transport infrastructure are associated with different types of connectivity. For example, air transport connections are important because they allow for fast and direct access. However, this type of connectivity is presently only open to a small portion of the population. Transport connections by well-developed road infrastructure are not as fast and often more indirect. However, this infrastructure has the potential of forming the core of corridors that act as coordinated bundles of interaction between numerous centers of economic activity and are accessible for a much larger part of the population. Second, regional, national, and international connectivity is clearly concentrated in the HoA's major cities, especially capital cities. These cities as well as the cities that have relatively strong connections with them have a comparative advantage over other cities. Meanwhile, relatively smaller and/or peripherally located cities are often poorly connected to these major nodes and transport corridors Thus, they risk being caught in a spiral of geographical and topological marginalisation. Nonetheless, targeted investments can radically change the development outlook of such cities. One of the objectives of this paper is to suggest which (types of) links have the most potential in this regard.

Within the above context, this background paper systematically maps and assesses the connectivity of cities in the Horn of Africa (HoA) and uses the results to proposes a number of policy perspectives on how to strategically boost connectivity in different parts of the region. Analytically, this is achieved through network analysis of the directness, the diversity, topology and the density of HoA cities' transport infrastructure connections. Crucially, network analysis allows proxy-ing HoA cities' potential to participate in value chains at various geographical scales and identifying key areas of possible intervention. Results can guide institutional and governance measures that can be taken to influence connectivity as a whole and for specific cities and transport corridors in particular. The output can thus help determine the interventions that are needed to tackle bottlenecks in corridors, addressing infrastructure, policy and regulatory constraints.

The remainder of this paper is organized as follows. Section 2 outlines the rationale for an analysis of inter-urban connectivity in general and its linkages with the broader topic of regional integration and the economic geographies of the HoA in particular. Section 3 discusses our analytical framework, while Section 4 discusses the results. The paper is concluded with a discussion of key policy perspectives in section 5.

SECTION 2

Why intercity connectivity is key to regional integration

The proposed network analysis of transport connections between cities obviously chimes well with broader scientific discussions on the impact of transport infrastructure provision on the economy 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 are an important component of the economy, impacting both the development of cities as well as the welfare of their population (e.g. Limao & Venables. 2001; Calderon & Serven. 2004; Brooks and Hummels, 2009; Yin et al., 2015; Glaeser et al., 2016). Enhanced transport corridors have been shown to increase trade, productivity, competition, and business activity because of the improved market access that comes with lowered transport costs. Having reliable strong and robust transport connections to external labor, resource and consumer markets makes a location more attractive by providing productivity or profitability benefits in addition to bringing lower unit costs for workforce and facilities operations. The extensively documented impact of transport on economic growth is discursively reinforced by policy narratives: many transport expansion or improvement projects are justified because of their alleged ability to bolster economic development in the broadest sense. Indeed, policy-makers and planners frequently cite economic growth as a key motivation and justification for major investments in cyber-infrastructure, highways, rail lines, airports, and intermodal facilities for developing intra-regional, inter-regional, and international markets.

The presence of increasingly extensive infrastructure networks may suggest that, in an increasingly globalized and urbanized economy, knowledge and goods are almost instantly available to economic agents at limited cost. However, such naïve 'death-of-distance' readings of the space-economy obviously ignore that in reality there are still substantial and geographically uneven costs associated with overcoming distance. An important concept in this regard is that of 'urban connectivity'. In its most basic guise, urban connectivity refers to the observable pattern of linkages between cities that can be examined using tools of graph theory. Although interest in 'city networks' dates back to at least the 1960s (e.g., Nystuen and Dacey 1961; Haggett and Chorley 1969), there has been a recent surge in interest in this field since the 2000s (Neal, 2012). Crucially, the concept of urban connectivity entails much more than the mere stock or quality of transport infrastructures associated with a city: it refers to the directness, the diversity, the topology and the density of a city's connections with other cities. For example, the presence of a sizable airport alone does not make a city into a well-connected node, as this also depends on the nature and variety of its direct connections and a number of other connectivity characteristics. For instance, a city's connectivity may change because of topological changes that are not directly related with that city: creating additional air transport connection in a proximate city with which it has good road connectivity may also change the city's network position. The added value of thinking in terms of spatial networks instead of spatial interaction, therefore, resides in (also) systematically considering the value of connections beyond 'direct neighbors' (Derudder, 2020).

In general terms, a network perspective focuses on the extent to which benefits of one entity (i.e. a city) being connected to the network spill over to other entities (i.e. cities). Katz and Shapiro (1985) coined the term network externalities to refer to the effects a product or service has on a user while others are using the same or compatible products or services. Positive network externalities exist if the advantages (or, more technically, the marginal utility) are an increasing function of the number of other users. Katz and Shapiro (1985) discussed the example of ICT infrastructure where the utility that a given user derives from the good depends on the number of other users in the same network. Cast in the context of inter-city transport networks, this would suggest that cities stand to benefit – albeit unevenly – from an enhanced supply of connectivity across the

network. However, it is useful to point out that there are also negative network externalities, which emerge if the benefits are a decreasing function of the number of other users. For example, a new and improved road can confer negative network externalities if it attracts new, disproportionally large traffic volumes thus creating congestion that ultimately lower connectivity. However, in most instances, and this is also the assumption in this background paper, additional or improved inter-city transport connections are regarded as creating positive network externalities.

Camagni (1993) and later Capello (1996, 2000) generalized this line of thinking for city-systems by proposing the related notion of 'urban network externalities' referring to the urban-economic benefits associated with inter-city interactions. They advance a 'club good' perspective on urban network externalities (van Meeteren et al., 2016), emphasizing that benefits accrue on the level of the city production function as connections deliver beneficial synergies and complementarities (Camagni et al. 2013; van Oort et al. 2010). In our research on the HoA, we will follow this line of research theorizing that urban network externalities are above all positive externalities that are derived from the directness, the diversity, the topology and the density of a city's connections with other cities.

City network analysis in the HoA needs to consider that many connections are often average at best compared to other geographical settings (e.g. the relatively lower quality of highways between major centers in different countries, as well as the relatively longer/more complex border crossings on roads), with many of these being of relatively recent date (e.g. the recent development of an Ethiopian national train system). 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. When implemented, such a 'mature' system will allow for a more efficient exploitation of economies of scale and scope as well as productivity benefits in the cities along the corridors. The spatial concentration of flows in economic centers along these axes turns them into privileged sites within the wider region. One of the key objectives of the infrastructure investments in the Horn of Africa (HoA) is to facilitate the development of such an integrated regional transport system anchored in its cities.


FUJIFILM
MODERN PHOTO
TOYOTA

SECTION 3
Analytical framework

3.1 Identifying the key nodes for connectivity in the HoA

One of the recurring challenges in urban research is the formal identification of cities. Measures of cities often tend to rely on national definitions, which vary considerably and limit comparability and integrated analysis. Importantly, in addition to harmonization as such, definitions and indicators also ideally need to capture the role of cities as economic centers. Over the past years there have been a number of large-scale efforts to develop harmonized indicators of cities in their role as economic centers. One of the most consistent frameworks in this regard is provided in the context of the European Union-initiated 'Global Human Settlement' (GHS) project, which *inter alia* entails the development of a spatial raster dataset depicting the global distribution of population: the Global Human Settlement Layer (GHSL). The GHSL uses heterogeneous data including global archives of fine-scale satellite imagery, census data, and volunteered geographic information. The data is processed automatically using machine learning techniques and generates analytics and knowledge reporting objectively and systematically about the presence of population densities and built-up infrastructures.

This spatial raster with population densities is used as the input to a Degree of Urbanization (DoU) algorithm, which assigns territories to different classes based on spatial contiguities of similar raster cells. This leads to the identification of 'cities' according to a uniform set of attributes gathered from the GHSL raster data. The DoU is calculated by assigning 1 km² grid cells to one of the different classes based on contiguity, density, and population size. The 'cities' class is defined as contiguous sets of grid cells with a density of at least 1,500 inhabitants per km² that collectively have a population of at least 50,000. Any gaps within this collection of grid cells are then filled, after which the edges are smoothed with an iterative application of the majority rule (i.e. if five out of the eight surrounding cells are part of an urban center, this cell is added to the center). Figures 1a and 1b show the result for the examples of Ziway (Ethiopia) and Mogadishu (Somalia).

Figure 1: Title of Figure

A. Ziway according to the DoU classification

B. Mogadishu 'according to the DoU classification

Source: Insert source here.

Using the DoU-based definition of cities has several benefits, the three most pertinent ones in the context of this research being that: (1) it can be applied in a very cost-effective manner; (2) allows for a consistent perspective on the size of cities; and (3) is conceptually and operationally linked to the broader conception of economic centers. This is because the methodology captures spatial concentration of people directly, instead of relying on proxies such as built-up areas, night lights, or administrative units.[iii]

A total of 84 centers in the Horn of Africa are formally identified as 'cities' in the DoU classification, 3 of which are cross-border cities (Busia at the Uganda/Kenya border, Mandera at the Kenya/Somalia border, and Moyale at the Kenya/Ethiopia border). With the exceptions of Djibouti (Djibouti) and Asmara (Eritrea), the 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 a total of 93 cities, with at least 5 cities in each HoA country. Figure 2 shows the geographical layout of the urban system in the region, while Appendix 1 (cities rank-ordered by population) and Appendix 2 (cities rank-ordered by population per country) provide an overview of the framework of analysis.

Figure 2: Framework for analysis: 'cities' in the HoA based on the Degree of Urbanization methodology

Source: Insert source here.

3.2 Data sources and specification of connections

The connectivity analysis is based on a combination of three transport networks: road, air, and train. Although air transport networks and train networks are increasingly important connectivity providers within the region at large, the often-crucial connectivity they provide is presently restricted to specific parts of the population and specific HoA cities and corridors. This makes the specification of, and a focus on the road network of crucial importance, both analytically and in terms of policy perspectives: today, most inter-city connections in the HoA are provided via road connections. Furthermore, the road network is also a major actual and potential 'feeder' of air transport connectivity, especially for cities that are located in the relative vicinity of major air transport hubs (e.g., Athi River near Nairobi, or Debre Zeit near Addis Ababa): depending on distance and road quality, these cities can also draw on the air transport connectivity nominally associated with the capital cities. In light of this, we specify a network that combines all three networks but with a more inclusive approach for road connectivity.

Road connectivity is based on measures of driving time and driving distance for the fastest routes given by Google Maps between all 93*(93-1)/2 = 4278 pairs of cities. A conservative 15-minute penalty is added to all international connections to account for time lost at border-crossings (it is accepted that this is a gross underestimate of the time to cross borders in the region, which often takes several hours if not days). The strongest connections are found on the Kenyan sections of the A2 (Kenya)-A7 (Ethiopia) corridor connecting Addis Ababa with Nairobi via the cross-border city of Moyale, with some inter-city connections allowing for an average speed of up to 1.3km/min. 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). Rather than simply using distance per time, we therefore specify a road connectivity measure that draws on a spatial interaction approach: our specification jointly considers the population sizes of the cities being connected and the road quality when making the connection. As to not overestimate the virtuous effects of larger population sizes and shorter driving distances and driving times we use logarithms, thus arriving at the following road connectivity measure for a pair of cities a and b:

$$Road_{a\text{-}b} = \frac{\log(Pop_a)*\log(Pop_b)}{\log(Distance_{a\text{-}b)}*\log(TravelTime_{a\text{-}b)}} \qquad (1)$$

This results in a distribution with a theoretical minimum of 0 but in practice infinitesimally converging upon 0 (small cities divided by extremely long driving distances and/or driving times) and – based on experimentation – a practical maximum of around 30 (large twin cities divided by a very short distance and efficient infrastructure). Table 1 shows the 10 strongest national and international road connections. The strongest national connections are between (very) proximate cities, e.g. between of Dese and Tita (Ethiopia, 10 km, Roada-b = 23,9) and Nairobi and Ndenderu (Kenya, 15 km, $Road_{a\text{-}b}$ = 18,6). 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 ($Road_{a\text{-}b}$

= 8,2) because it takes on average 73 minutes to cover the 46 km separating them in light of the congestion around Nairobi. The strongest international road connections are between cities located near borders, e.g. between Dolo (Ethiopia) and Mandera (Kenya) and between Jijiga (Ethiopia) and Hargeisa (Somalia). The connection between Nairobi and Kenya, requiring 22h50 min to cover 1556kms, falls just out of the international top 10 ($Road_{a\text{-}b}$ = 4,4). Overall, international road connectivities are markedly lower than the national connections. This is partly due to the (modest) time penalties for border crossings but, as will be discussed below, also reflects the poor road infrastructures between these cities.

Table 1: Major national and international road connections in the HoA

National			International		
City a	City b	$Road_{a\text{-}b}$	City a	City b	$Road_{a\text{-}b}$
Dese	Tita	23,9	Dolo	Mandera	8,0
Nairobi	Ndenderu	18,6	Jijiga	Hargeysa	6,5
Debre Zeyit	Dukem	16,6	Harer	Hargeysa	5,2
Nairobi	Ruiru	15,5	Dire Dawa	Hargeysa	5,1
Mojo	Nazret	15,3	Djibouti	Dire Dawa	5,1
Arsi Negele	Shashemene	15,0	Asmera	Mekele	4,7
Awasa	Shashemene	14,7	Djibouti	Hargeysa	4,7
Mombasa	Utange	14,5	Ali sabieh	Dire Dawa	4,6
Adis Abeba	Sululta	14,0	Kisii	Busia	4,6
Nairobi	Athi River	13,4	Dolo	Baydhabo	4,6

Notes:

- Population data were derived from https://ghsl.jrc.ec.europa.eu/degurba.php for 2015, unless stated otherwise via * or **. * Additional cities for Djibouti were derived from http://citypopulation.de/Djibouti.html. ** Additional cities for Eritrea cities were derived from https://www.geonames.org/ER/largest-cities-in-eritrea.html.
- Road distance and travel time data were derived from GoogleMaps.

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. Google's information on weekly direct flights draws on ITA Software's QPX software, which uses algorithms to combine and parse multiple sets of flight information from airlines. This includes availability data, which allows Google to keep an up-to-date database that can be searched just like Google's overall search engine. Using the logarithm of weekly flights as to not inflate the importance of the few sizable air transport links that exist in the HoA leads to the following air connectivity measure for a pair of cities a and b:

$$Air_{a\text{-}b} = \log(\#weekly\ direct\ flights_{a\text{-}b} + 1) \qquad (2)$$

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

$$Train_{a\text{-}b} = \log(\#weekly\ direct\ trains_{a\text{-}b} + 1) \tag{3}$$

Table 2 shows the 10 strongest air transport and train connections. The strongest air connection 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 a total of 38 weekly direct flights. The strongest 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 also serves as the backbone 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.

Table 2: Major air and train connections in the HoA

Rank	City a	City b	Weekly flights	City a	City b	Weekly trains
1	Mombasa	Nairobi	169	Mombasa	Nairobi	21,0
2	Kisumu	Nairobi	85	Addis Ababa	Dire Dawa	7,5
3	Addis Ababa	Bahir Dar	84	Djibouti	Dire Dawa	7,5
4	Addis Ababa	Dire Dawa	75	Addis Ababa	Nazret	7,5
5	Addis Ababa	Jijiga	56	Djibouti	Ali sabieh	7,5
6	Addis Ababa	Mekele	46	Dire Dawa	Nazret	7,5
7	Addis Ababa	Gonder	42	Ali sabieh	Dire Dawa	7,5
8	Eldoret	Nairobi	39	Nairobi	Ruiru	7,0
9	Addis Ababa	Nairobi	38	Nairobi	Athi River	7,0
10	Nairobi	Ukunda	34	Mombasa	Athi River	7,0

Notes:

- Air transport data was derived from Google, which draws on ITA Software's QPX software using algorithms to combine and parse multiple sets of flight information from airlines.
- Train data was derived from national railway enterprise websites, most notably for Kenya (e.g., https://metickets.krc.co.ke/) and Ethiopia (http://www.erc.gov.et/).
- Note that actual measures (Aira-b and Traina-b) used in the subsequent analyses are logarithms of these weekly connections as to not inflate the importance of the most sizable connections. In the table we report initial measures as this allows for a more intuitive discussion.

3.3 Analytical framework

A. Network specification

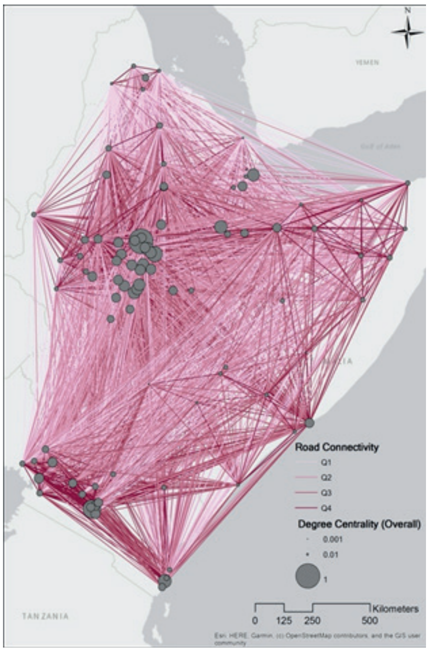
The specification of the connections produces three networks: a fully connected road network, a sparse air transport network, and an even sparser train network. The three networks are combined into a composite network. This integration is needed because it allows assessing how, for example, strong connectivity via road or train to a well-connected air transport hub influences a city's position in the overall network. This integration consists two steps: combining the three networks and deleting all non-viable connections.

First, the three sub-networks are combined into a composite network. To this end, we first 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 averaging the three scores:

$$Connectivity_{a\text{-}b} = \sum(Road_{a\text{-}b} + Air_{a\text{-}b} + \mathrm{Train}_{a\text{-}b})/3 \quad (4)$$

The second step entails 'preparing' the network for formal network analysis. The network specified in Equation 1 and subsequently Equation 4 is fully connected because of the road network: Equation 1 produces infinitesimally small numbers rather than actual 0s for weakly connected cities. Indeed, as can be seen in Figure 3, it is always possible to get from city a to city b, no matter how (in)efficient that connection is. However, in addition to these connections being conceptually negligible, a fully connected network is also not very interesting from an analytical point of view. For example, it is difficult to identify the gateway function of specific cities in a fully connected network and/or corridors of enhanced connectivity when every city is deemed to be connected to every other city. We therefore imposed a connectivity threshold that removes small connections. To decide on the cut-off point, starting with the poorest connection (between Barentu in Eritrea and Ukunda in Kenya: no air or train connections, and 2958 min required to cover 3345 km all the way through Ethiopia), we eliminated connections in a stepwise fashion. 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 (Figure 4). Ultimately, we decided on a cutoff point of Connectivitya-b = 0,035, shown as a vertical dashed line in Figure 4. This produces a network that has a very sizable correlation of 0.96 with the original network, but only retains 563 of the 4278 (13,16%) original city-pairs. However, it is important to stress that each city has at least one connection and is therefore connected to the network at large. The 'strongest' connection that was thus dropped is between the Ethiopian cities of Tita (Dessie) and Mojo, which requires 504 min to cover 463 km. The retained connections are shown in Figure 5: this network very closely resembles the structure of the original network, but with a density that allows for a more thorough network analysis of its topology and structure as only the most meaningful connections are retained. All 4278 inter-city connections as measured and subsequently specified and transformed in this framework are given in Appendix 3.

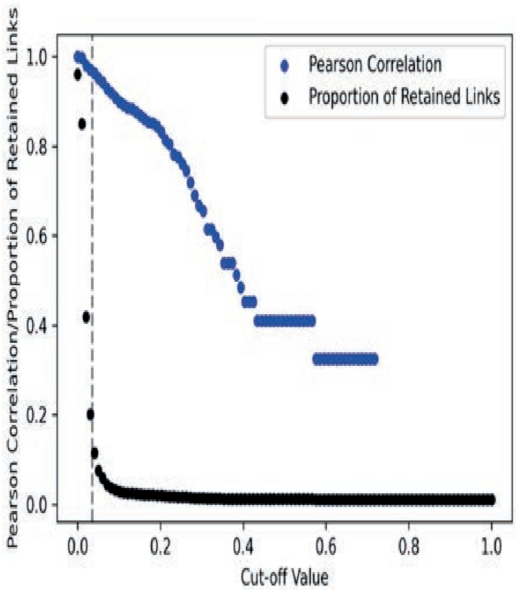
Figure 3: The (fully connected) road network in the HoA



Note:

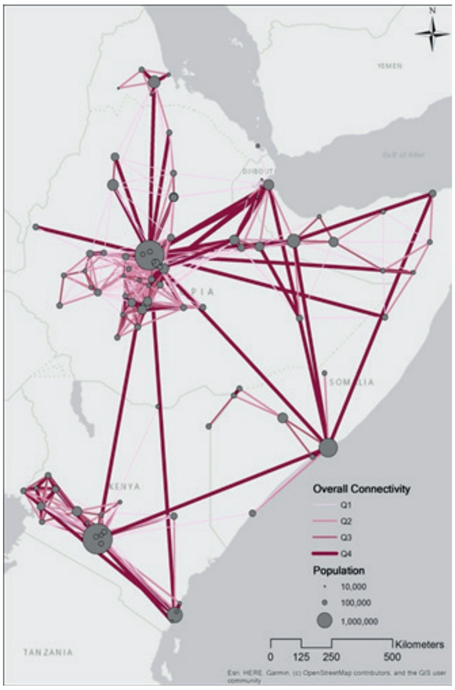
- To be able to differentiate between the relative strength of the different connections, we divided the distribution into quartiles.

Figure 4: Impact of stepwise removal of weakest connections on network density and resemblance with the original network



Source:

Figure 5: Geographical distribution of Connectivity$_{a-b}$ in the HoA after network parsing



Note:

- To be able to differentiate between the relative strength of the different connections, we divided the distribution into quartiles.

B. Formal network analysis of connectivity matrix

Network analysis offers the opportunity for a systematic appraisal of city connectivity. In our research, we implemented three complementary centrality measures that collectively inform our understanding of the position of individual cities within the HoA's infrastructure networks. To specify these measures, we adopt 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 $G(V,E)$ is constructed with each of the $N=|V|$ nodes representing a city, with the connections between them being encoded in the set of links 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 as per Equation 4 (and subsequently pruned as shown in Figures 4 and 5). Obviously, $i \neq j$.

The reason for calculating and discussing different centrality measures is that there are different reasons why a node can be important in a network. For example, a node can be important because it has many connections, but it can also be important because it connects otherwise unconnected nodes. Different centrality measures have been devised to capture these different dimensions, and here we report on three of the most commonly used measures: degree centrality (DC), betweenness centrality (BC), and eigenvalue centrality (EC). Here we restrict ourselves to an intuitive interpretation of what these measures capture.

The first and most straightforward centrality measure is a node's degree centrality (DC), which accounts for the total strength of a node's connections. For each city $i \epsilon V$ DC can be computed from W as follows:

$$DC\,(\mathrm{i}) = \sum_{i=1}^{N} w_{ij} \qquad (5)$$

In topological terms, this is a 'local' measure in that it only considers nodes' first-order neighbours: their direct connections. In our research, DC will foreground cities that are well-connected in more than one of the three network layers and/or cities along major transport corridors as this provides them with connections with many other cities.

The second measure is a node's betweenness centrality (BC), which accounts for a node serving as the most efficient gateway for otherwise unconnected nodes. For each city $i \epsilon V$ DC can be computed from W as follows:

$$BC\,(\mathrm{i}) = \sum_{a \neq i \neq b \epsilon V} \frac{\sigma_{ab\,(i)}}{\sigma_{ab}} \qquad (6)$$

Where σ_{ab} is the total number of shortest paths between nodes a and b and $\sigma_{ab}(\mathrm{i})$ is the number of those paths that pass through i. In our research, BC will foreground cities with a number of 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. In topological terms, this is a 'global' measure in that it looks beyond nodes' first-order neighbours. 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 also cities along long road corridor acting as the most efficient gateway for entire parts of the network that would otherwise be unconnected. This also implies that cities with poor connections can emerge with sizable BC if one of those poor connections nonetheless serves to link other cities to the remainder of the network. BC is typically much more skewed than DC, as often only a limited number of nodes perform this role.

The third measure is a node's eigenvalue centrality (EC), which accounts for the strategic value of a node's connections. A city has a large EC if it is, on average, well connected to well-connected cities. This also a 'global measure' in that it looks specifically beyond first-order neighbours. EC can be cast as a generalization of DC in that it is given by:

$$EC\,(\mathrm{i}) = u_{1,i} \tag{7}$$

with $u_{1,i}$ representing the i^{th} component u_1, the eigenvector associated with the eigenvalue λ_1 of A, so that it satisfies:

$$Au_1 = \lambda_1 u_1 \tag{8}$$

In this case $A = \{a_{ij}\}$ 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 smaller cities located near well-connected nodes such as Addis Ababa and/or cities located along major transport corridors because of the externalities associated with having access to multiple nodes that are in turn also connected. In contrast, cities that have above all connections with poorly connected cities will have small EC.

In addition to these centrality measures, we will also present the results of a community detection exercise. In network analysis, 'communities' refer to the occurrence of cohesive sub-networks in the sense that there are groups of nodes (i.e. communities) that are, on average, more densely interconnected than with 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. We applied the InfoMap community detection method to disaggregate the network into subnetworks. Based on the cursory overview of connections in Tables 1 and 2 as well as visual inspection of Figure 5, it can be expected that communities will broadly reflect national spaces. However, this overlap between geographical space and topological space can well be more complex than this: national patterns can be variegated in their own right, while some geographically peripheral nodes may hold a specific position. Applying community detection and cross-referencing this with national and regional geographies can shed light on the network structure.


StarTimes

SECTION 4

Results: city connectivity in the HoA

The presentation of our results proceeds in three consecutive steps. First, we focus on the inter-city connections by discussing some notable examples of strong and weak connections. Second, we present the results of the centrality analysis, zooming in on the most significant patterns. Third, we reflect on the overall integration of the HoA through the lens of inter-city connections by exploring the results of the community detection in combination with the most notable international connections. This descriptive overview will then be used in the fifth and final section to elaborate on policy perspectives.

4.1 Inter-city connections in the HoA

The most obvious starting point is a discussion of the region's strongest connections. Table 3, which shows the 10 strongest connections in the HoA, shows that Nairobi-Mombasa is the most connected dyad: it has both the strongest air and train connections alongside a moderate level of road connectivity via the (often-congested) A109. This is followed by the Addis Ababa-Dire Dawa connection, which likewise has air and train connections alongside road connectivity via the A1 and A10 highway system. The strongest connections are clearly at the national level, with Djibouti-Dire Dawa and Djibouti-Addis Ababa being the sole non-national connections in the top 10. Overall, the strongest connections are unsurprisingly between the few city-pairs that are connected by more than one mode: all three modes in the case of Nairobi-Mombasa and Addis Ababa-Dire Dawa; air and road in the case of Nairobi-Kisumu (Kenya) and Addis-Ababa-Bahir Dar (Ethiopia); and train and road in the case of Nairob-Ruiru (Kenya), Nairobi-Athi River (Kenya), and Addis Ababa-Nazret (Ethiopia). Beyond and alongside these multimodal connections, the importance of road connectivity shows from the strongest road-only connection making it into the top 10 (Dese-Tita in Ethiopia).

Table 3: Strongest inter-city connections in the HoA

Rank	City a	Country city a	City b	Country city b	$Road_{a-b}$	Air_{a-b}	$Train_{a-b}$	$Connectivity_{a-b}$
1	Mombasa	Kenya	Nairobi	Kenya	0,177	1,000	1,000	0,726
2	Addis Ababa	Ethiopia	Dire Dawa	Ethiopia	0,162	0,843	0,692	0,566
3	Nairobi	Kenya	Ruiru	Kenya	0,623	0,000	0,673	0,432
4	Nairobi	Kenya	Athi River	Kenya	0,527	0,000	0,673	0,400
5	Djibouti	Djibouti	Dire Dawa	Ethiopia	0,157	0,313	0,692	0,387
6	Djibouti	Djibouti	Addis Ababa	Ethiopia	0,124	0,467	0,552	0,381
7	Kisumu	Kenya	Nairobi	Kenya	0,177	0,867	0,000	0,348
8	Addis Ababa	Ethiopia	Nazret	Ethiopia	0,349	0,000	0,692	0,347
9	Addis Ababa	Ethiopia	Bahir Dar	Ethiopia	0,159	0,865	0,000	0,341
10	Dese	Ethiopia	Tita	Ethiopia	1,000	0,000	0,000	0,333

Note:

- Grey shaded connections are international.

The observation that 8 out of the 10 strongest connections are between cities located in the two largest economies in the region shows the imprint of national economies on connectivity. This also implies that a nuanced discussion of inter-city connections has to move beyond the strongest connections at large. Therefore, in the remainder of this section we elaborate on two complementary perspectives on HoA connections: one focusing on individual countries and one focusing on the major international connections. The latter also includes a preliminary overview of border cities, the specific position of which will be further discussed in 4.2, 4.3 and 5.

Table 4 shows the 5 strongest national inter-city connections for each of the five countries. In Djibouti, the Djibouti-Ali Sabieh connection towers over the rest due to the combination of train connectivity and the road connectivity (mostly) provided by the RN-1 national highway. The latter is part of the larger Ndjamena–Djibouti Highway as part of the Trans-Africa Highway network and the most important road link in the country. The remaining connections in Djibouti are all road-based, with above all Tadjourah being constrained by the relative lack of well-developed road infrastructure in the face of the physical boundary of the Gulf of Tadjourah . In Eritrea, the relatively small number of internal flight connections and the defunct train system results in small national inter-city connectivities in comparison with Kenya and Ethiopia. The connections between Asmara and Mendefera (via the asphalted P-4 primary road) and Keren (via the asphalted P-2 primary road) emerge as the strongest links. Four of the five strongest connections in Ethiopia involve Addis Ababa, showing the marked urban primacy of the country. In addition to the three-mode connection with Dire Dawa, there are also strong connections with Bahir Dar and Jijiga (air transport and moderate road connections) and Nazret (train and fairly strong road connections). In contrast to Ethiopia, Kenya has a slightly more polycentric system with also major connectivity vested in the port city of Mombasa. As already pointed out, the Nairobi-Mombasa link is the strongest in all of the HoA, which in Kenya is trailed by inter-city connections via more than one mode: Nairobi-Ruiru via daily trains and the A2 highway, Nairobi-Athi River via daily trains and the A104/A109 system branching off to Arusha/Mombasa, and Nairobi-Kisumu via sizable air transport connections. Finally, Somalia largely replicates the pattern of Eritrea with poor national air connectivity and no train connectivity implying that road connectivity is the key national connectivity infrastructure. The twice-weekly flights between Mogadishu and Hargeysha make this into the strongest connection, followed by other cities being connected by air, even if only weakly so. The fact that a limited number of air connections shapes the national ranking is reflective of the combination of long distances between cities and poor road infrastructure: the road system in the north detours via Berbera (reflected in the Berbera-Burco connection), while despite recent investments in the Garowe–Bossaso Highway – the major thoroughfare in the autonomous Puntland region in northeastern Somalia connecting Garowe with the commercial hub of Bossaso – average speeds still being limited.

Table 4: Strongest national inter-city connections in the HoA for each of the countries

City a	City b	Connectivity a-b
	Djibouti	
Djibouti	Ali Sabieh	0,305
Djibouti	Arta	0,106
Ali Sabieh	Dikhil	0,074
Djibouti	Dikhil	0,061
Ali Sabieh	Arta	0,061
	Eritrea	
Asmara	Mendefera	0,102
Asmara	Keren	0,090
Asmara	Massawa	0,074
Keren	Mendefera	0,048
Keren	Barentu	0,046
	Ethiopia	
Addis Ababa	Dire Dawa	0,102
Addis Ababa	Nazret	0,090
Addis Ababa	Bahir Dar	0,074
Dese	Tita	0,048
Addis Ababa	Jijiga	0,046
	Kenya	
Mombasa	Nairobi	0,726
Nairobi	Ruiru	0,432
Nairobi	Athi River	0,400
Kisumu	Nairobi	0,348
Mombasa	Ukunda	0,308
	Somalia	
Mogadishu	Hargeisa	0,136
Bossaso	Hargeisa	0,134
Mogadishu	Bossaso	0,097
Mogadishu	Merca	0,082
Berbera	Burco	0,065

Table 5 shows the 10 strongest international connections. The ranking is dominated by connections along the corridor from Addis Ababa to Djibouti, above all by cities connected by more than one mode: Addis Ababa-Djibouti and Dire Dawa-Djibouti by all three modes, and Djibouti-Nazret, Dire Dawa-Ali Sabieh, Nazret-Ali Sabieh, and Addis Ababa-Ali Sabieh by both train and road. Importantly, however, this 'international' connectivity builds on national connectivity projects, most notably the national railway system in Ethiopia (consisting of three lines, with further expansions being planned) and the Addis Ababa–Adama Expressway. This toll road is the first six-lane highway in Ethiopia, constructed to abate the heavy traffic between its two endpoints and to reduce the time required to reach Adama from Addis Ababa by more than 50% to 45 minutes. This is a relevant observation from a policy perspective as it shows that national and international connectivity improvements can be complementary (see section 5).

Overall, international connections reveal stronger east-west corridors than south-north corridors in the HoA, which can in large part be explained by the importance of access to the coast and more specifically the ports. This is further corroborated by the Addis Ababa-Djibouti corridor via Dire Dawa also being extended further east to northern Somalia via air transport connections such as Addis Ababa-Hargeisa and moderate yet viable connections between Dire Dawa and Jijiga in Ethiopia on the one hand and Hargeisa and Berbera in Somalia on the other hand (see Figure 5). The exception to this pattern is Nairobi-Addis Ababa. This connection is ranked 3rd for international connections and 17th in the HoA at large. In addition to the all-tarmac road connecting both cities via Moyale (further discussed below), where recently also a One-Stop Border Post was inaugurated to further facilitate connectivity across the border, the connection is also defined by sizable air transport connections.

Table 5: Strongest international inter-city connections in the HoA

City a	Country city a	City b	Country city b	$Road_{a-b}$	Air_{a-b}	$Train_{a-b}$	$Connectivity_{a-b}$
Djibouti	Djibouti	Dire Dawa	Ethiopia	0,157	0,313	0,692	0,387
Djibouti	Djibouti	Addis Ababa	Ethiopia	0,124	0,467	0,552	0,381
Addis Ababa	Ethiopia	Nairobi	Kenya	0,123	0,713	0,000	0,279
Ali Sabieh	Djibouti	Dire Dawa	Ethiopia	0,136	0,000	0,692	0,276
Addis Ababa	Ethiopia	Mogadishu	Somalia	0,106	0,627	0,000	0,244
Addis Ababa	Ethiopia	Hargeisa	Somalia	0,133	0,593	0,000	0,242
Djibouti	Djibouti	Nazret	Ethiopia	0,102	0,000	0,552	0,218
Ali Sabieh	Djibouti	Addis Ababa	Ethiopia	0,095	0,000	0,552	0,216
Nairobi	Kenya	Mogadishu	Somalia	0,120	0,514	0,000	0,211
Ali Sabieh	Djibouti	Nazret	Ethiopia	0,078	0,000	0,552	0,210

4.2 City centrality in the HoA

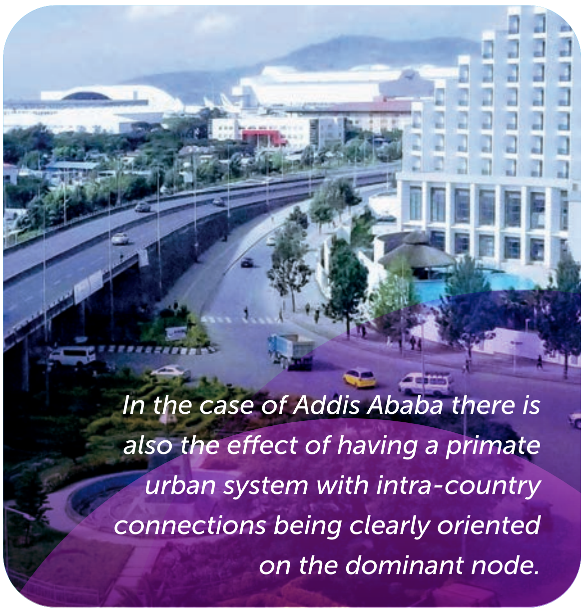
Table 6 gives an overview of the 92 HoA cities' centrality measures, with cities rank-ordered based on their average position in the DC, BC, and EC rankings.

The DC ranking above all foregrounds the region's main economic centers, with Addis Ababa and Nairobi being much more connected than the other cities in the HoA. This reflects both the size of their national economies and the diverse ways in which both cities are connected with a large number of cities. Furthermore, in the case of Addis Ababa there is also the effect of having a primate urban system with intra-country connections being clearly oriented on the dominant node. In contrast, in Kenya, there is more of a dual-primate system with Mombasa as a second important node. The importance of capital cities is also shown from Djibouti (3rd), Mogadishu (29th) and Asmara (46th) being by far the most connected cities in their own country. The remainder of the top of the DC ranking is confined to cities along multimodal major transport corridors, such as Dire Dawa, Nazret, and Debre Zeit in Ethiopia and Athi River and Ndenderu in Kenya.

At the bottom of the ranking, there are above all Somalian cities, which reflects a combination of the lack of non-road based transport infrastructure, average or sometimes even poor road infrastructure, and large distances between the different cities. An obvious example is Beledweyne, located in central Somalia. Although a fairly 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 furthermore 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 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 viable connections into Ethiopia, and only fairly low-speed road connections with Mendefera, Keren, and Asmara in Eritrea.

More generally, weak DC connectivities are associated with cities that are peripheral 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 commercial airport, are not located along major road corridors, often lack suitable inter-city road infrastructure at large, and are located fairly far away from other cities. Even though these cities often function as trading centers for their respective regions, their very modest connectivities reflect and reproduce patterns of peripheralization. The culmination of these patterns can be found in border cities, most prominently in the Kenyan-Ethiopian-Somalian border regions: Dolo (Ethiopia/Somalia), Mandera (Kenya/Ethiopia/Somalia), and Moyale (Kenya/Ethiopia) are among the weakest connected nodes, even if in the case of the latter city there being ongoing efforts to better connect the city as part of the Addis Ababa-Nairobi link.



In the case of Addis Ababa there is also the effect of having a primate urban system with intra-country connections being clearly oriented on the dominant node.

Table 6: DC, BC, and EC centrality for 92 cities in the HoA

City	Country	DC	DC rank	BC	BC rank	EC	EC rank	Average rank
Addis Ababa	Ethiopia	1,0000	1	0,8050	1	1,0000	1	1,00
Nairobi	Kenya	0,5533	2	0,3376	2	0,4431	5	3,00
Djibouti	Djibouti	0,2554	7	0,0689	7	0,4550	4	5,50
Dire Dawa	Ethiopia	0,2749	5	0,0215	15	0,5546	2	6,00
Nazret	Ethiopia	0,3962	3	0,0227	14	0,5486	3	6,25
Mombasa	Kenya	0,2843	4	0,0435	9	0,3337	6	6,50
Awasa	Ethiopia	0,2529	8	0,0938	4	0,3242	7	7,00
Muqdisho	Somalia	0,1484	29	0,1459	3	0,2306	15	13,25
Ali Sabieh	Djibouti	0,1522	26	0,0191	19	0,3198	8	17,50
Jima	Ethiopia	0,1518	27	0,0413	12	0,2038	21	18,75
Debre Zeyit	Ethiopia	0,2638	6	0,0000	28	0,2985	9	19,00
Hargeysa	Somalia	0,1253	34	0,0757	6	0,1887	24	19,25
Mojo	Ethiopia	0,2244	11	0,0000	28	0,2733	10	20,75
Shashemene	Ethiopia	0,2403	9	0,0000	28	0,2433	11	21,00
Jijiga	Ethiopia	0,1047	41	0,0215	16	0,2102	18	21,25
Arsi Negele	Ethiopia	0,2317	10	0,0002	23	0,2367	13	21,50
Sululta	Ethiopia	0,1695	19	0,0000	28	0,2269	16	21,50
Dese	Ethiopia	0,1148	39	0,0432	10	0,1853	26	22,25
Kisumu	Kenya	0,1627	24	0,0625	8	0,1268	39	22,50
Mek'i	Ethiopia	0,2217	12	0,0000	28	0,2408	12	22,75
Dukem	Ethiopia	0,1818	15	0,0000	28	0,2338	14	23,00
Bahir Dar	Ethiopia	0,1022	42	0,0000	28	0,2144	17	23,75
Genet	Ethiopia	0,1667	20	0,0000	28	0,2088	19	24,25
Athi River	Kenya	0,1652	22	0,0000	28	0,1585	32	25,00
K'olito	Ethiopia	0,2031	13	0,0005	21	0,1973	23	27,00
Ruiru	Kenya	0,1515	28	0,0000	28	0,1324	38	27,50
Ziway	Ethiopia	0,1934	14	0,0000	28	0,2062	20	28,00
Asela	Ethiopia	0,1791	16	0,0000	28	0,2019	22	28,00
Robe	Ethiopia	0,1205	38	0,0203	18	0,1674	29	29,00
Eldoret	Kenya	0,1549	25	0,0000	28	0,1170	42	29,00
Giyon	Ethiopia	0,1712	18	0,0000	28	0,1780	27	29,25

City	Country	DC	DC rank	BC	BC rank	EC	EC rank	Average rank
Butajira	Ethiopia	0,1763	17	0,0000	28	0,1858	25	29,50
Hagere Hiywet	Ethiopia	0,1665	21	0,0000	28	0,1771	28	29,50
Asmera	Eritrea	0,0856	46	0,0858	5	0,0964	47	30,50
Gonder	Ethiopia	0,0599	53	0,0000	28	0,1574	33	31,25
Mekele	Ethiopia	0,0584	54	0,0000	28	0,1526	35	32,25
Ndenderu	Kenya	0,1301	33	0,0000	28	0,0951	48	33,50
Debre Birhan	Ethiopia	0,1439	31	0,0000	28	0,1655	31	33,75
Ukunda	Kenya	0,0916	45	0,0000	28	0,1154	44	34,75
Hosaina	Ethiopia	0,1635	23	0,0000	28	0,1657	30	35,00
Arba Minch	Ethiopia	0,0810	49	0,0000	28	0,1373	37	35,25
Welkite	Ethiopia	0,1470	30	0,0000	28	0,1564	34	37,00
Tita	Ethiopia	0,0993	43	0,0000	28	0,1028	46	37,25
Thika	Kenya	0,1227	36	0,0000	28	0,0763	52	38,25
Kitale	Kenya	0,0832	47	0,0000	28	0,0651	53	38,50
Garoowe	Somalia	0,0435	63	0,0393	13	0,0789	51	38,75
Sodo	Ethiopia	0,1334	32	0,0000	28	0,1373	36	39,75
Asosa	Ethiopia	0,0341	71	0,0000	28	0,1161	43	40,50
Dila	Ethiopia	0,1101	40	0,0000	28	0,1249	40	41,25
Baco	Ethiopia	0,1241	35	0,0000	28	0,1196	41	41,25
Harer	Ethiopia	0,0635	52	0,0000	28	0,1032	45	41,75
Nakuru	Kenya	0,1206	37	0,0000	28	0,0565	55	43,25
Gaalkacyo	Somalia	0,0347	70	0,0000	28	0,0804	50	44,25
Nekemte	Ethiopia	0,0978	44	0,0002	24	0,0882	49	45,25
Utange	Kenya	0,0531	59	0,0000	28	0,0479	57	45,50
Naivasha	Kenya	0,0818	48	0,0000	28	0,0454	58	46,50
Nyeri	Kenya	0,0685	50	0,0000	28	0,0382	62	49,50
Agaro	Ethiopia	0,0533	58	0,0000	28	0,0435	59	50,00
Boosaaso	Somalia	0,0359	69	0,0022	20	0,0241	73	51,25
Burco	Somalia	0,0562	56	0,0213	17	0,0405	61	52,50
Kebri Dehar	Ethiopia	0,0388	66	0,0000	28	0,0305	68	52,75
Kisii	Kenya	0,0666	51	0,0000	28	0,0314	66	53,50

City	Country	DC	DC rank	BC	BC rank	EC	EC rank	Average rank
Arta	Djibouti	0,0275	77	0,0000	28	0,0351	64	54,00
Kilifi	Kenya	0,0379	67	0,0000	28	0,0314	67	54,00
Weldiya	Ethiopia	0,0465	61	0,0000	28	0,0505	56	55,00
Bungoma	Kenya	0,0567	55	0,0000	28	0,0250	72	55,25
Ginir	Ethiopia	0,0458	62	0,0000	28	0,0637	54	55,50
Bedele	Ethiopia	0,0543	57	0,0000	28	0,0406	60	55,50
Meru	Kenya	0,0426	64	0,0000	28	0,0259	71	57,75
Dikhil	Djibouti	0,0284	75	0,0000	28	0,0377	63	58,25
Busia	Kenya	0,0513	60	0,0000	28	0,0232	74	58,25
Metu	Ethiopia	0,0419	65	0,0000	28	0,0323	65	59,50
Garissa	Kenya	0,0374	68	0,0000	28	0,0300	69	59,50
Merca	Somalia	0,0216	82	0,0000	28	0,0101	78	62,00
Keren	Eritrea	0,0298	74	0,0000	28	0,0047	85	63,00
Tepi	Ethiopia	0,0322	73	0,0000	28	0,0291	70	63,25
Laascaanood	Somalia	0,0340	72	0,0005	22	0,0084	80	63,25
Mendefera	Eritrea	0,0246	80	0,0000	28	0,0052	84	63,50
Baydhabo	Somalia	0,0254	79	0,0002	25	0,0075	82	64,00
Dolo	Ethiopia	0,0283	76	0,0428	11	0,0045	86	65,00
Berbera	Somalia	0,0214	83	0,0000	28	0,0113	76	65,25
Massawa	Eritrea	0,0207	84	0,0000	28	0,0038	87	67,75
Kismaayo	Somalia	0,0149	85	0,0000	28	0,0135	75	68,00
Tadjoura	Djibouti	0,0060	90	0,0000	28	0,0106	77	69,00
Qardho	Somalia	0,0270	78	0,0002	26	0,0034	88	69,25
Beledweyne	Somalia	0,0060	89	0,0000	28	0,0054	83	70,75
Assab	Eritrea	0,0051	91	0,0000	28	0,0090	79	71,00
Mandera	Kenya	0,0240	81	0,0002	27	0,0004	91	72,25
Moyale	Kenya	0,0046	92	0,0000	28	0,0080	81	72,50
Barentu	Eritrea	0,0114	88	0,0000	28	0,0021	89	73,25
Ceerigaabo	Somalia	0,0148	86	0,0000	28	0,0011	90	73,75
El Wak	Kenya	0,0120	87	0,0000	28	0,0001	92	74,75

Note:

- Cities are rank-ordered based on their average position in the three rankings.

The BC ranking adds a different dimension to the discussion of centrality. It replicates and even accentuates the dominance of Addis Ababa and Nairobi, which clearly act as the HoA's regional gateways in addition to their broader international gateway function. Beyond this leading pair of cities, however, patterns are very different compared to the DC ranking. Mogadishu (3rd) and Asmara (5th) 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 4th) also emerges as a major gateway, as 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.

Only 27 cities have a non-zero value for BC, whose ranking is – as expected – much more skewed than the DC ranking: the majority of cities do not perform a gateway function for other cities. Nonetheless, a number of HoA cities that are (relatively) weakly connected make an appearance here. Examples are Hargeisa (Somalia, 6th), Kisumu (Kenya, 8th), and Robe (Ethiopia, 18th). What sets these cities apart from, say, Bahir Dar and Gondar in Ethiopia is that they can also be 'used' by other cities in their region to connect to the network.

Finally, there is the eigenvalue centrality ranking (EC). This perspective on the importance of being connected to well-connected nodes above all foregrounds the privileged position of cities along major transport corridors: this allows them to connect with cities with sizable air transport connectivity and/or with a large number of other cities located along these corridors. Obvious examples are cities with strong connections with Addis Ababa: Dire Dawa (2nd) and Nazret (3rd) by rail and road, and Debre Zeit (9th) and Dukem (14th) along the expressway to Adama. A similar interpretation holds for Ali Sabieh (8th) in Djibouti. The EC perspective also emphasizes the strategic importance of having a major direct air service to the HoA's major gateways, as this brings other key centers in closer reach. Kenya's somewhat more polycentric system works to its disadvantage here, as the variegated nature of connections does not allow for consistent fast connectivity to major HoA centers. However, at the same time and from another perspective, Ethiopian cities' clear dependence on Addis Ababa raises questions from a network resilience point of view: Addis Ababa acting as the de facto provider of HoA connectivity for the majority of Ethiopian cities implies that a 'failure' of this node (e.g. the airport being down) threatens to cut their connectivity.

The importance of air connectivity, no matter how small, shows from the example of Kismayo (Somalia, 76th). Although it is one of the least connected cities in the HoA, its small direct links with Mogadishu allows for potentially faster access to the other major cities in the HoA than 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 when compared with other peripheral cities such as El Wak, Ceerigaabo, Mandera, and Dolo.

4.3 Regional integration in the HoA

An implicit but nonetheless evident finding running through the above discussion is that even though there are some notable international connections in the HoA – above all air transport connections between the capital cities and the rail corridor between Addis Ababa and Djibouti – the vast majority of connections are within-country linkages. Although connectivity is almost always to a degree co-defined by distance decay in general and national functional spaces in particular, the lack of regional integration in the HoA is manifest, especially compared with other regional spaces across the world. For example, unlike transnational infrastructure connectivity in Europe and across Asia (especially in the context of the Belt and Road Initiative), HoA connectivity can still first and foremost be described as a collection of 'national spaces'. This is clearly shown by the average value of intra-country connectivities (0.02905) being more than 15 times larger than the average value of inter-country connectivities (0.00182). In short, the lack of regional economic integration results in, and also results from, the lack of connectivity between the HoA's major cities.

Table 7 presents the average values of inter-city connectivities aggregated at the level of country-pairs. The five largest values are uniformly for the intra-country connections, with Djibouti – unsurprisingly given its small size compared with other countries – featuring the strongest connections. The connections between the Djibouti-Ethiopia-Somalia triad form a second block, with most connections emanating from the relatively strong connections by road and train in the Djibouti-Dire Dawa-Hargeisa triangle, arguably the only part of the HoA where multiple cities are reasonably well connected across borders. 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 very minor connections between Djibouti and Eritrea, Ethiopia and Eritrea, Kenya and Somalia, and Somalia and Ethiopia. The latter is to some degree an artifact of both countries' size with no major connections expected between Ethiopia's north and Kenya's south. However, the low average connectivities between cities in the region's two largest economies require attention. 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. And finally, there are no connections between Djibouti and Kenya, Eritrea and Kenya, and Somalia and Eritrea.

Table 7: Average value of inter-city connections for country-pairs in the HoA

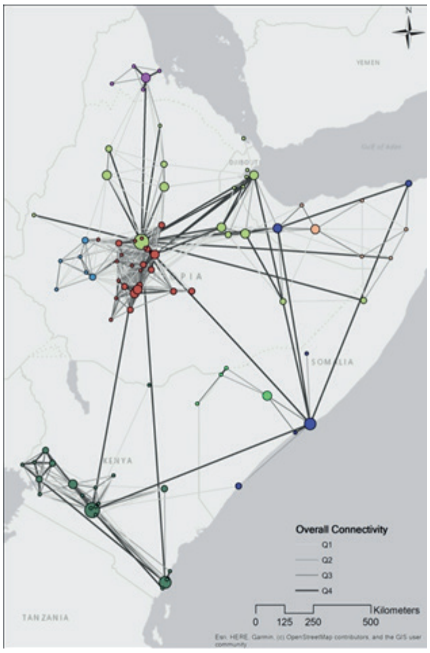
Rank	Country 1	Country 2	Average Connectivity
1	Djibouti	Djibouti	0,06996
2	Kenya	Kenya	0,04714
3	Eritrea	Eritrea	0,03256
4	Ethiopia	Ethiopia	0,02622
5	Somalia	Somalia	0,01557
6	Djibouti	Ethiopia	0,00890
7	Djibouti	Somalia	0,00338
8	Ethiopia	Somalia	0,00219
9	Eritrea	Ethiopia	0,00134
10	Djibouti	Eritrea	0,00130
11	Kenya	Somalia	0,00088
12	Ethiopia	Kenya	0,00060
13	Djibouti	Kenya	0
13	Eritrea	Kenya	0
13	Eritrea	Somalia	0

The strong imprint of national spaces is also visible in the network communities shown in Figure 6, in which national borders are very visible, above all in Kenya, Eritrea, and Ethiopia. The latter is itself subdivided into four communities, which can roughly be described as north (Addis Ababa with air connections to cities in the north), west (regional road connections), south (regional road connections and connectivity among corridors to Addis Ababa), and east (train and road corridors in the direction of Dire Dawa). However, community detection also picks up the relevance of international connections which, no matter how small, change the picture. For example, the Ethiopian community in the east actually takes a northeastern bent to include the Djibouti centers and the Eritrean port city of Assab, while continuing to the east Jijiga is more strongly connected with cities in northern Somalia. The latter community reflects the de facto 'split' within Somalia, with Somaliland cities and cities in the southern part of Somalia forming cohesive subnetworks.

Some of the strongest international road connections, for example Addis Ababa-Burco and Nazret-Hargeisa, are along the west-east corridor running from central Ethiopia to Djibouti and northern Somalia. A key node here is Awash: here the A1 highway branches off to Djibouti in a northeasternly direction, while there is also connectivity further to the east in the direction of Dire Dawa and onwards to Jijiga and Hargeisa. The latter connections bring Dire Dawa and Jijiga in the realm of the Djibouti and Somaliland communities, respectively. The rail link between Dire Dawa and Djibouti on the one hand, and the envisaged rail link between Awash and Weldiya on the other hand, (will) further strengthen the road-based connectivity in this part of the HoA. 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. And finally, 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 further strength this potential.

Notably present/absent international connections of cities located near the border are identified in Table 8 and Figure 7. Figure 7 shows the strength of international road connections of city-pairs that made the threshold as per Figure 4. Table 8, in turn, shows the 10 least proximate international city-pairs that nonetheless have a meaningful road connection on the one hand, and the 10 most proximate international city-pairs that have no meaningful road connection on the other hand. The former set of connections allow assessing how and where there is already some potential for regional integration via inter-city connectivity. The latter connections allow identifying the most striking missing links that call for obvious policy attention.

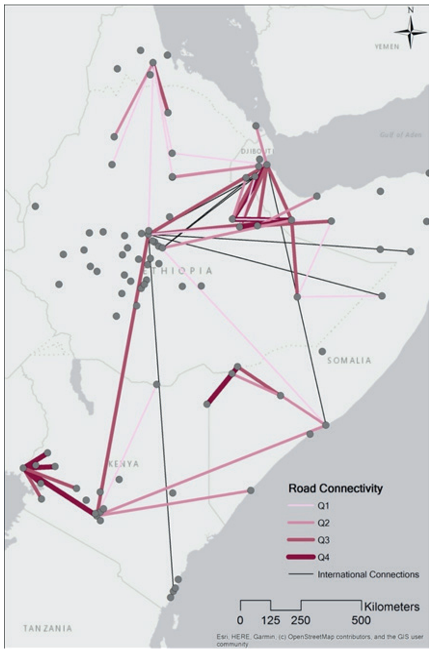
Figure 6: Network communities in the HoA



Note:

- Node size varies with cities' total population.
- To be able to differentiate between the relative strength of the different connections, we divided the distribution into quartiles.

Figure 7: International inter-city road connections



Note:

- To be able to differentiate between the relative strength of the different connections, we divided the distribution into quartiles.
- Direct air or train connections are shown for reference.

The focus on road connections bring the dominance of the west-to-east orientation even clearer to the fore. Some of the strongest connections, for example Addis Ababa-Burco and Nazret-Hargeisa, connect central Ethiopia to Djibouti and northern Somalia. A key node here is Awash: here the A1 highway branches off to Djibouti in a northeasterly direction, while there is also connectivity further to the east in the direction of Dire Dawa and onwards to Jijiga and Hargeisa. The latter connections bring Dire Dawa and Jijiga in the realm of the Djibouti and Somaliland communities, respectively. The rail link between Dire Dawa and Djibouti on the one hand and the envisaged rail link between Awash and Weldiya on the other hand, (will) further strengthen the road-based connectivity in this part of the HoA. 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.

Although there are fewer international road connections run 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 further strengthen this potential. The strongest north-south connection is the earlier-mentioned connection between Addis Ababa and Nairobi, reflecting the size of both cities and – by the standards of the region – 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 time at the Moyale border-crossing, our data suggests a possible average speed of up to 1.3km/min. In addition, the opening up of a border facility at Moyale easing the flow of goods and people allows capitalizing on this potential: when experimenting with our data, it became apparent that if border crossings times were set to an – often more realistic – two-hour penalty, then international road connections all but disappeared. This shows that upgrades to road connectivity also require upgrades to border services and facilities, which in the case of the Nairobi-Addis Ababa link has been well understood.

At the same time, and from another perspective, it can be said that the road connectivity between both cities still falls short of their economic potential (and that of southern Ethiopia and northern Kenya more generally). For example, the anticipated 22h25 needed to cover the 1556kms between both cities 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 roughly similar distance, e.g. Paris-Warsaw (15h47), Vancouver-San Francisco (14h43), and Bangkok-Kuala Lumpur (17h59). Although the road upgrades and the efforts at the Moyale border crossing serve does serve as an exemplar, it is clear that there is scope further improvements, especially when considering that Moyale is the only authorized/formal gateway between both countries.

Table 8: **Notable presences/absences among international inter-city connections without air/ train component**

Longest distances where a viable road connection is present				
Addis Ababa	Ethiopia	Burco	Somalia	748
Nairobi	Kenya	Kismaayo	Somalia	644
Asmara	Eritrea	Bahir Dar	Ethiopia	448
Nazret	Ethiopia	Hargeisa	Somalia	538
Asmara	Eritrea	Tita	Ethiopia	472
Dire Dawa	Ethiopia	Burco	Somalia	403
Djibouti	Djibouti	Weldiya	Ethiopia	386
Kebri Dehar	Ethiopia	Burco	Somalia	338
Djibouti	Djibouti	Tita	Ethiopia	386
Asmara	Eritrea	Gonder	Ethiopia	341

Shortest distances where a viable road connection is absent				
Tadjoura	Djibouti	Assab	Eritrea	206
Arta	Djibouti	Dire Dawa	Ethiopia	294
Mendefera	Eritrea	Mekele	Ethiopia	308
Arta	Djibouti	Assab	Eritrea	315
Dikhil	Djibouti	Harer	Ethiopia	328
Ali sabieh	Djibouti	Assab	Eritrea	333
Arta	Djibouti	Harer	Ethiopia	347
Dikhil	Djibouti	Assab	Eritrea	355
Ali sabieh	Djibouti	Jijiga	Ethiopia	382
Tadjoura	Djibouti	Dire Dawa	Ethiopia	393

The weakest connections – defined here as the shortest distances without a viable road link – are found in the borderlands between Ethiopia, Djibouti, and Eritrea. This is to some degree a physical-geographical artifact with the Gulf of Tadjourah acting as a barrier. However, above all it shows that the connectivity coming from Ethiopia into 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, and this in spite of its potential importance as a port. In order 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 both road and rail connections that are furthermore connected to wider networks that either exist or in the making.

SECTION 5

Policy perspectives of connectivity for the HoA

Investments in trade and transport corridors seek to reduce the friction associated with often vast distances between economic centers and trade gateways. The increased inter-city connectivity that ensues from these investments facilitates the mobility of goods, people, capital and ideas, further unleashing the economic potential contained within the cities and the regions which they are at the centre of. In the HoA, the following corridors have been put forward as potential levers for regional integration:

A Kismayo, Lamu and Mogadishu Corridor: Ethiopia (Negele – Filtu – Siftu) to Somalia (Mogadishu – Baidoa – Dolo) and (Kismayo – El Wak – Mandera) to Kenya (Lamu – Isiolo – Wajir – Mandera);

B Assab and Djibouti Corridor: Ethiopia (Adama – Awash) and (Manda – Bure) to Eritrea (Bure – Assab) to Djibouti (Galafi – Dikhil – Djibouti Port) and (Balho – Tajoura Port);

C Berbera and Djibouti Corridor: Ethiopia (Harar – Jigjiga) and (Diredawa – Meiso) to Somalia (Togochale – Berbera) to Djibouti (Loyada – Borema – Hargessa);

D Mogadishu, Berbera and Bossasso Corridor: Ethiopia (Ginir – Gode) to Somalia (Mogadishu – Baladwen – Ferfer) and (Turdibi – Galdogobi – Galkayo – Bossasso) to Ethiopia (Kebridhar – Warder – Turdibi) and (Ferfer – Warder – Aware – Hargessa) to Djibouti (Djibouti Port – Holl Holl – Dewele).

These and other policy ideas surrounding infrastructure coordination, policy and procedure harmonization, railway connections, dry ports, road upgrades, joint border posts, airports, free trade zones and pipelines that are currently being implemented or envisaged by regional organisations and national governments in the HoA are promising, but must be grounded in the development of coherent and comprehensive connectivity corridors. Rather than a range of blanket-type strategies, this calls for diverse, integrated and complementary approaches tailored to the needs of different stakeholders and cities. Drawing on our analyses, we propose four key elements as potential complements to already-envisaged policies.

(a) National level level connectivity is much more evident in the HoA than in other parts of the world. There are a number of reasons for this, ranging from the development context to evolving geopolitical and geoeconomic tensions. As a result, connectivity provision often follows a logic that promotes national cohesion rather than regional integration. This is very clear in Ethiopia, where connectivity provision has above all been oriented on centrally located 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 presently striking. In addition to the regional plans being drawn up, there are however already a number of encouraging exceptions to this general pattern. Prime examples of these exceptions include the rail and road connectivity on the west-east axis 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. Other obvious instances where national policies would have 'regional spillovers' are connections between landlocked Ethiopia and a range of Read Sea ports, the Liboi-Kismayo Road facilitating connectivity between Nairobi and southern Somalia, and aligning upgrades to Eritrean infrastructure with connections into northern Ethiopia. A first element of policies is that existing initiatives, often having both national and regional effects, can be strengthened and serve as exemplars for consolidating regional integration through inter-city connectivity provision.

(b) Thick borders result in distinct lagging borderlands. The debilitating effect of national borders on intra-regional connectivity in the HoA is nowhere more manifest than in border cities, which tend to suffer from national development policies often being characterized as 'borderland blindness' (cf. Trémolières and Walther, 2019). Border cities find themselves at the very bottom of the degree centrality and eigenvalue centrality rankings because they tend to 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, but there is a further debilitating effect here because border cities stand to benefit the most from connectivity investments aimed at promoting regional integration, because they are often veritable trans-border agglomerations with a high potential for social and commercial exchanges. For example, Dolo is an Ethiopian market market town at the Somali border that has been extended with refugee camps that were created around 2010. According to UNHCR registration data, 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 do not preclude that, according to a recent report by the University of Oxford's Refugee Studies Centre, 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 300km in every direction.

The case of Moyale again serves to illustrate the potential of an enhanced focus on borderlands. There have been joint infrastructure initiatives over the past decade to develop it into a commonly administrated cross-border East African trade hub that establishes the surrounding region on both sides of the border as a strong economic zone. Concrete initiatives have been the development of a highway corridor linking Kenya and Ethiopia and a one-stop border post to streamline and curtail illicit trade. Importantly, this has not only facilitated connections between Nairobi and Addis Ababa, but also reduced Moyale's peripheral position in both Kenya and Ethiopia. At the same time, the vast distances and the border post often being little used reveal the intricacies of such development policies. Thus, a second element of policies is that these should build on, facilitate, regulate, and further develop actually existing exchanges across borders.

(c) There is a need for complementary investments in connectivity at the national, regional, and global gateway levels. However, investments in cross-border connectivity – whether in general or focused on border cities – should not be detached from investments and policy visions at other scales. This is very clear in discussions surrounding the opening up of new ports such as Assab in southern Eritrea as gateways for the HoA at large, 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


Concrete initiatives have been the development of a highway corridor linking Kenya and Ethiopia and a one-stop border post to streamline and curtail illicit trade.

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. 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 modalities, roads, and relays are essential to any expansion of trade. In the HoA, this crucially requires coordination between national, bilateral, region-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, (3) integration with plans for expanding the Ethiopian railway system. A third element of policies, therefore, is the need for coordination across different scales of action, especially in the case of connectivity to port cities, an element that was somewhat snowed under in this study given the focus on air transport. Further research could explore the potential of multi-modal and topological resilience of port access from a network perspective, also opening up the discussion beyond the HoA given that Port Sudan provides an alternative for landlocked Ethiopia.

(d) There is a need for policies tailored at enhancing connectivity within metropolitan regions. The emphasis on connectivity provision for border cities and port cities should not preclude the need for improving connectivity around the capital cities' metropolitan regions, even though these presently emerge as the connectivity hotspots within the HoA. This additional focus is justified because the virtuous effects of air transport connectivity and rail corridors between major cities tend to spill over to proximate cities. The eigenvalue centrality ranking reveals these regional spillover effects: cities such as Athi River in Kenya, Ali Sabieh in Djibouti, and Debre Zeit in Ethiopia 'profit' from their connectivity with Nairobi, Djibouti, and Addis Ababa, respectively. More generally, when multiple cities form a dense regional network, a larger number of producers and consumers can be connected. The infrastructure built by public authorities in these urban regions is also more profitable than elsewhere because it is shared. This paper has implicitly charted the emergence of metropolitan regions centered on Nairobi and Addis Ababa, with – albeit to a lesser degree – broadly similar patterns of urbanization emerging around Asmara and Djibouti. It has been argued that cities in these polycentric metropolitan regions enjoy the benefits of centralized connectivity provision while suffering less from the drawbacks of overcrowding. A fourth element of connectivity policies, therefore, is the need for tailored policies for emerging metropolitan regions, where tackling congestion and thinking outside the box of road/rail can strengthen connectivity can unleash network spillover effects. In the case of Addis Ababa, this could focus on an extension or further development of the light rail system now running from the city centre to industrial areas in the south of the city into a fully-fledged metropolitan network.

References

Brooks, D. H. and Hummels, D. 2009. Infrastructure's Role in Lowering Asia' s Trade Costs: Building for Trade, Cheltenham, UK, Edward Elgar Publishing.

Calderon, C. A. and Serven, L. 2004. The effects of infrastructure development on growth and income distribution. World Bank Policy Research Working Paper No. WPS 3400. Washington, DC: World Bank.

Camagni, R., Capello, R. and Caragliu, A. 2013. One or infinite optimal city sizes? In search of an equilibrium size for cities. The Annals of Regional Science, 51, 309-341.

Camagni, R. P. 1993. From city hierarchy to city network: reflections about an emerging paradigm. Structure and change in the space economy. Heidelberg: Springer Verlag.

Capello, R. 1996. Industrial enterprises and economic space: the network paradigm. European Planning Studies, 4, 485-198.

Capello, R. 2000. The city network paradigm: measuring urban network externalities. Urban Studies, 37, 1925-1945.

Chen, C. L. and Vickerman, R. 2017. Can transport infrastructure change regions' economic fortunes? Some evidence from Europe and China. Regional Studies, 51, 144-160.

Derudder, B., Liux, Kunaka, C. 2018. Connectivity along overland corridors of the Belt and Road Initiative. World Bank Policy Research Working Paper No. 130490. Washington, DC: World Bank.

Derudder, B. 2020. Network analysis of 'urban systems': potential, challenges, and pitfalls. Journal of Economic and Social Geography, https://doi.org/10.1111/tesg.12392.

Glaeser, E. L., Ponzetto, G. A. and Zou, Y. 2016. Urban networks: Connecting markets, people, and ideas. Papers in Regional Science, 95, 17-59.

Haggett, P. and Chorley, R. 1969. Network Analysis in Geography, London, Butler and Tanner.

Katz, M. L. and Shapiro, C. 1985. Network externalities, competition, and compatibility. The American economic review, 75, 424-440.

Kunaka, C. and Carruthers, R. 2014. Trade and Transport Corridor Management Toolkit, Washington, DC, World Bank.

Limao, N. and Venables, A. J. 20 Trémolières, M and Walther, O.J. 201901. Infrastructure, geographical disadvantage, transport costs, and trade. The World Bank Economic Review, 15, 451-479.

Meeteren, M., Neal, Z. and Derudder, B. 2016. Disentangling agglomeration and network externalities: A conceptual typology. Papers in Regional Science, 95, 61-81.

Neal, Z. 2012. The connected city. New York and London, Routledge.

Nystuen, J. D. and Dacey, M. F. 1961. A graph theory interpretation of nodal regions. Papers of the Regional Science, 7, 29-42.

Trémolières, M. and Walther, O.J. 2019. Accessibility and infrastructure in border cities. OECD West African Working Papers N. 23, Paris, OECD.

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

Footnotes

[i] See Trade and Transport Corridor Management Toolkit, World Bank.

[ii] Although this background 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.

[iii] For example, as shown in a recent World Bank blogpost by Dijkstra et al. (2020), the cost of service provision tends to increase from cities to towns and semi-dense areas and then to rural areas as defined by the DoU. As a result, access to services is highest in cities and lowest in rural areas, so that 'cities' as conceived in the DoU are de facto economic centers.

[iv] There are, broadly speaking, two main road network datasets: OpenStreetMap and Google Maps. OpenStreetMap (OSM) is currently the largest openly licensed collection of geospatial data. It is now regularly used in research projects as an alternative to/or integrated with authoritative data. Brovelli and Zamboni (2018) point out that OSM maps can often considered to be a valid base map for direct and derived usage. Moreover, they show that OSM maps could be used for integrating with authoritative maps where they are not complete and a rigorous quality certification in terms of metric precision is not always required. However, one of the possible drawbacks of this dataset in the HoA context is that, being a collaborative product created mainly by citizens without formal qualifications, its quality is spatially heterogenous. Because the data collection depends on volunteers, data quality and consistency can be irregular. In places where a community of local mappers make a concerted effort to improve the database, base maps are detailed and accurate. However, it is unclear whether this is the case for parts of the HoA, and this is why we settled for Google Maps (GM). GM uses a variety of sources to collect data including satellite imagery, geological surveys, municipality maps, third-party surveys and street view cars (5M+ miles covered). These disparate data sources are combined using proprietary technology to create the maps. One of the advantages of using Google Maps is that it continually refreshes based on anonymously tracked user data, traffic sensors, and satellite data to make sure it is displaying the most accurate traffic conditions possible as it assesses driving time.

[v] In practice, there are number of ferries running between Djibouti and Tadjourah that boost the strength of this particular city-dyad.

[vi] There used to be Massawa-Asmara link that has been partly rebuilt, but the functional parts are above all used for charter trains for tourists rather than regular, scheduled services between both cities.

THE WORLD BANK
IBRD • IDA | WORLD BANK GROUP