

Infrastructure and Structural Change in Africa

Matías Herrera Dappe and Mathilde Lebrand

Abstract

Past investments in electricity, Internet, and road infrastructure, in isolation and bundled, have contributed to structural transformation and economic development in Africa. Using new data on the expansion of the road, electricity, and Internet networks over the past two decades, the paper shows that having access to both paved roads and electricity has led to a significant reallocation of labor from agricultural to both manufacturing and services. Adding access to fast Internet has had a major impact on structural change, with an even larger impact on reallocating labor away from agriculture. The paper then uses a spatial general-equilibrium model to quantify the impacts of future regional transport investments, bundled with electricity and Internet investments, on economic development in countries in the Horn of Africa and Lake Chad region.

JEL classification: F15, J24, L16, O13, O14, O18, Q41, R1

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1. Introduction

Infrastructure investments can support economic development through both capital accumulation and structural transformation. The former assumes that the accumulation of skills, capital, and broad institutional capabilities is needed to generate sustained productivity growth. The latter assumes a dual economy in which long-run growth is driven by the flow of resources to modern economic activities, which operate at higher levels of productivity. Structural change—the movement of workers from lower- to higher-productivity employment—is essential to growth in low-income countries where there is a large share of employment in low-productivity sectors. Trade, and economic integration more broadly, can be an important source of productivity gains and structural transformation.

Transport and Internet infrastructure alleviate distance and information frictions, decreasing the economic distance of people and firms and fostering the economic specialization within and across neighboring countries. Electricity and Internet allow for the use of more modern productive technologies and complement transport infrastructure by boosting firm productivity. The literature has studied specific infrastructure expansions as potential drivers of development, but little work has been done on the associated structural change or on whether the combinations of different infrastructure create a big push

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development impact. This paper investigates how investments in electricity, Internet, and transport infrastructure, and their interactions affect economic development through productivity gains and structural change for countries in Africa. The paper focuses on two regions of interest to study the drivers of structural change: the Horn of Africa and the Lake Chad region.

This paper first uses reduced-form analysis to understand the relationship between past investments in electricity, Internet, and road infrastructure and sectoral employment in countries of the Horn of Africa and Lake Chad region. The objective of this part is to motivate the rest of the work. Geo-identified data on the infrastructure expansion of roads, electricity, and access to fast Internet over time and across space were collected and linked with information on local economic activity based on household-survey data. Three instrumental variables are developed to overcome the endogeneity concerns for electricity, road, and Internet investments. Straight transmission lines connecting the main cities with newly opened hydropower dams and power plants are used for electrification, the construction of a hypothetical least-cost network expansion using a minimum spanning tree algorithm is used for road expansion, and lightning intensity is used for Internet.

Reduced-form results capture the localized effects in the areas that have been affected, but do not capture the general-equilibrium effects and spillovers due to the network nature of infrastructure such as roads and the presence of regional trade. The paper then uses a spatial general-equilibrium model, based on [Moneke \(2020\)](#), to assess the aggregate and spatial impacts of planned infrastructure investments in the region. The general-equilibrium model captures the spillover effects that a localized investment has on the rest of the country and all the countries in the two regions, and generates welfare estimates.

The model focuses on a few mechanisms through which roads, electricity, and Internet can affect structural change. Good roads reduce trade costs and increase market access, while access to electricity and Internet increase productivity. While electricity has an obvious impact on firm productivity through the use of better technologies, the impacts of access to fast Internet are multiple. Better Internet can have a direct impact on firms' use of better technologies and access to markets but can also facilitate firm-worker matching, firm-customers matching, and human capital accumulation inside the firm. The model in this paper, however, assumes a similar channel for access to fast Internet and electricity for simplicity. More research needs to be done to understand how to model the different impacts that access to Internet and electricity have on firms. The counterfactuals rely on productivity estimates from the literature. However, the expected impacts from the counterfactuals depend on two heterogeneous aspects: first the shocks differ across subnational areas, and second the areas differ according to their productivities, geographic location, and initial endowments. In the model, the resulting sectoral labor demand changes result from two effects: a comparative advantage effect, from domestic and regional trade competition in a Ricardian inter-regional trade model, and a revenue effect from lower trade cost and higher productivity gains.

The paper finds different effects of bundled and isolated infrastructure investments on sectoral employment. Based on data for several African countries, the analysis finds that access to paved roads but no good electricity coverage does not significantly impact structural change, and reduces manufacturing employment shares if anything. Having access to both paved roads and electricity leads to a significant reallocation of resources from the agricultural sector to both manufacturing and services. While the analysis covers six countries, the estimated impacts are in line with those estimated by [Moneke \(2020\)](#) for Ethiopia. Lastly, adding access to fast Internet has a major impact on structural change, with an even larger impact on reallocating labor away from agriculture toward manufacturing and services.

Simulations using a spatial general-equilibrium model show that bundled infrastructure investments cause different patterns of structural transformation and welfare gains from isolated infrastructure investments. Simulations quantify the structural change and welfare gains from future regional corridors, when built in isolation and when bundled with additional investments in electrification and access to fast Internet. At the local level, the analysis shows that planned regional road investments in the Horn of Africa and the Lake Chad region will have a larger impact on structural change when complemented with better

access to electricity and fast Internet. Simulations show that better regional market access could bring large welfare gains, especially when complemented with smaller border delays. Lower transport costs reduce spatial frictions and increase specialization within and across countries. Better regional integration is predicted to yield the largest reduction in agriculture employment in Kenya, where several regions have a comparative advantage in manufacturing, and the smallest in Ethiopia and Somalia. However, Somalia enjoys the largest welfare gains from lower border and transport frictions because of access to cheaper goods and a wider variety of goods.

Several papers have examined the impact of infrastructure investment on sectoral employment at the micro-level. [Gertler et al. \(2016\)](#) find that lower transport costs empower women by opening up labor-market opportunities and increasing their employment in the non-agricultural sector. [Asher and Novosad \(2020\)](#) find that a new rural road in India causes a 9-percentage-point decline in the share of agricultural workers and an equivalent rise in wage labor. This paper adds to this literature by looking at the district-level impact of infrastructure on sectoral employment for many countries in Africa.

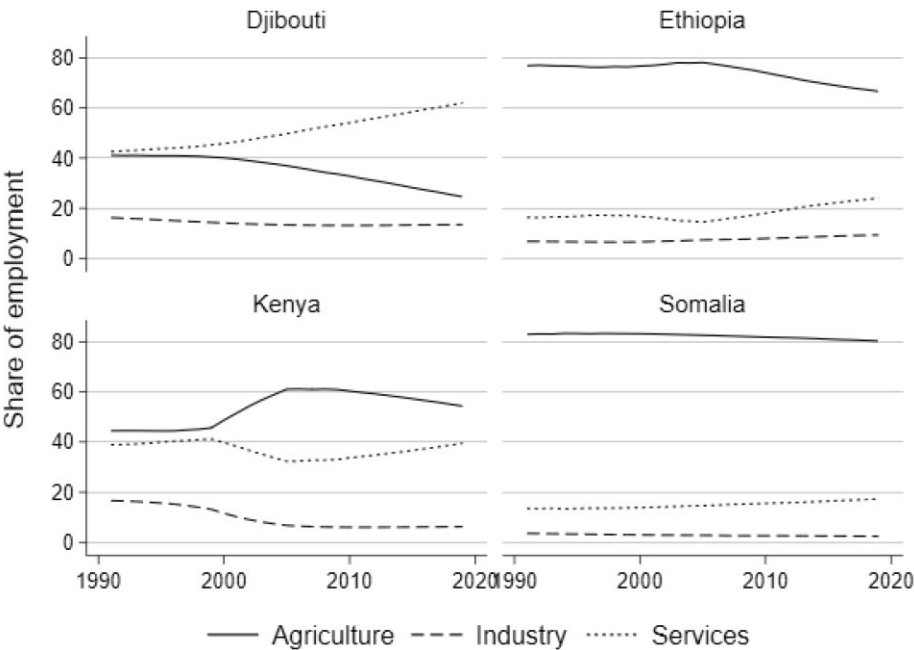
Most of the literature studying the impact of infrastructure considers the gains from energy, transport, and digital investments in isolation or bundled in a unique infrastructure index. The aggregate impact of infrastructure has been measured through the elasticity of output with respect to a synthetic infrastructure index, which includes transport along with electricity and telecommunications ([Calderon, Moral-Benito, and Serven 2015](#)). This approach does not allow us to isolate the complementarities of different infrastructure. [Moneke \(2020\)](#) shows that transport and electricity investments are complementary and that they increased economic development in Ethiopia. He finds starkly different patterns of bundled infrastructure investments on sectoral employment compared with only road investments. Roads alone cause service-sector employment to increase at the expense of agriculture and, especially, manufacturing employment. In contrast, the interaction of roads and electrification causes a strong reversal in manufacturing employment. This paper adds to the strand of literature initiated by [Moneke \(2020\)](#) by studying the impact of Internet, electricity, and transport, and their complementarities, and extends the validity of his results by including several countries in Africa, as well as the additional impact of fast Internet access.

There is a growing body of literature using quantitative spatial general-equilibrium models to assess the impacts of infrastructure. [Allen and Arkolakis \(2014\)](#) develop a general-equilibrium framework to determine the spatial distribution of economic activity and use it to assess the impact of the US interstate highway system. [Michaels, Rauch, and Redding \(2011\)](#) look at changes in sectoral employment as an outcome that captures the underlying infrastructure-induced effects.¹ [Bustos, Caprettini, and Ponticelli \(2016\)](#) and [Fried and Lagakos \(2020\)](#) study the general-equilibrium implications of electrification via its effect on productivity. Several papers provide policy counterfactuals for future road and border infrastructure improvements for the Belt and Road Initiative ([Lall and Lebrand 2020](#); [Bird et al. 2020](#)), in Bangladesh ([Herrera Dappe and Lebrand 2019](#)), and between Bangladesh and India ([Herrera Dappe, Lebrand, and Patten 2021](#)). The paper contributes to this strand of the literature by assessing the spatial general-equilibrium impacts of several planned transport investments and trade facilitation measures in neighboring countries that are at different stages of development.

The paper is structured as follows. A background section provides an overview of the Horn of Africa and Lake Chad region. A data section includes details of the data used in the analysis. The next section presents the empirical strategy and results. The final section develops a spatial general-equilibrium model to produce counterfactuals for deeper domestic and regional integration.

1 See [Redding and Turner \(2015\)](#) and [Redding \(2016\)](#) for surveys of the literature on the impacts of transport infrastructure and the growing use of models to quantify these impacts.

Figure 1. Employment per Sector in Horn of Africa Countries, 1990–2020.



Source: World Bank data indicators.

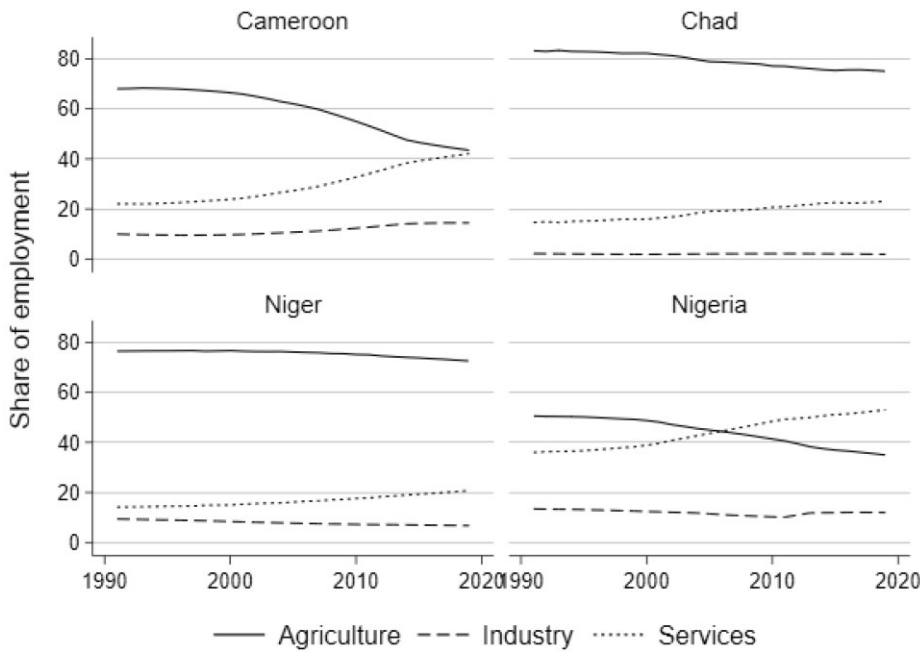
Note: Each line reports the share of employment for agriculture, industry, and services in total employment.

2. Background

Horn of Africa. Economic growth in the Horn had been relatively strong before the COVID-19 pandemic, but countries in the region still lag behind other African countries and the pace of structural change has been slower than expected. At approximately \$1,000, the per capita income in the Horn of Africa remains well below the Sub-Saharan African average of about \$1,500. Structural transformation out of agriculture is at different stages across countries. Employment in non-agricultural sectors accounts for about 45 percent of total employment in Kenya, 35 percent in Ethiopia, and less than 20 percent in Somalia (fig. 1). The share of employment in agriculture in Djibouti, Ethiopia, and Kenya has been declining since the mid-2000s. In contrast, it has stagnated at high levels in Somalia.

The extent and quality of infrastructure networks varies across the Horn. The region is a collection of national spaces rather than an integrated economic space. Ethiopia undertook significant investments in roads and electricity over the last decade, which lead to expansion in the road and electricity network. The all-weather road network expanded roughly fourfold between the late 1990s and the late 2010s, and the electricity network doubled, from 95 to 191 major electric substations (Moneke 2020). But the country still lags behind Kenya in access to electricity and all-weather roads in rural areas. Only 55 percent of the population had access to electricity in Ethiopia in 2018, a smaller share than in Djibouti (60 percent) or Kenya (75 percent). Access to all-weather roads and electricity are both lagging in remote areas in Kenya, including the northern border areas. Somalia has limited infrastructure coverage. Only 32 percent of its rural population lived within 2 kilometers of an all-weather road in 2016, and only 35 percent of the total population had access to electricity in 2018. The Internet backbone fiber network and mobile coverage increased significantly in recent decades. Access in the region is still low, however, at 2 percent of the population in Somalia, 19 percent in Ethiopia, 22 percent in Kenya, and 56 percent in Djibouti in 2019.

Figure 2. Employment per Sector in Cameroon, Chad, Niger, and Nigeria, 1990–2020.



Source: World Bank data indicators.

Note: Each line reports the share of employment for agriculture, industry, and services in total employment.

Lake Chad Region. Similar to the Horn of Africa, structural transformation out of agriculture is at different stages across countries for the Lake Chad region. Employment in non-agricultural sectors in 2019 accounted for about 65 percent of total employment in Nigeria, 56 percent in Cameroon, and around 25 percent for Chad and Niger (fig. 2). The share of employment in agriculture in Cameroon and Nigeria has been significantly declining since 2000. In contrast, it has stagnated at high levels in Chad and Niger.

Access to infrastructure, including paved roads, electricity, and broadband Internet, remains problematic for Nigeria, Cameroon, and Chad. Nigeria has the highest level of access to paved roads and electricity with more than 90 percent of the districts and population having access to a paved road in 2018. While access to paved roads has barely changed since 2000, access to electricity has increased significantly from 35 percent to 56 percent of districts having access to electricity between 2003 and 2018.² In 2018, 23 percent of districts were connected to the fiber network as defined by the presence of a node from the fiber backbone.

In Cameroon, 60 percent of the communes and 80 percent of the population are connected to a paved road. The coverage falls when restricting access to fair or good paved roads. Access to electricity and Internet covers a small number of communes but the most populated ones. Between 2003 and 2018, the number of communes covered has more than doubled, but the percentage of population covered has increased by only 17 percent. The additional communes that have received electricity coverage over the last two decades are much less populated.

Access to infrastructure in Chad is very limited compared to other countries. In 2014, only 2.6 percent of communes had access to a paved road, 3 percent to broadband Internet, and 6 percent to the electricity

2 A district is classified as electrified when at least 50 percent of its population has access to electricity as monitored with nighttime lights.

Table 1. Summary of Infrastructure Data

Infrastructure	Country	Year	Source
Roads	Ethiopia	1996, 2006, 2016	Ethiopian Roads Authority (ERA)
	Kenya	2003, 2009, 2016–2018	Kenya Road Board
	Nigeria	1991	Jedwab and Storeygard (2020)
		2009	Foster and Briceno-Garmendia (2010)
		Around 2013	Ali et al. (2015)
	Cameroon	2009	Foster and Briceno-Garmendia (2010)
		2018	Road authorities
	Chad	2009	Foster and Briceno-Garmendia (2010)
Electricity	All	Vary across countries	Road authorities
			Nighttime lights/population raster
Electricity grid	All	Around 2006	Foster and Briceno-Garmendia (2010)
	All	Most recent	gridfinder.org and Arderne et al. (2020)
Internet (fiber backbone)	All	2009–2019	Africa Bandwidth Maps 2009–2019

Source: Authors’ collection of data.
Note: The table summarizes the geographic and time coverage of the data used in the paper as well as the source of the data for each country.

network. The covered communes are the most populated ones, as 20 percent of the population has access to electricity and 15 percent of the population has access to broadband Internet. Improvements to the paved road network since 2014 show that the percentage of communes and population having access to a paved road has largely increased.

The Lake Chad region, which includes the Far North region in Cameroon, the regions of Kanem, Lac, Hadjer-Lamis, and Chari-Baguirmi in Chad, and the regions of Borno, Yobe, and Adamawa in Nigeria, is characterized by very limited access to infrastructure. Only 30 percent of the 80 locations—districts in Nigeria, communes in Cameroon and Chad—have a paved road, 16 percent have access to electricity, and 10 percent have access to Internet. Only half of the population has access to a paved road, 20 percent to electricity, and 30 percent to broadband Internet.

3. Data

This paper uses household survey data that have been georeferenced, new spatial infrastructure data, and district characteristics.

Infrastructure. New information on road network expansions, access to the electricity network, and access to Internet fiber backbone was collected from various sources (table 1).

Official geospatial maps of road expansion and previously harmonized collections of road networks (Foster and Briceno-Garmendia 2010; Jedwab and Storeygard 2020) were gathered. The quality of the network and associated features and the frequency of updates vary across countries. Road networks from Foster and Briceno-Garmendia (2010), which relied on surveys and governments sources, were used as baseline for years between 2000 and 2007. Additional government surveys provided more recent road networks for Cameroon and Chad. The road network for Nigeria comes from Ali et al. (2015) and includes road survey data from the Nigeria Federal Roads Maintenance Agency (FERMA) and the World Bank Fadama project.³ For Ethiopia and Kenya, rich panels of data on road network expansions complemented by details on road conditions (a panel of GIS data and maps for 1996, 2006, and 2016 for Ethiopia

3 To “ground truth” and take advantage of first-hand local knowledge, Ali et al. (2015) detail how government offices across Nigeria were surveyed about the conditions of specific road segments near them.

and 2003, 2009, and 2018 for Kenya that rely at least partially on actual road surveys) were used.^{4,5} Two methods were used to map access to the electricity network: nighttime lights and maps of power transmission grids. Nighttime light data are available for most years and locations but convey imperfect information on electrification. Historical maps of electricity grids are more difficult to find and use in a consistent way. Satellite images of annualized nighttime lights (VIIRS for 2016, DMSP for 1992–2013) and population rasters from World Pop were used to calculate the percentage of the population that was electrified (lived in settlements that produce some light at night). The results for two metrics were compared: a dummy that is equal to 1 if at least 50 percent of the population has access to electricity and the share of the electrified population per district. Such methods have been used before to estimate electricity access in remote areas and guide grid extension programs.⁶ This method assumes that locations that emit light at night are in settlements that have electricity access and that their electricity is most likely supplied from an electrical grid. It assumes that small off-grid systems do not emit enough light to be captured by satellites but that larger isolated power networks do. The numbers obtained were cross-checked with country estimates of electrified population from the World Bank.⁷

Information on transmission grids based on past efforts to harmonize infrastructure data from primary sources and recent mapping strategies to infer the electricity grids based on satellite data were collected. For past data, the electricity grids from the Africa Infrastructure Country Diagnostic (AICD), which collected primary data covering network service infrastructure from 2001 to 2006 in 24 African countries (Foster and Briceno-Garmendia 2010), were used. These data were complemented with data from a recent effort by the World Bank, Facebook, the KTH Royal Institute of Technology, World Resources Institute, and the University of Massachusetts Amherst that relied on remote sensing, machine learning, and big data to map connected populations and the systems that support them. This group created an algorithm for estimating the location of medium-voltage infrastructure based on nighttime lights and the location of roads assuming that medium-voltage lines are more likely to follow (or be followed by) main roads.⁸

Fast Internet infrastructure was proxied by access to the fiber broadband backbone network. Data for all Africa for 2009–2020 were obtained from Africa Bandwidth Maps, which provides the exact location of fiber nodes along the backbone network. A proxy for access to the fiber backbone that is equal to 1 if there is a node of the backbone in the location of interest was constructed. Each node has a year attribute, which allows us to build a panel for access to the backbone. It was assumed that access before 2008 was null everywhere, an assumption that is supported by World Bank data on access to Internet, which reports that fewer than 4 percent of individuals in Sub-Saharan African countries (including high-income countries) had access to Internet in 2008. The figures were confirmed by cross-checking them against World Bank indicators reporting the percentage of the population using Internet.⁹

Isolated versus Bundled Investments. Given the small number of districts with electricity but no paved road, it was assumed that there is no district with electricity but no paved road.

4 Data for Ethiopia come from Croke and Duhaut (2020). Related papers studying the expansion of the Ethiopian road network are Adamopoulos (2019), Gebresilas (2019), and Kebede (2020), all of which focus on the feeder roads from the 2016 Ethiopian Roads Authority survey. The study by Moneke (2020), which focuses on all-weather (gravel, asphalt, or bitumen surface) roads, is closer to this study.

5 Figures S2.5 and S2.6 in the online supplementary appendix show the extensions of the paved road network for Kenya and Ethiopia.

6 An example of mapping rural electrification based on nighttime lights can be found at <http://india.nightlights.io/>.

7 The World Bank reports access to electricity (percentage of population) for most countries for a long period at <https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS>.

8 More details can be found on the blog <https://blogs.worldbank.org/energy/using-night-lights-map-electrical-grid-infrastructure> and in the paper Arderne et al. (2020).

9 The World Bank reports access to Internet (percentage of population) for most countries for a long time period. See <https://databank.worldbank.org/source/world-development-indicators/Series/IT.NET.USER.ZS>

Employment. Structural transformation is interpreted as changes in sectoral employment, in line with the literature (Herrendorf, Rogerson, and Valentinyi 2014). Sectoral employment shares were derived from Demographic and Health Surveys (DHS), which produce harmonized survey data with GPS coordinates for most surveys and are available for several rounds per country. The DHS is a repeated cross-section of enumeration areas (EA), with approximately 20–30 households enumerated per EA. Four rounds of survey data are covered in Ethiopia (2000, 2005, 2011, 2016) and four in Kenya (1991, 2003, 2009, 2018). For Ethiopia, the DHS rounds included 12,751 individuals in 2000, 14,052 in 2005, 21,080 in 2011, and 19,157 in 2016, from approximately 650 EAs, which differ per round. Five rounds of survey data are covered in Nigeria (1990, 2003, 2008, 2013, 2018), four in Cameroon (1991, 2004, 2011, 2018), and one in Chad (2014). Djibouti, Niger, and Somalia did not conduct DHS for the period of interest.

DHS data provided the occupation of the individuals as well as a proxy for their location. The DHS are cross-sectional surveys that have been conducted in the majority of developing countries since the 1980s. They are representative at the national and highest subnational level. Information on demographic characteristics and socioeconomic status (for example, age, gender, education, occupation) of all household members is collected in interviews. Respondents' answers to questions about their current occupation were grouped into three sectors, agriculture, manufacturing and services, using a similar methodology to (Moneke 2020). Most DHS surveys include nine categories of workers, that are consistent across time. There are potential issues with such a classification. It introduces a bias for two particular categories: manual workers are currently allocated to the manufacturing sector while they could be working in the agricultural sector, and professional workers could be in both manufacturing and services. For the latest, it would not affect the impact on relocating resources away from the agricultural sector. The misclassification could however affect the effect of which sector would benefit from this reallocation. Duernecker et al. (2022) provide a thorough discussion of whether measuring structural transformation using occupations or using sectoral employment matters. They show that both methods can be used to offer insights. They classify occupations as goods occupations, which produce, process, or transform tangible value added, and service occupations, which produce, process, or transform intangible value added. In that sense, professionals and managers can be classified as services occupations.

In order to create a panel, individual responses were aggregated to the EA and then an unbalanced panel was generated across districts. While the DHS focus on women, they also provide occupation information for men in the household. Women are overrepresented, but working only with information on occupation allows us to include a significant number of men in the surveys. One limitation of this analysis is that DHS surveys are not representative at the district level. Using the first administrative level would only allow for an empirical analysis with too few observations. Another limitation is on the spatial identification of households. Each household belongs to an EA whose DHS-provided GPS coordinates are not perfectly reliable due to anonymity concerns.¹⁰ Aggregating at the district level, however, softens this concern.

District Characteristics. Additional data were used to control for district heterogeneity: population data from the Global Human Settlement Layer (GHSL),¹¹ land categories from the European Space Agency land cover (see (Defourny 2017)), distance to the coast from the Global Self-Consistent, Hierarchical, High-Resolution Geography Database (GSHHG),¹² distance to the border,¹³ access to a city larger than

10 DHS coordinates of rural (urban) EAs are randomly displaced within a 0–10 kilometer (0–5 kilometer) radius.
 11 GHSL: Population count from the Global Human Settlement Layer. Based on population data from Gridded Population of the World v4.10 polygons, distributed across cells using the Global Human Settlement Layer global layer. Source data provided in 9-arc-second (250-meter) grid cells.
 12 Distance to the coast (on land only) is measured in meters. It is derived using World Vector Shorelines (Wessel and Smith 1996).
 13 Distance to country borders is measured in meters. It is derived using the database of Global Administrative Areas (GADM) 2.8 ADM0 (Country) boundaries.

50,000 inhabitants from the Malaria Atlas Project,¹⁴ temperature from Land Processes Distributed Active Archive Center,¹⁵ and elevation from CGIAR-CSI.¹⁶

4. Empirical Strategy and Results

There are several identification challenges. Infrastructure investments are likely endogenously allocated with respect to the outcomes of interest. Given the high cost of infrastructure investments, conscious allocation decisions are to be expected (by, for example, targeting high-growth-potential locations or politically demanded locations). Measurement error in the right-hand-side variables may lead to attenuation bias (from, for example, inaccurate information on the timing of infrastructure expansion or imprecise historic road and grid maps). Measurement errors, which are expected to be large in this case, lead to OLS estimates that are biased toward zero.

To deal with the potential endogeneity in the placement of roads and electricity, an instrumental variables identification strategy is used, as in [Moneke \(2020\)](#), together with a difference-in-difference approach for the arrival of fast Internet, as in [Hjort and Poulsen \(2019\)](#). Then an instrument for Internet access based on [Manacorda and Tesei \(2020\)](#) is added.

Instrumental variables for electrification, access to a paved road, and access to fast Internet are used. Regarding electrification, the instrumental variable relies on four assumptions. First, electricity generation must be connected to demand, which comes mostly from the main cities. Second, the sources of energy generation that are identified are the main sources of electricity generation. Third, the locations of the supply sources are exogenous to economic geographic development. Finally, the locations between the generation sources and the main demand centers are more likely to be electrified.

Two sources of energy generation that can be used for the IV strategy were identified: dams for hydroelectricity, and wind farms. The main sources of energy supply are hydropower in Cameroon and Ethiopia, hydropower and wind in Kenya, and gas in Nigeria. Similar to [Moneke \(2020\)](#), an IV that yields a hypothetical electrification status based on a location's proximity to a straight-line corridor from electricity generators to the main cities was developed. The locations of the electricity generators were identified using two databases, one on the opening year of dams and another on the locations of power plants (Platts database). For Cameroon and Ethiopia, a database including all dams in Africa, their locations, and their years of opening was used. For Kenya and Nigeria, the global power plant database, which includes the capacity and year of commissioning of all power plants by type of energy (hydro, wind, gas, and geothermal) was used. From the year of the dam opening or power plant commissioning onward, all districts lying along the straight lines connecting the dams or power plants to the main demand centers are considered as having access to electricity.

The main sources of demand in each country were identified. In Ethiopia it is Addis Ababa and in Kenya, Nairobi and Mombasa.¹⁷ For Nigeria and Cameroon, the main sources of demand vary across time. All dams in Cameroon had already been opened at the beginning of period of analysis, therefore a panel IV is created by varying the sources of demand rather than the sources of supply. For Cameroon, a threshold of 500,000 inhabitants was used for a city to be included as a main source of demand. In 1990, only Douala and Yaounde are included. In 2000, Garoua in the north is included, and in 2015, Maroua is also included. For Nigeria, all cities with more than a million inhabitants were used. For each year, all

14 Data incorporate data from Open Street Map (OSM) and the Google roads database. See [Weiss et al. \(2018\)](#).

15 Yearly daytime land-surface temperatures are from [Wan and Hook \(2015\)](#).

16 Global elevations (in meters) are from Shuttle Radar Topography Mission (SRTM) dataset (v4.1) at 500-meter resolution. See [Jarvis et al. \(2008\)](#).

17 Map S1.1 in the supplementary online appendix shows the results of the construction of the electrification instrument around 1990 and 2015.

districts lying along the straight lines connecting the dams to the cities were considered hypothetically electrified.

The IV satisfies the main assumptions of an IV strategy. The choice of location of hydro and wind generators can be assumed to be driven by geographic and climatic characteristics of the locations and not by economic activity in the area. The timing of opening can be considered exogenous, as years of delay are common for such projects. The random assignment assumption of the IV would imply that a district's inclusion along a straight-line corridor is spatially and temporally as good as random assignment.

To instrument for the timing of a district's paved road connection, the optimal network to connect all cities with more than 50,000 inhabitants in a least-cost fashion is found by using common minimum spanning tree algorithms, such as Kruskal's and Boruvka's algorithms (Faber 2014; Banerjee et al. 2020). The list of cities with more than 50,000 inhabitants varies over time because of changes in population, which creates a panel of roads for each country. Map S1.2 in the supplementary online appendix shows the results of the construction of the road instrument around 1990 and 2015 for the Horn of Africa countries.

An instrument for access to Internet using the incidence of lightning strikes is created following Manacorda and Tesei (2020), Guriev and Treisman (2019), and Do, Gomez Parra, and Rijkers (2021). The instrumental variable measures the incidence of lightning strikes per geographical unit proxied by flash density, that is, the average number of ground flashes per square kilometer per year between 1995 and 2012. Following Manacorda and Tesei (2020), the lightning intensity is interacted with a yearly dummy to create a time-varying instrument. The rationale behind the first stage is that lightning strikes increase the cost of using information-technology-related infrastructure because they create voltage surges and dips. The exclusion restriction, therefore, postulates that lightning strikes affect structural change only through their impact on Internet access. However, as discussed by Manacorda and Tesei (2020), lightning strikes might be correlated with other climatic or topographical characteristics like rainfall, which in turn might affect economic development. A vector of controls at the provincial and year levels and a series of district controls are added.

First, a two-stage least squares (2SLS) regression including only road and electricity IVs, province and year fixed effects, and district-level controls is run:¹⁸

$$\begin{aligned} \text{IV infrastructure} = & \alpha + \beta^R (\text{RoadIV}_{i,t} = 1 \ \& \ \text{ElectricityIV}_{i,t} = 0) \\ & + \beta^{RE} (\text{RoadIV}_{i,t} = 1 \ \& \ \text{ElectricityIV}_{i,t} = 1) \\ & + \beta^I \text{Internet}_{i,t} + \text{Controls}_i + \text{FE} + \epsilon_{i,t}, \end{aligned} \quad (1)$$

with IV infrastructure the instrument for either paved roads only or electricity and paved road.

The second stage equation is given by

$$\begin{aligned} \text{Sector}_{i,t} = & \alpha + \gamma^{R,2SLS} (\text{RoadIV}_{i,t} = 1 \ \& \ \widehat{\text{ElectricityIV}}_{i,t} = 0) \\ & + \gamma^{RE,2SLS} (\text{RoadIV}_{i,t} = 1 \ \& \ \widehat{\text{ElectricityIV}}_{i,t} = 1) \\ & + \gamma^I \text{Internet}_{i,t} + \text{Controls}_{i,t} + \text{FE} + \epsilon_{i,t}, \end{aligned} \quad (2)$$

with $\text{Sector}_{i,t}$ being the share of employment in agriculture, manufacturing, or services in district i in year t .

Table 2 reports the results for the 2SLS method for all countries from the Horn of Africa and the Lake Chad region. First-stage results (available on demand) show a strong and statistically significant relationship between the instrumental variables and the endogenous regressors. For multiple endogenous regressors, Sanderson and Windmeijer (2016) provide the most relevant weak in-

18 District-level control variables are interacted with the country dummy such that the effects of distances can only be compared within countries.

Table 2. Second Stage of Two-Stage Least Squares Regression Results, without an IV for Internet

	Agriculture	Manufacturing	Services
Only paved road	0.232 (0.442)	−0.372 (0.347)	0.139 (0.319)
Paved road and electricity	−0.264** (0.0928)	0.134+ (0.0766)	0.130+ (0.0672)
Internet	−0.0341* (0.0146)	−0.00570 (0.0122)	0.0398** (0.0104)
N. of observations	4,685	4,685	4,685

Source: Authors' analysis.

Note: Districts are defined by the administrative levels 2 or 3 depending on availability per country. Using all countries from the Horn of Africa and Lake Chad samples yields a total of 4,685 district-years. Individual answers to survey question about current occupation are grouped into sectors. "Sector variable" denotes the share of district-year survey sample of working-age population that respond to work in an occupation grouped in that sector. Road only indicator and road + electricity indicator denote predicted values from the two first-stage specifications. Region-year trends are added. Time-invariant controls and initial values of time-varying controls at the district levels are added. Standard errors in parentheses. All standard errors clustered at the district level. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

strument F -test statistic. Both Sanderson–Windmeijer and classic F -test statistics indicate non-weak instruments

Access to paved roads only has a non-significant impact on sectoral employment, while the combination of roads and electricity leads to a 26 percentage-point decrease in the share of agricultural employment and a 13 percentage-point increase in the shares of manufacturing and services employment (table 2). The coefficient for roads is negative in the regression of manufacturing, suggesting that roads may have a negative impact on manufacturing employment when not complemented by electricity. Access to Internet has a smaller but significant impact on sectoral employment. Access to fast Internet leads to a decrease of 3 percentage points in the share of agricultural employment and an increase in the share of services employment. The results are in line with Moneke (2020) who does a similar exercise for Ethiopia using more survey rounds. He finds a strong reduction in the share of manufacturing employment as a result of improved road access. He also documents a large increase in the share of manufacturing employment when complementing roads with electricity. The results in this paper, therefore, generalize the empirical study of Moneke (2020) when including more African countries.

Then the Internet IV, $\text{InternetIV}_{i,t} = \text{lightning}_{i,t} \times t$, is included and the following specification is estimated:

$$\begin{aligned} \text{IV infrastructure} = & \alpha + \beta^R (\text{RoadIV}_{i,t} = 1 \ \& \ \text{ElectricityIV}_{i,t} = 0) \\ & + \beta^{RE} (\text{RoadIV}_{i,t} = 1 \ \& \ \text{ElectricityIV}_{i,t} = 1) \\ & + \beta^I Z_{i,t} + \beta^I \text{InternetIV}_{i,t} + \text{Controls}_i + \text{FE} + \epsilon_{i,t}, \end{aligned} \quad (3)$$

with IV infrastructure the instrument for paved roads only, electricity and paved road, or Internet.

The second stage equation is given by

$$\begin{aligned} \text{Sector}_{i,t} = & \alpha + \gamma^{R,2SLS} (\text{RoadIV}_{i,t} = 1 \ \& \ \widehat{\text{ElectricityIV}}_{i,t} = 0) \\ & + \gamma^{RE,2SLS} (\text{RoadIV}_{i,t} = 1 \ \& \ \widehat{\text{ElectricityIV}}_{i,t} = 1) \\ & + \gamma^I \widehat{\text{InternetIV}}_{i,t} + \text{Controls}_{i,t} + \text{FE} + \epsilon_{i,t}. \end{aligned} \quad (4)$$

Including the Internet IV in the regression leads to a large and significant coefficient for Internet. Access to fast Internet leads to a 40 percentage-point decrease in the share of agricultural employment, an 18

Table 3. Second Stage of Two-Stage Least Squares Regression Results, with an IV for Internet

	Agriculture	Manufacturing	Services
Only paved road	0.101 (0.531)	− 0.306 (0.273)	0.204 (0.342)
Paved road and electricity	0.0168 (0.184)	− 0.00808 (0.0913)	− 0.00871 (0.109)
Internet	− 0.402* (0.184)	0.180+ (0.108)	0.222+ (0.128)
N. of observations	4,685	4,685	4,685

Source: Authors’ analysis.
Note: Districts are defined by the administrative levels 2 or 3 depending on availability per country. Using all countries from the Horn of Africa and Lake Chad samples yields a total of 4,685 district-years. Individual answers to survey question about current occupation are grouped into sectors. “Sector variable” denotes the share of district-year survey sample of working-age population that respond to work in an occupation grouped in that sector. Road only indicator, road + electricity indicator, and the Internet indicator denote predicted values from the first-stage specifications. Region-year trends are added. Time-invariant controls and initial values of time-varying controls at the district levels are added. Standard errors in parentheses. All standard errors clustered at the district level. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

percentage-point increase in the share of manufacturing employment, and a 22 percentage-point increase in the share of services employment (table 3). The coefficients for access to electricity and paved roads become non-significant. However, the lightning intensity can also be used as an IV for the quality of the electricity network, and therefore it might be difficult to conclude whether it captures the impact of Internet alone or of both electricity and Internet. Including only a dummy for access to fast Internet, as done in the first regression and in Hjort and Poulsen (2019), leads to significant impacts from both electricity and Internet (table 3).

5. Model and Counterfactuals

This section presents the general-equilibrium model used to assess the welfare impacts of infrastructure investments, including the calibration of the model, and shows the results under several counterfactual scenarios. The model focuses on a few mechanisms through which roads, electricity, and Internet can affect structural change. Good roads reduce trade costs and increase market access, while access to electricity and Internet increase productivity. While electricity has an obvious impact on firm productivity through the use of better technologies, the impacts of access to fast Internet are multiple. Fast Internet can have a direct impact on firms’ use of better technologies and access to markets but can also facilitate firm–worker matching, firm–customers matching, and human capital accumulation inside the firm. The model, however, assumes a similar channel for access to fast Internet and electricity for simplicity.

5.1. The Model

The spatial general-equilibrium model is based on Moneke (2020). It is characterized by the following features. Locations differ in their productivity, geography, and trade links. Road investments are assumed to have general-equilibrium effects via changes in trade costs and the resulting reallocation of labor across space, as in Allen and Arkolakis (2014) and Redding (2016). Electrification investments are assumed to have general-equilibrium effects via productivity, similar to models of differential productivity shocks across space such as Bustos, Caprettini, and Ponticelli (2016). The economy is assumed to consist of multiple sectors of production, such that changes in sectoral employment across

locations (i.e., spatial structural transformation) capture an outcome of interest, as in Michaels, Rauch, and Redding (2011) and Eckert and Peters (2018). Compared to Moneke (2020), the model considers a geography that includes several countries that can trade with each other, with additional trade barriers applying for cross-border trade. Workers can move across locations within but not across countries.

5.1.1. Setup

The whole geography consists of many locations, $n \in N$, of varying land size (H_n) and endogenous population (L_n). Consumers value consumption of agriculture goods, C^T ; manufacturing goods, C^M ; services, C^S ; and land, b . Utility of a representative household in location n is assumed to follow an upper tier Cobb–Douglas functional form over goods and land consumption, scaled by a location-specific amenity shock v_n :

$$U_n = v_n C_n^\alpha h_n^{1-\alpha} \quad (5)$$

with $0 < \alpha < 1$. The goods consumption index is defined over consumption of each tradeable sector's composite good and services:

$$C_n = [\psi^T (C_n^T)^\rho + \psi^M (C_n^M)^\rho + \psi^S (C_n^S)^\rho]^\frac{1}{\rho}, \quad (6)$$

assuming consumption of sectoral composite goods to be complementary, that is, $0 < \kappa = \frac{1}{1-\rho} < 1$.

Consumers exhibit a love of variety for both tradeable sectors' goods, C^T and C^M , which is modeled in the standard CES fashion, where n denotes the consumer's location and i the producer's location, whereas j is a measure of varieties. Consumption of each tradeable sector's good is defined over a fixed continuum of varieties $j \in [0, 1]$:

$$C_n^T = \left[\sum_{i \in N} \int_0^1 (c_{ni}^T(j))^\nu dj \right]^{1/\nu}, \quad (7)$$

with ν an elasticity of substitution across varieties such that varieties within each sector are substitutes for each other: $\sigma = \frac{1}{1-\nu} > 1$. An equivalent formulation is used for C_n^M . The following equation provides the classic Dixit–Stiglitz price index over traditional sector goods:

$$P_n^T = \left[\sum_{i \in N} \int_0^1 (p_{ni}^T(j))^{1-\sigma} dj \right]^\frac{1}{1-\sigma}. \quad (8)$$

On the production side, there are two tradable sectors from which firms produce varieties that can be traded across many other locations. Production uses labor and land as inputs under constant returns to scale subject to stochastic location:

$$Y_n^i = z^i \left(\frac{L_n^i}{\mu^i} \right)^{\mu^i} \left(\frac{h_n^i}{1 - \mu^i} \right)^{1-\mu^i}, \quad i = T, M, \quad (9)$$

where $0 < \mu^i < 1$ and z^i denotes the sector-location-specific realization of productivity z for a variety in sector i and location n . Following Eaton and Kortum (2002), locations draw sector-specific idiosyncratic productivities for each variety j from a Fréchet distribution:

$$F_n^i(z^i) = e^{(-A_n^i z^i)^{-\theta}}, \quad i = T, M, \quad (10)$$

with A_n^i the average sectoral productivity in location n . The shape parameter, θ , determines the variability of productivity draws across varieties in a given location n .

Trade in both sectors' final goods is costly, and trade costs are assumed to follow an iceberg structure. Trade costs between locations n and m are denoted as d_{nm} , such that quantity $d_{nm} > 1$ has to be produced in m for one unit to arrive in n . We assume that trade costs are the same across sectors and are symmetric.

Given perfect competition in both production sectors, the price of a given i -sector variety equals marginal cost inclusive of trade costs:

$$p_{nm}^i = \frac{\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm}}{z_m^i}, \quad (11)$$

with ω_m the wage of a worker and r_m the price of land.

Each location n will buy a given variety from its minimum-cost supplier location m :

$$p_{nm}^i = \min\{p_m^i, m \in N\}. \quad (12)$$

The share of expenditure that the destination location n spends on agricultural sector (and equivalently manufacturing sector) goods produced in origin m is given by

$$\pi_{nm}^i = \frac{A_m^i (\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm})^{-\theta}}{\sum_{k \in N} A_k^i (\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta}}. \quad (13)$$

Production of non-tradeable services also uses labor and land as inputs, but output is a single homogeneous service. The model assumes agriculture to be the most and services the least land-intensive sector: $\mu^T < \mu^M < \mu^S$.

Within each location, the expenditure share on each tradeable sector's varieties and services depends on the relative (local) price of each sector's (composite) good:

$$\xi_n^K = \frac{(\psi^K)^\kappa (P_n^K)^{1-\kappa}}{(\psi^M)^\kappa (P_n^M)^{1-\kappa} + (\psi^T)^\kappa (P_n^T)^{1-\kappa} + (\psi^S)^\kappa (P_n^S)^{1-\kappa}}, \quad K \in \{T, M, S\}. \quad (14)$$

Given the properties of the Fréchet distribution of productivities, tradeable sectoral price indices can be further simplified:

$$P_n^i = \gamma \left[\sum_{k \in N} A_k^i (\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta} \right]^{-1/\theta} = \gamma (\Phi_n^T)^{-1/\theta}. \quad (15)$$

Conditions for land-market clearing, labor-market clearing, and labor mobility define the spatial equilibrium. For an equilibrium in the land market, total income from land must equal total expenditure on land, where the latter summarizes land expenditure by consumers, T -sector firms, M -sector firms, and S -sector firms. Similarly, labor-market clearing requires that total labor income earned in one location must equal total labor payments across sectors on goods purchased from that location everywhere. Finally, it is assumed that workers can freely move across locations within a country, but cannot move across countries. Therefore, free mobility of workers across locations within country implies that the wage earned by workers in a given location after correcting for land and goods prices, and a location's amenity value, must be equalized across locations of the same country. The welfare in each location of the same country c is given by

$$V_{n,c} = \bar{V}_c = \frac{\alpha^\alpha (1-\alpha)^{1-\alpha} v_{n,c} \omega_{n,c}}{[P_{n,c}]^{\alpha/(1-\kappa)} r_{n,c}^{1-\alpha}} \quad \forall n \in \text{country } c, \quad (16)$$

where $P_{n,c} = (\phi^M)^\kappa (P_{n,c}^M)^{1-\kappa} + (\phi^T)^\kappa (P_{n,c}^T)^{1-\kappa} + (\phi^S)^\kappa (P_{n,c}^S)^{1-\kappa}$.

Following the specification in Moneke (2020) and Michaels, Rauch, and Redding (2011), the district specific parameter $v_{n,c}$ is included in the wage so that the welfare can be interpreted as the real income in each location.

5.2. Calibration of the Model

The model is calibrated using some parameters from the literature and by recovering the key productivity parameters and wages to obtain an equilibrium for the current situation (see table 4 for the parameters

Table 4. Parameters for Structural Estimation

Parameter	Value	Source	Description
σ	4	Bernard, Eaton, and Jensen (2003)	Elasticity of substitution between varieties
$1 - \alpha$	0.25	Data for Ethiopia (HCES)	Expenditure share on land/housing
κ	0.5	Ngai and Pissarides (2007)	Elasticity of substitution across sectors
μ^M	0.82	Moneke (2020) for Ethiopia	Labor share in M-production
μ^T	0.78	Moneke (2020) for Ethiopia	Labor share in T-production
μ^S	0.84	Moneke (2020) for Ethiopia	Labor share in S-production
τ	0.3	Moneke (2020) for Ethiopia	Elasticity of trade cost with respect to distance
θ	4	Donaldson (2018)	Shape parameter of productivity distribution across varieties & locations

Source: Authors' collection of parameters.

Note: The table reports the parameters for the structural estimation and their sources. HCES denotes the Central Statistical Agency's Household Consumption and Expenditure Surveys.

used to calibrate the model partly taken from Moneke (2020) whose model is calibrated to Ethiopia). The productivity parameters are recovered using the labor-market clearing conditions, the land-market conditions, and the labor-mobility conditions. For each location, the model generates three equations for the three endogenous variables in each location—land-market clearing, labor-market clearing, and labor-mobility conditions—which allows us to solve for a general equilibrium of the model in terms of its core endogenous variables: wages, land rental rates, and population. Moneke (2020) shows the uniqueness of the equilibrium based on a similar work by Michaels, Rauch, and Redding (2011). The series of sectoral productivities $\{A_n^T, A_n^M, A_n^S\}_{n \in N}$ is obtained as the solution for which the current distribution of population, employment, and land is an equilibrium.

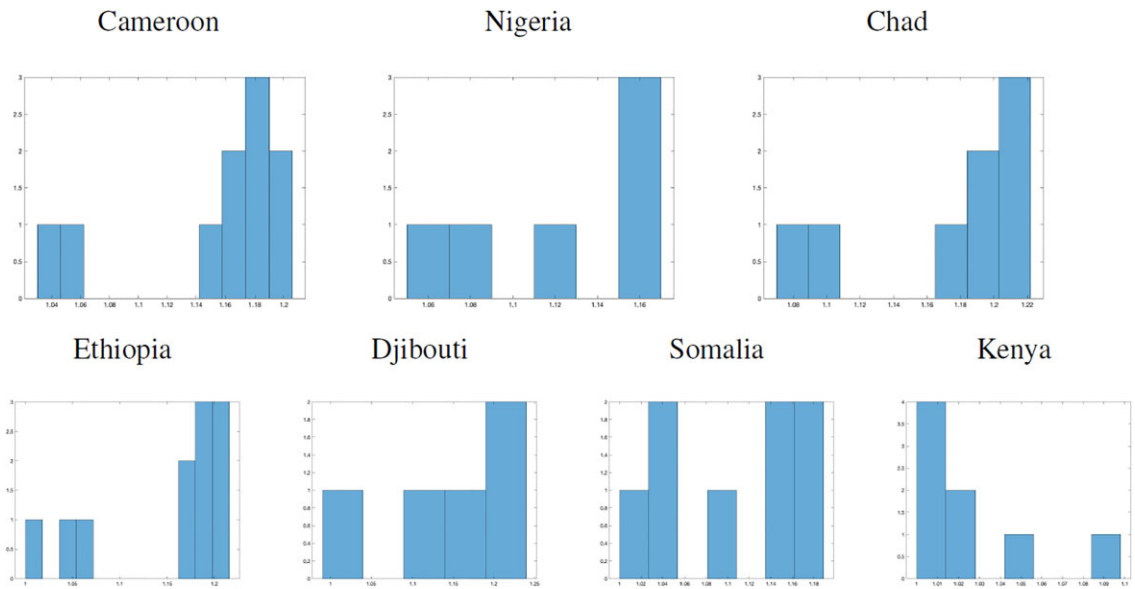
5.3. Counterfactuals

The model is calibrated to assess the welfare and spatial impacts of new infrastructure investments. The counterfactual exercise is done in three steps. First, the model is calibrated to obtain its underlying parameters for the baseline situation, without the new investments. Second, the trade costs and sectoral productivity parameters are updated based on the new assumptions. Third, the model is used to obtain the new employment shares given the new transport costs and productivities, the wage per location, and therefore the real wage given the new equilibrium goods and housing prices.

Three types of infrastructure counterfactuals are considered: (a) improvement in road quality reducing trade costs, (b) better access to electrification, and (c) access to fast Internet. Electrification and access to fast Internet increase productivity in modern sectors (manufacturing and services as in Moneke (2020)) and transport investments increase market access by reducing transport times. To build the transport counterfactuals, the available road networks for each country are used and assumptions about speed along the networks are made based on the type and condition of roads that are registered. Investments are assumed to increase the speed at which vehicles can travel along segments that are improved or to build new links between locations. Trade costs are iceberg costs, such that the costs between the origin location o and destination d are given by $d_{od} = \max\{1, \text{time}^\tau\}$. Border costs are also added to travel costs.

The model is calibrated using the spatial data for land, population, and sectoral shares described in the data section. Because of the complexity of the convergence of a three-sector model, in order to recover the initial sectoral productivities, the spatial disaggregation is reduced to fewer locations. Such aggregation also smoothed measurement issues of sectoral employment based on the DHS data. The Lake Chad region is divided into 24 areas, including 8 first-order administrative divisions in Cameroon, 6 in Nigeria, and 8

Figure 3. Distribution of Productivity Shocks from Universal Access to Electricity.



Source: Authors' calculations.

Note: Each graph reports the distribution of productivity shocks across locations of each country following an improvement in access to electricity.

in Chad.¹⁹ The Horn of Africa is divided into 32 areas, including 11 first-order administrative divisions in Ethiopia, 5 in Djibouti, 8 groupings of first-order administrative divisions in Somalia, and 8 groupings in Kenya.²⁰

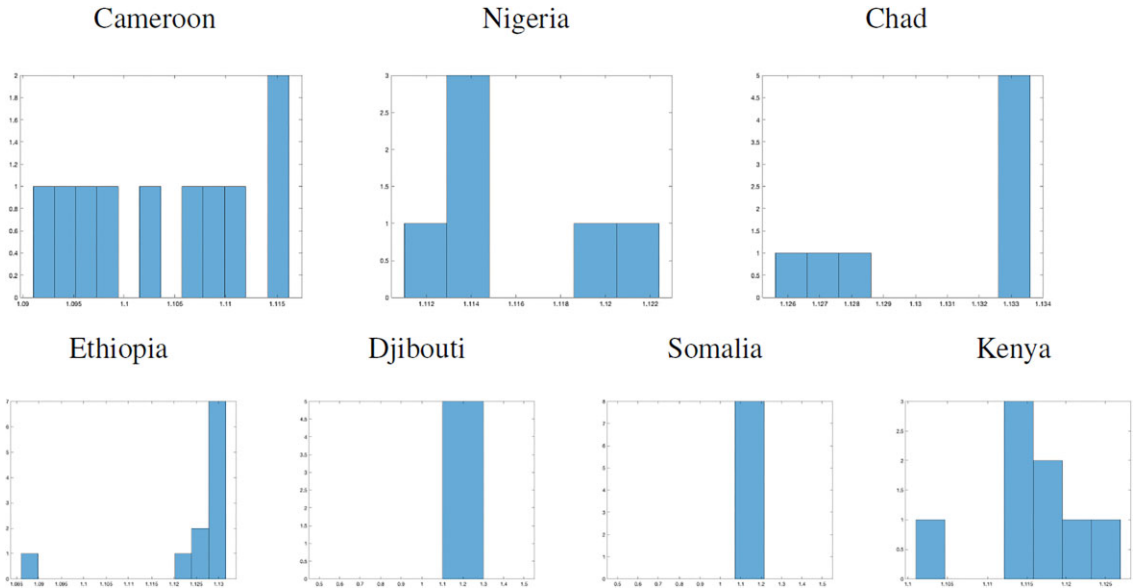
5.3.1. Productivity Shocks from Universal Electrification

The counterfactual consists in providing access to electricity for all in each area based on the current coverage measured by nighttime lights as described in the data section. The increase in productivity is calibrated using the estimated productivity increase of 25 percent by [Fried and Lagakos \(2020\)](#) and the current coverage of electricity per area. [Fried and Lagakos \(2021\)](#) estimate that eliminating outages leads to large increases in output per worker in all countries, ranging from 16.8 percent in Uganda to 30.7 percent in Ethiopia. Ghana, Nigeria, and Tanzania are in the middle, with increases in output per worker of 24.9 percent, 28.4 percent, and 27.1 percent, respectively. Averaging across all five countries, they find that eliminating outages increases output per worker in the long-run general equilibrium by approximately 25 percent. Because they abstract from several mechanisms through which electricity affects productivity, such estimates might represent a lower bound. The lower the existing coverage, the higher the productivity increase in the counterfactual. The new productivity levels A^* are given by $A_n^* = A_n^i + A_n^i \times (1 - \text{Elec}_n) \times 0.25$, with $n = M, S$, and Elec_n being the current ratio of electrified population. The productivity shocks from an improvement in electricity vary within and across countries ([fig. 3](#)). The shock is the largest in most of Ethiopia, in the northern part of Somalia, in Cameroon, and in southern Chad. Areas that already

19 [Figure S1.3](#) in the supplementary online appendix shows the share of agricultural employment and population for each of these areas.

20 [Figure S1.4](#) in the supplementary online appendix shows the share of agricultural employment and the population for each area.

Figure 4. Distribution of Productivity Shocks from Access to Fast Internet.



Source: Authors' calculations.

Note: Each graph reports the distribution of productivity shocks across locations of each country following an improvement in access to fast Internet.

have large access to electricity will benefit less and experience a lower productivity shock (figs S1.6 and S1.6 in the supplementary online appendix).

5.3.2. Productivity Shocks from Access to Fast Internet

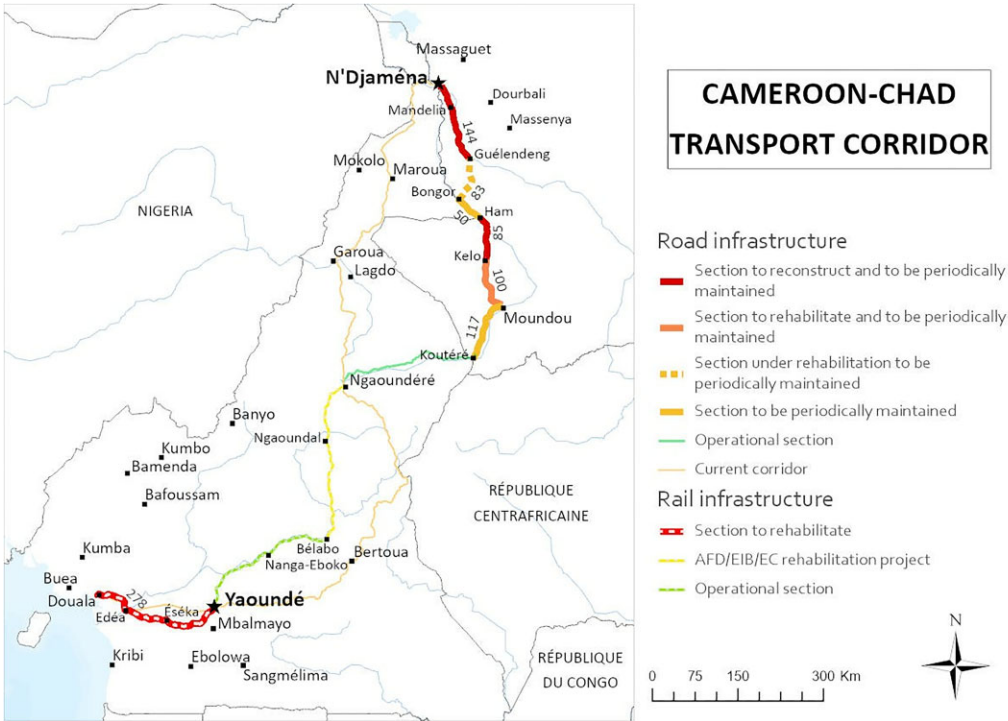
The Internet counterfactual assumes that access to fast Internet will be available for all regions. The increase in productivity relies on the results by Hjort and Poulsen (2019), who find that firm-level productivity increases by about 13 percent when fast Internet becomes available. The new productivity levels A^* are given by $A_n^* = A_n^i + A_n^i \times (1 - \text{Internet}_n) \times 0.13$, with Internet_n being the share of population who already have access to fast Internet in location n . The productivity shocks from an improvement in access to Internet vary within and across countries (fig. 4).

5.3.3. New Transport Infrastructure

New Rail and Road Corridors in Chad and Cameroon. Major transport projects are ongoing in Chad and Cameroon to improve the connectivity to the port of Douala in Cameroon, the regional connectivity between Cameroon and Chad to avoid the conflict-ridden Far North region in Cameroon, and the domestic connectivity in Chad between the capital city and other major secondary cities in the south. An ongoing World Bank project has focused on the rail line in Cameroon and the road corridor in Chad (fig. 5). The rehabilitation of the rail line between Ngaoundéré, Yaounde, and Douala in Cameroon, financed by the World Bank and other international donors, aims at improving the movement of goods from and to the port of Douala for both countries. From Ngaoundéré on, there are several historical corridors between Cameroon and Chad.

Tensions in the Far North have closed the corridors passing by the northern part of Cameroon and opened the possibilities for other corridors to develop. An alternative road corridor from Ngaoundéré to Ndjamena crosses the border near Moundou (second largest city in Chad) and then connects Moundou

Figure 5. Planned Road and Rail Investments in Cameroon and Chad.



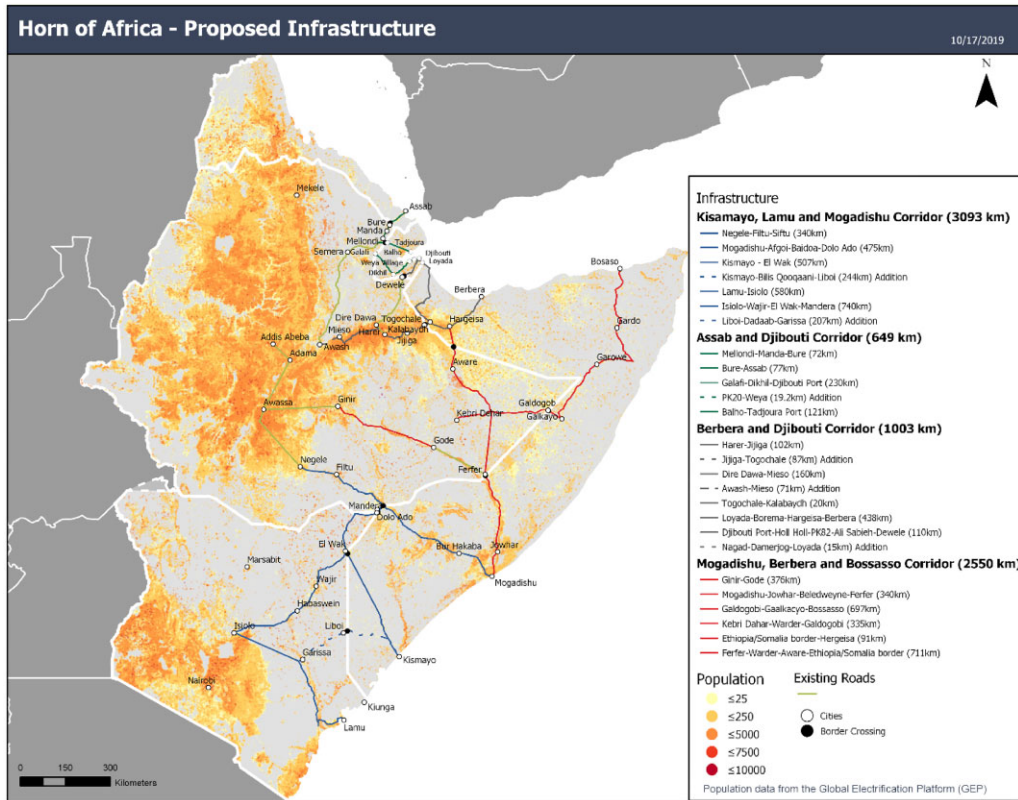
Source: World Bank Project Appraisal Document for the Cameroon–Chad Transport Corridor project (project P167798).
Note: The map reports the location of the road- and rail-corridor projects in Cameroon and Chad, as well as the status of each segment at the time of the project appraisal.

with Ndjamen (about 600 kilometers). As of today, the road is paved but totally dilapidated. This corridor would improve connectivity to the port of Douala, improve domestic connectivity between the main two cities of Chad, and improve the regional/international connectivity of Moundou. The proposed project covers the whole corridor between Koutéré–Moundou–Ndjamena under a phased 10-year approach that entails rehabilitation works, reinforcement, maintenance, and axle-load-monitoring facilities. This project is part of a program to provide a long-term, reliable, safe, and efficient multimodal corridor over the entire 1,800-kilometer-long stretch between Douala–Ngaoundéré–Koutéré–Moundou–Ndjamena (World Bank Project Appraisal Document for the P167798 Cameroon–Chad Transport Corridor project). The corridor contributes to improving domestic, regional and international connectivity for both countries.

Counterfactuals were created by assuming new speed along the rehabilitated segments and reduced border times. For the rail-corridor scenario, the road network was kept as is and a new direct rail line between Ngaoundéré, Yaounde, and Douala was created. New transport times were computed assuming that the existing roads can be used as well as the new rail line, which is more efficient. Stops between the main cities were not permitted. The section between Ngaoundéré and Yaounde is assumed to be 627 kilometers and the section between Yaounde and Douala is assumed to be 261 kilometers.²¹ The average speed on rehabilitated road segments goes from 30 kilometers per hour to 70 kilometers per hour and on rehabilitated rail segments from 40 kilometers per hour to 70 kilometers per hour. Reductions of transport costs for domestic and regional pairs of locations vary across and within countries (figs 7 and 8).

21 Distance assumptions come from the website rome2rio.com which reports distance per transport mode.

Figure 6. Proposed Road Corridors in the Horn of Africa.



Source: World Bank.

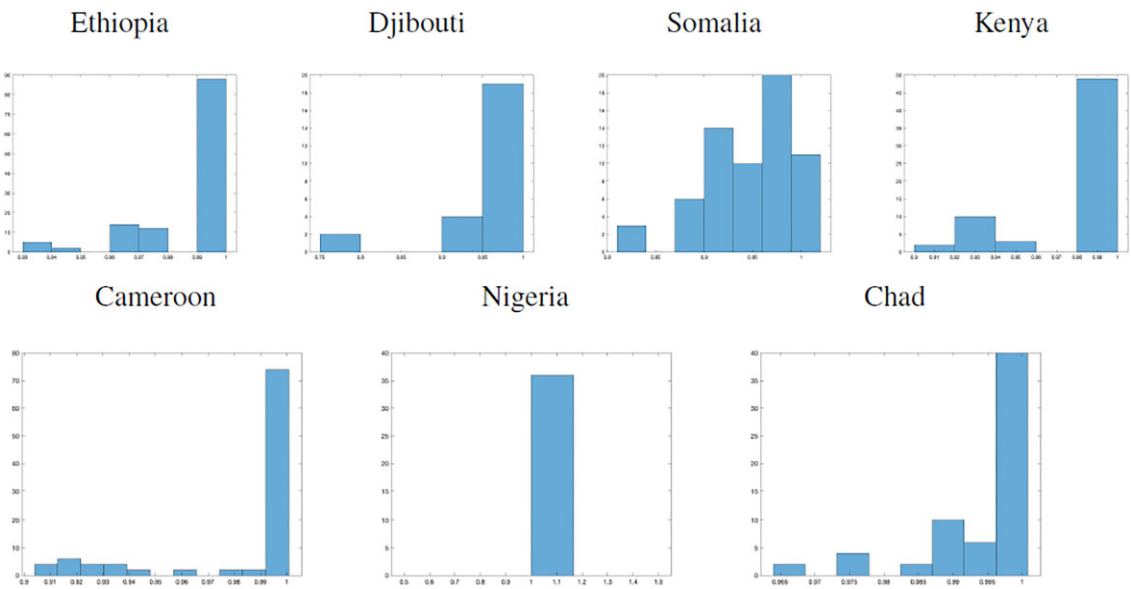
Note: The map reports the location of four corridors being discussed to improve regional integration.

New Road Corridors in the Horn of Africa. Future investments along four major regional transport corridors have been discussed to improve regional integration in the region. Figure 6 shows the four corridors of interest: (a) the Kismayo, Lamu, and Mogadishu corridor, which links population centers in Ethiopia, Kenya, and Somalia with the Somali ports of Mogadishu and Kismayo and the Kenyan port of Lamu; (b) the Assab and Djibouti corridor, which provides an alternate route between Ethiopia and the coast in Djibouti and complements existing linkages, reestablishing the historically important route to the port of Assab in Eritrea; (c) the Berbera and Djibouti corridor, which is a vital import route as well as the primary path for export of goods out of Ethiopia; and (d) the Mogadishu, Berbera, and Bossaso corridor, which provides access to the port of Mogadishu in the southeast.²² Counterfactuals were created using the transport networks from each country described in the data section. A speed of 70 kilometers per hour for the new corridors and a 50 percent reduction in the border crossing time were assumed. Reductions of transport costs for domestic and regional pairs of locations vary across and within countries (figs 7 and 8). Counterfactuals combining road, electricity, and Internet investments were created to study the interaction effects from combining infrastructure investments.

Lower Border Frictions. Most transport investments aim at improving regional connectivity and improving the connectivity of isolated areas to the main ports and capitals of each region. However, borders

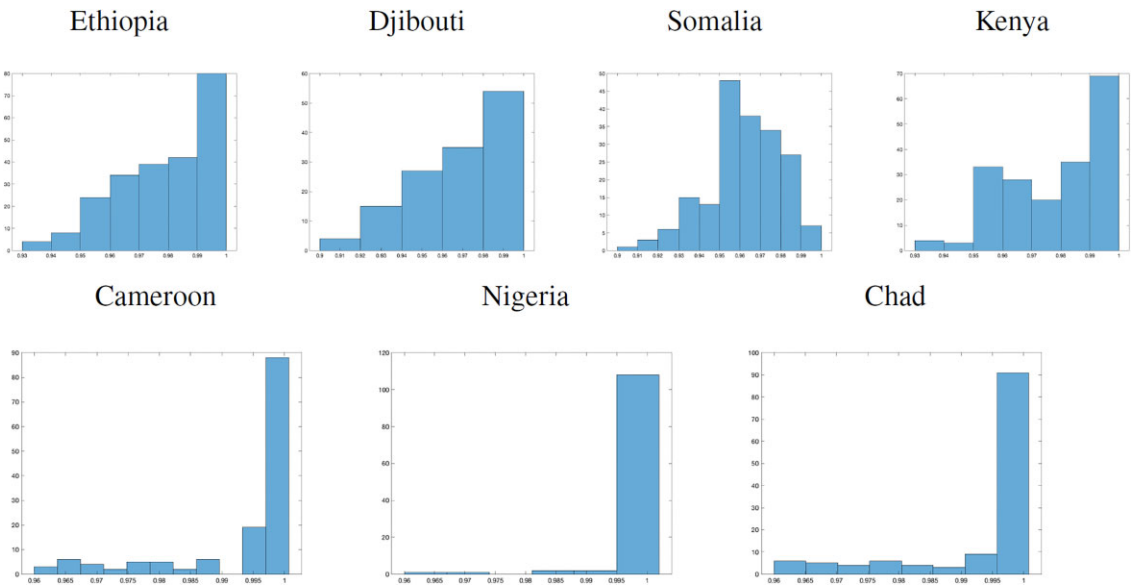
22 More description for each corridor can be found in the supplementary online appendix.

Figure 7. Distribution of Transport Cost Reductions for Domestic Origin–Destination Pairs, by Country.



Source: Authors' calculations.
Note: Each graph reports the distribution of transport cost reductions for domestic origin–destination pairs following an improvement in transport infrastructure.

Figure 8. Distribution of Transport Cost Reductions for Regional Origin–Destination Pairs, by Country.



Source: Authors' calculations.
Note: Each graph reports the distribution of transport cost reductions for regional origin–destination pairs following an improvement in transport infrastructure.

Table 5. Change in Share of Non-agricultural Employment in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points)

Scenarios	Total	Cameroon	Nigeria	Chad
Transport (road and rail)	0	0	0	0
Electrification	− 0.9	− 0.8	− 0.7	− 2.6
Electrification and Internet	− 1.7	− 1.6	− 3.5	− 1.6
Transport + electrification + Internet	− 1.7	− 2.8	− 3.9	− 1.4
Transport + border	0.4	0	− 1.8	0.6
All infrastructure + border	− 1.4	− 2.5	− 5.5	− 0.9

Source: Authors' calculations based on the counterfactuals results.

Note: The table reports the change in percentage points in the share of non-agricultural employment in the entire region and per country for each counterfactual relative to the baseline.

are thick in the region. It was assumed that traders have to wait 30 hours to cross a border,²³ which was assumed to decrease by half in the counterfactual scenario. The aim of this counterfactual is to better understand the impact of regional connectivity on sectoral change and welfare to inform policy decisions.

6. Welfare Impacts of Future Infrastructure Investments

6.1. Aggregate Impacts

The expected impacts from the counterfactuals will depend on two heterogeneous aspects: first, the shocks will differ across areas; second, the areas differ according to their productivities, geographic location, and initial endowments. In the model, the resulting sectoral labor-demand changes will result from two effects: a comparative advantage effect, from domestic and regional trade competition in a Ricardian inter-regional trade model, and a revenue effect from lower trade cost and productivity gains.

Partial equilibrium analysis based on reduced-form methods fails to capture the aggregate effects of infrastructure investments on the entire country, and on the entire Horn of Africa and entire Lake Chad region. The model captures the heterogeneous effects of the shocks, the geography of places, and the spillovers from trade and the movement of people across locations.

6.1.1. Employment Impacts

Access to better infrastructure has a large impact on the shares of non-agricultural employment for countries in both regions and across the various scenarios (tables 5 and 6). For countries in the Lake Chad region, the impact of new infrastructure investments differs from the results of the reduced-form analysis. In most scenarios, infrastructure investments do not trigger structural change. In the case of the Horn of Africa, positive impacts on non-agricultural employment shares emerge in Djibouti, Somalia, and Kenya. Most changes are expected to happen within country through worker reallocation between sectors and across areas. In this case, the aggregate changes from relocation between sectors across areas are limited because of large welfare gains from lower prices in poorer areas reducing the incentives of workers to move out of the most agricultural areas.

23 This number is an estimate based on reported observations from the ground. Doing Business indicators report an estimated border compliance time for exports per country, which is higher than 30 hours. For example, traders in Cameroon are estimated to wait 202 hours, in Chad 106 hours, in Djibouti 71 hours, in Ethiopia 51 hours, and in Nigeria 128 hours. The results of the paper are therefore conservative estimates.

Table 6. Change in Share of Non-agricultural Employment in Counterfactual Scenarios Relative to Baseline in the Horn of Africa (in Percentage Points)

Scenarios	Total	Ethiopia	Djibouti	Somalia	Kenya
Roads only	1.5	1.1	1	0.2	2.6
Electrification only	0.3	−0.7	0.8	1.3	2.1
Roads and electrification	0.3	−0.8	3	2.5	2.2
Electrification and Internet	−0.9	−2	3	3.5	1.2
Roads, electrification, and Internet	−0.5	−1.5	1.7	1.4	1
Roads and trade facilitation	1.7	−0.5	3.3	0.5	6.7
Roads, trade facilitation, and electrification	1	−1.1	2.7	−0.2	6
All infrastructure and trade facilitation	0	−2	1.9	−0.9	5

Source: Authors' calculations based on the counterfactuals results.
*Note:*The table reports the change in percentage points in the share of non-agricultural employment in the entire region and per country for each counterfactual relative to the baseline.

Table 7. Change in Nominal GDP in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points)

Scenarios	Total	Cameroon	Chad	Nigeria
Road (Chad)	0.1	0	0.1	0
Road and rail	0.1	0	0.3	0
Electrification	0.4	0.2	0	0.4
Electrification and Internet	0.3	0	0	0.4
Electrification + road and rail + Internet	1.9	0	2.2	1.3
Road and rail + trade facilitation	0	0	0.6	0
All infrastructure + trade facilitation	1	0.2	1.6	1.1

Source: Authors' calculations based on the counterfactuals results.
*Note:*The table reports the change in percentage points in nominal GDP in the entire region and per country for each counterfactual relative to the baseline.

6.1.2. Welfare Impacts

The impacts on nominal GDP are measured as the changes in total nominal incomes:

$$\Delta \text{NominalGDP}_c = \Delta [\text{Population}_{n,c} \times \text{Nominal Income}_{n,c}], \tag{17}$$

with $\text{Nominal Income}_{n,c}$ the total nominal income in location n of country c . Changes in national incomes do not include gains in purchasing power from lower prices.

Welfare is defined as the real income available to workers in a specific location, with nominal wages deflated by the prices for goods and housing across locations, as well as an amenity from living in different places. The total welfare impact in each counterfactual is computed and compared to the baseline welfare:

$$\Delta \text{Welfare}_{n,c} = \Delta [\text{Population}_{n,c} \times V_{n,c}], \tag{18}$$

with $V_{n,c}$ the welfare or real income in location n of country c defined in equation (16).

Table 7 shows the change in nominal income and tables 8 and 9 the change in welfare. The welfare gains are overall much larger than the gains in nominal GDP, indicating that lower prices and the reallocation of workers toward places with high real incomes are two main sources of welfare gains.

Transport investments have significant spillover effects. While the road upgrade only benefits Chad, improvements to the rail line in Cameroon have strong spillover effects in Chad, which benefits from better access to Douala port and centers of production in Cameroon. The welfare gains for Chad increase from 0.2 to 0.7 percent when including the rail investment in Cameroon. The welfare gains from the electricity and Internet productivity shocks are very large, more than 9 percent for all countries. While

Table 8. Change in Welfare in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points)

Scenarios	Total	Cameroon	Chad	Nigeria
Road (Chad)	0.03	0.0	0.23	0.02
Road and rail	0.13	0.5	0.7	0.03
Electrification	4.4	5.7	5.2	4.2
Electrification and Internet	9.2	9.3	9.3	9.2
Electrification + road and rail + Internet	9.7	9.6	10.1	9.7
Road and rail + trade facilitation	2.5	2.8	3.7	2.3
All infrastructure + trade facilitation	12.2	12.3	13.7	12

Source: Authors' calculations based on the counterfactuals results.

Note: The table reports the change in percentage points in welfare in the entire region and per country for each counterfactual relative to the baseline.

Table 9. Change in Welfare in Counterfactual Scenario Relative to Baseline in the Horn of Africa (in Percentage Points)

Scenarios	Total	Ethiopia	Djibouti	Somalia	Kenya
Electrification only	3.5	4.8	1.7	3.5	0.9
Electrification and Internet	6	5	5.6	8.9	2.7
Roads only	0	0	2	2.3	0.1
Roads and trade facilitation	5	4.6	4.5	6	6
Roads and electrification	2.1	2.6	7.6	6.2	0.3
Roads, electrification and Internet	6.8	8	10	10	4
All infrastructure + trade facilitation	13	12.9	13.8	15	9.4

Source: Authors' calculations based on the counterfactuals results.

Note: The table reports the change in percentage points in welfare in the entire region and per country for each counterfactual relative to the baseline.

reducing time at the borders brings larger gains than building transport infrastructure alone, most of the gains come from access to electricity and fast Internet. The results are similar for countries in the Horn of Africa. Somalia, which experiences the largest productivity shocks, gains the most in terms of welfare.

6.2. Spatial Impacts of Infrastructure Investments

New infrastructure investments have different impacts across areas within a country. The comparative advantage of each area in producing agricultural or manufacturing goods and exporting to other areas, the attractiveness of each area, its distance to other places, and the land surface that can be used are key factors that determine the final impacts of such investments. This section discusses the spatial impacts of infrastructure investments in the Horn of Africa and Lake Chad region.

6.2.1. Horn of Africa

Local Complementary Impacts of Infrastructure. Table 10 describes how the simulated changes in non-agricultural employment correlate with local characteristics and the impact of infrastructure investments on accessibility and productivity. Controlling for initial characteristics of each region, the impact of improved market access is associated with a larger increase in the share of non-agricultural jobs when complemented with investments in electrification. The analysis looks at the different impact of road accessibility in areas with fewer than 50 percent of the population having access to electricity in the baseline and the rest of the areas.²⁴ Columns (1) and (2) show that there is no difference in the impact of road accessibility when comparing the two types of areas. Improvement in market access through roads only is not associ-

24 The 50 percent threshold corresponds to the threshold used in the reduced-form estimation part.

Table 10. OLS Results for Change in Non-agricultural Employment for Different Scenarios in the Horn of Africa

	Scenarios			
	Roads (1)	Roads + borders (2)	Roads + elect. (3)	All three (4)
Population	−1.928 (1.379)	0.239 (2.130)	5.027** (2.470)	4.710*** (1.570)
Wage	−4.999 (3.358)	−13.886*** (4.706)	−2.714 (5.716)	−8.174** (3.300)
Employment in agriculture	0.001 (0.026)	−0.080** (0.037)	0.111** (0.046)	0.034 (0.027)
MA (roads) * I(Elec = 1)	0.004 (0.060)	—	0.754*** (0.116)	—
MA (roads) * I(Elec = 0)	−0.100 (0.067)	—	0.133 (0.116)	—
MA (roads + borders) * I(Elec = 1)	—	0.072** (0.029)	—	0.175*** (0.023)
MA (roads + borders) * I(Elec = 0)	—	0.071** (0.031)	—	−0.013 (0.022)
Productivity shock	—	—	−0.739*** (0.099)	−0.753*** (0.059)
Constant	4.314* (2.327)	9.630*** (3.244)	2.809 (3.953)	9.567*** (2.268)
Observations	205	205	205	205
R ²)	0.035	0.077	0.277	0.483
Adjusted R ²)	0.011	0.054	0.255	0.467

Source: Authors’ calculations using the counterfactuals results for each of the column scenarios. MA stands for market access, and Elec for electrification.
Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

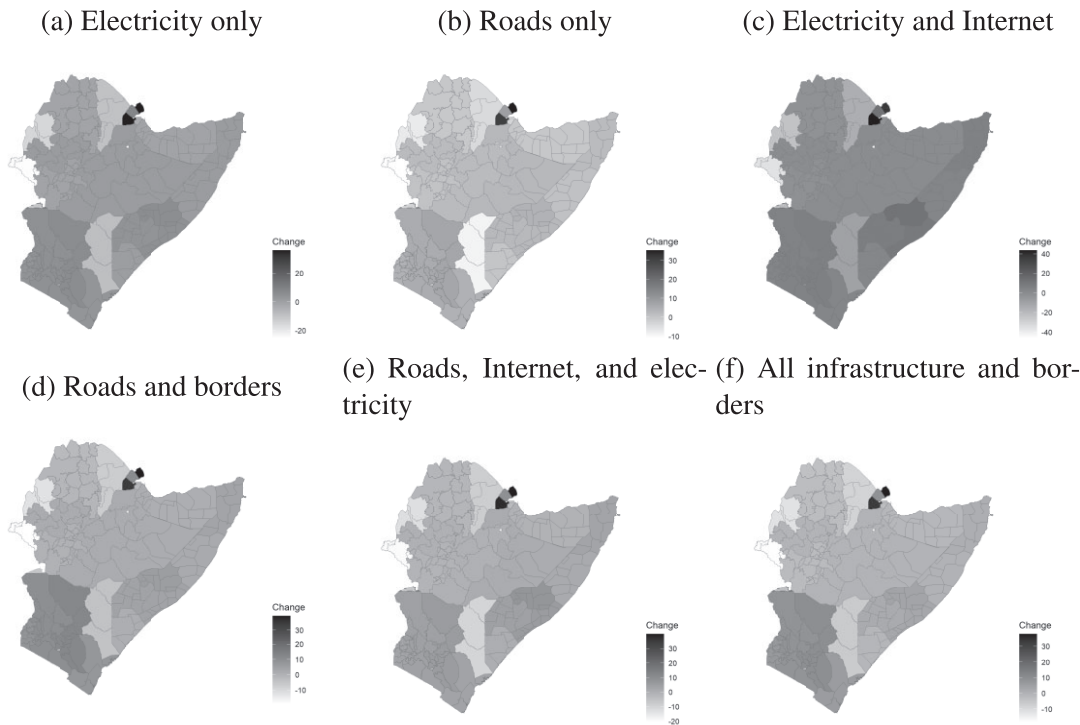
ated with change in sectoral employment. Columns (3) and (4) show that the impact on non-agricultural jobs is only significant for the regions that had less than 50 percent access to electricity before the simulated bundle of investments in infrastructure. In line with the reduced-form results, bundled investments are associated with larger impacts on sectoral change.

Overall Impacts. The impacts of infrastructure investments and their combinations differ across regions. Lower transport and trade costs increase market access, providing more opportunities for producers in districts that benefit from transport investments. Better connectivity leads to higher specialization and increases competition from imports from other regions in the country for the traded good sectors (manufacturing and agricultural activities). Electrification and access to fast Internet increases productivity in manufacturing and services sectors. Workers move across locations and sectors in response to changes in wages and prices.

For some regions, better regional connectivity or higher productivity in manufacturing and services sectors translates into higher specialization in agricultural production. In [fig. 9](#), the green areas are regions where the share of agricultural employment will increase; the orange and red areas are regions where the share of non-agricultural employment will increase. The regions that experience an increase in the share of agricultural employment are either isolated regions or border regions, mostly in the northwest of Ethiopia and the northeast of Kenya. The spatial patterns remain the same when the time to cross the borders is reduced by half, but the changes become larger. Investments in infrastructure tend to amplify the comparative advantage of each region and the regional specialization.

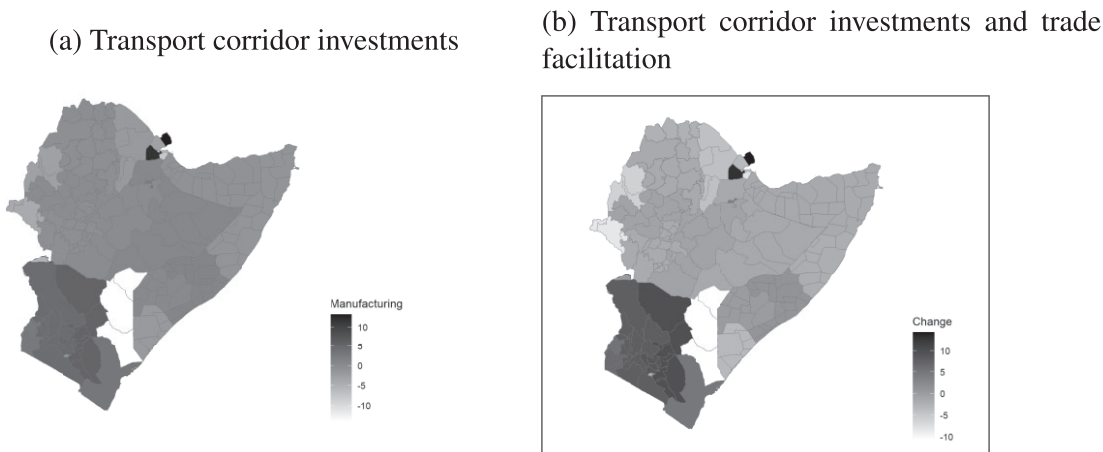
Specialization in manufacturing—the traded non-agricultural good—changes most in regions that benefit from corridor improvement. However, not all regions that benefit from better connectivity experience

Figure 9. Changes in Share of Non-agricultural Employment in Counterfactual Scenarios Relative to Baseline in the Horn of Africa (in Percentage Points).



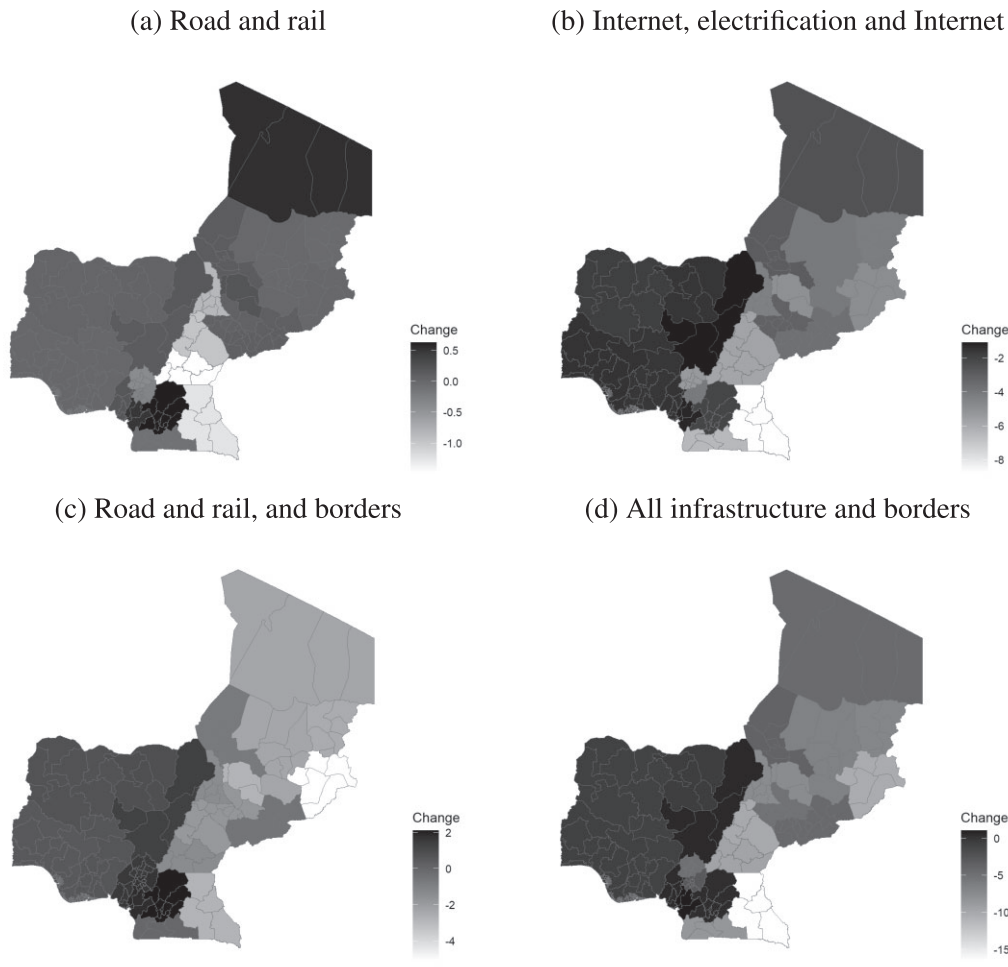
Source: Authors' calculations.
Note: Each map reports the change in sectoral employment from the counterfactuals for each scenario in percentage points.

Figure 10. Change in Share of Manufacturing Employment in Counterfactual Scenarios Relative to Baseline in the Horn of Africa (in Percentage Points).



Source: Authors' calculations.
Note: Each map reports the change in sectoral employment from the counterfactuals for each scenario in percentage points.

Figure 11. Change in Share of Employment in Non-agricultural Sectors in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points).



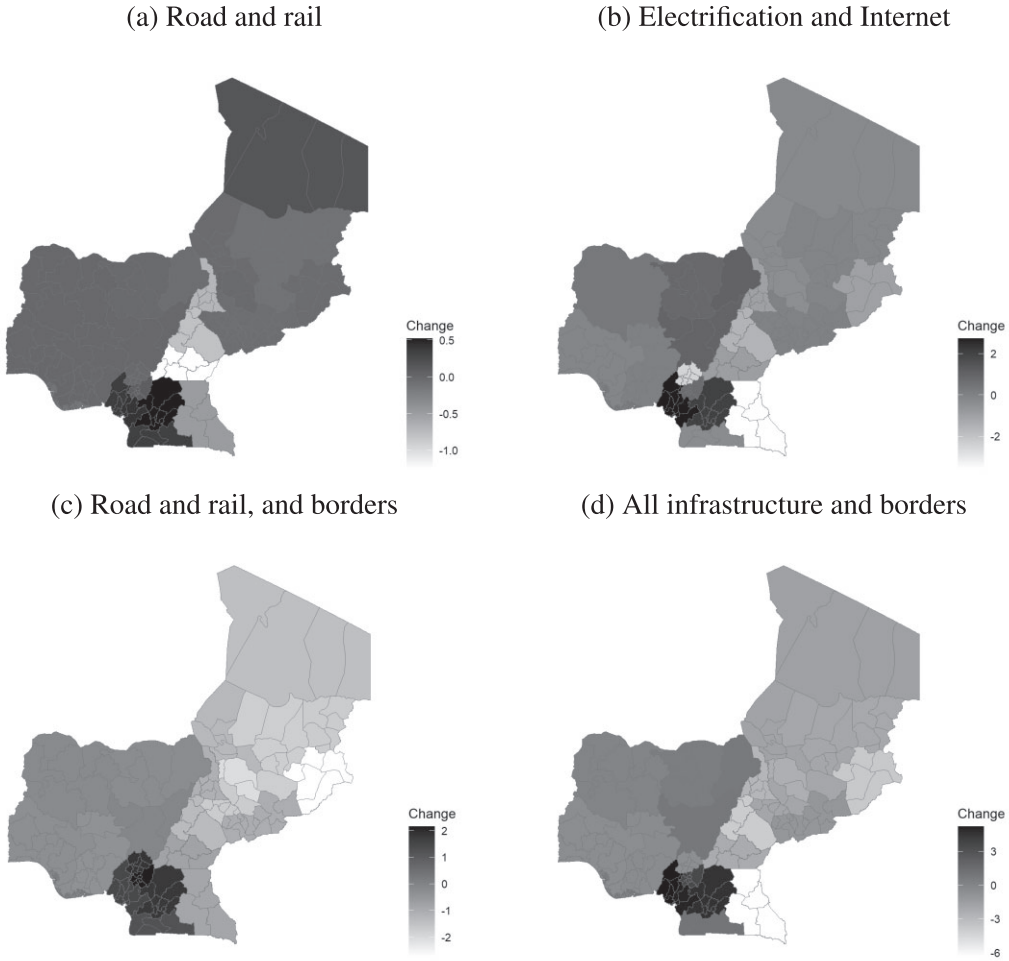
Source: Authors' calculations.
Note: Each map reports the change in sectoral employment from the counterfactuals for each scenario in percentage points.

an increase in specialization in manufacturing. The shares of manufacturing employment will increase the most in Djibouti and Kenya; they increase only slightly in the central and eastern parts of Ethiopia and in the regions around Mogadishu in Somalia (fig. 10). When transport investments are complemented with trade facilitation measures that reduce border times by half, the share of employment in manufacturing decreases across Ethiopia. In Somalia, and particularly in Kenya, the changes in employment shares become even larger, with most regions in Kenya further specializing in manufacturing.

6.2.2. Lake Chad

Structural Change. While small at the national level, changes in the employment structure vary significantly across subnational locations (see fig. 11 for non-agricultural employment and fig. 12 for manufacturing employment only). Two effects can emerge from an increase in productivity in two out of three sectors: either consumption of the goods whose production has improved increases and more workers move to these sectors, or more workers move to the sector whose productivity has not increased to

Figure 12. Change in the Share of Employment in Manufacturing Sectors in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points).

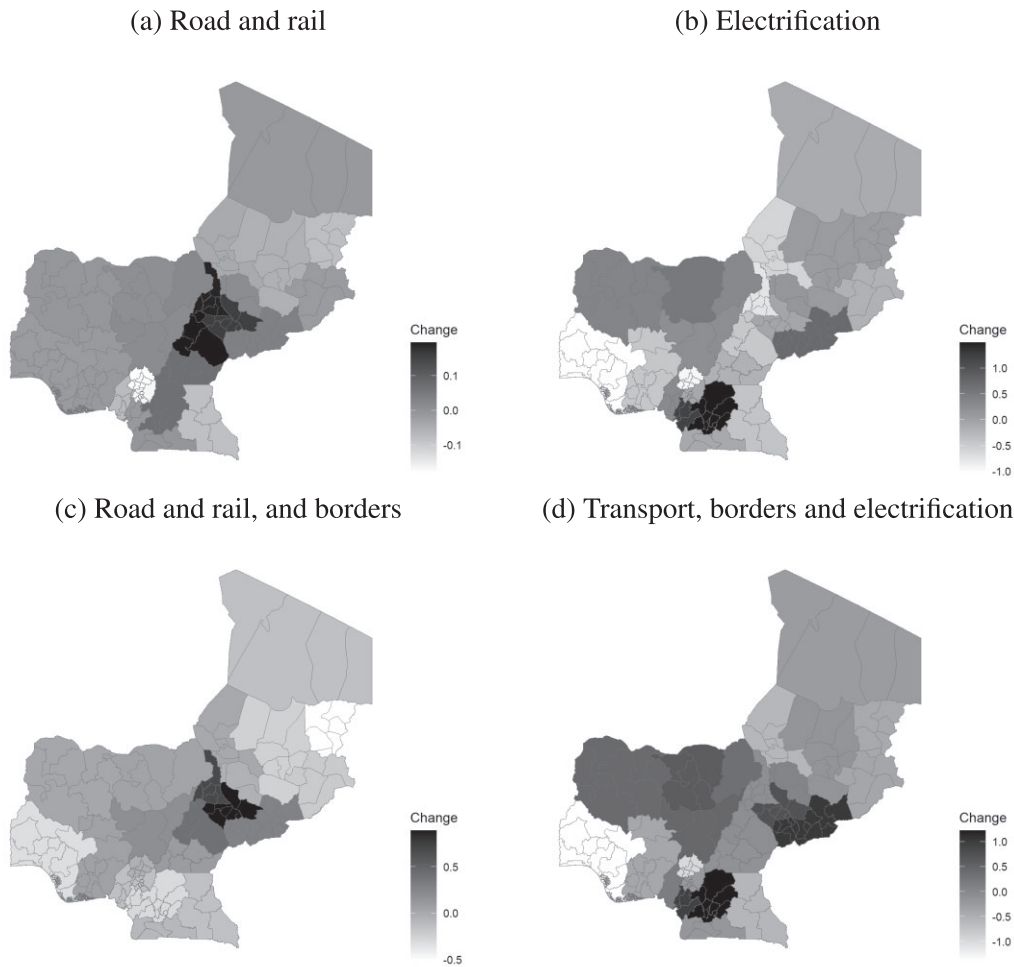


Source: Authors' calculations.

Note: Each map reports the change in sectoral employment from the counterfactuals for each scenario in percentage points.

compensate for an increase in consumption for the other sector. With the assumption of homothetic preferences, consumers still consume the same share of agricultural, manufacturing, and services products. In Lake Chad, electrification and fast access to Internet for all, which lead to productivity increases in the manufacturing and services sectors, increase the share of agricultural employment in all locations. Higher labor productivity in the non-agricultural sectors tends to push workers to the agricultural sector, whose productivity has not increased. This differs from the counterfactuals in the Horn of Africa where specialization from regional trade leads some locations to employ fewer workers in agriculture but more in services and manufacturing. However, the least agricultural areas experience the smallest increase in agricultural employment, and most of them experience an increase in the share of manufacturing employment (fig. 12). On the contrary, better connectivity through lower transport costs and lower border delays lead to higher shares in non-agricultural employment in the locations with a comparative advantage in non-agricultural activities. Overall, new infrastructure investments will not push for structural change

Figure 13. Change in the Share of Population in Counterfactual Scenarios Relative to Baseline in the Lake Chad Region (in Percentage Points).



Source: Authors' calculations.

Note: Each map reports the change in the share of population from the counterfactuals for each scenario in percentage points.

in Chad and northern Cameroon. The share of manufacturing employment will increase in the Centre and Littoral regions of Cameroon, which will benefit from better connectivity and a productivity shock. Manufacturing employment might also increase in northern and eastern Nigeria due to better access to electricity and a comparative advantage in manufacturing production.

Migration In and Out. New investments lead to migration in and out across regions and changes in population across locations (see [fig. 13](#)). Better transport connectivity and especially lower border delays made the regions around Lake Chad more attractive for workers, limiting the movements out of these highly agricultural places, but electrification had the reverse impact. Overall, southern Chad and the Centre and Littoral regions of Cameroon attracted new workers from other regions the most.

7. Conclusion

This paper investigates how infrastructure—transport, electricity, and Internet—affects economic development through sectoral employment and structural change. It first estimates the impact of transport, electricity, and Internet investments and their interactions on sectoral employment in countries in the Horn of Africa and Lake Chad region over the last two decades. The empirical analysis shows that combined access to paved roads and electricity, as well as access to fast Internet, triggered a large shift in employment from agriculture to manufacturing and services, while access to roads only had no impact.

The spatial general-equilibrium model estimates the potential impacts of future regional transport-corridor projects, universal access to electricity, and fast Internet access. One of the main contributions of the paper is to study the impact of regional transport corridors allowing for trade between neighboring countries. As border delays remain high around Lake Chad, the analysis also looks at the impact of complementary trade facilitation measures. The area around Lake Chad, one of the poorest and most fragile in Sub-Saharan Africa, would benefit from large welfare gains due to lower transport costs and border delays, but remain mostly agricultural. On the contrary, the Centre and Littoral regions of Cameroon, which have a comparative advantage in manufacturing, would increase their specialization into manufacturing and attract more workers from the rest of the country. Large welfare gains in the poorest areas around Lake Chad limit migration out of the sub-region. In the Horn of Africa, Kenya benefits from an increased specialization in manufacturing, while Ethiopia specializes more in agriculture production. The paper shows how the impact of infrastructure investments can differ from those estimated through reduced-form analysis because of spillover effects and the movement of people within countries.

This paper also opens several directions for future research. Little is said about the quality of jobs, especially of jobs in the booming services sector, and the role of the informal sector for economic development. Finally, it does not consider the role of conflicts or climate change in reshaping the needs for more and different investments in infrastructure.

Data Availability Statement

The data underlying this article will be shared on reasonable request to the corresponding author. Data from [Foster and Briceno-Garmendia \(2010\)](#) are available for request on the World Bank website. However, road data from road authorities and Internet bandwidth maps for Africa are not available to be shared.

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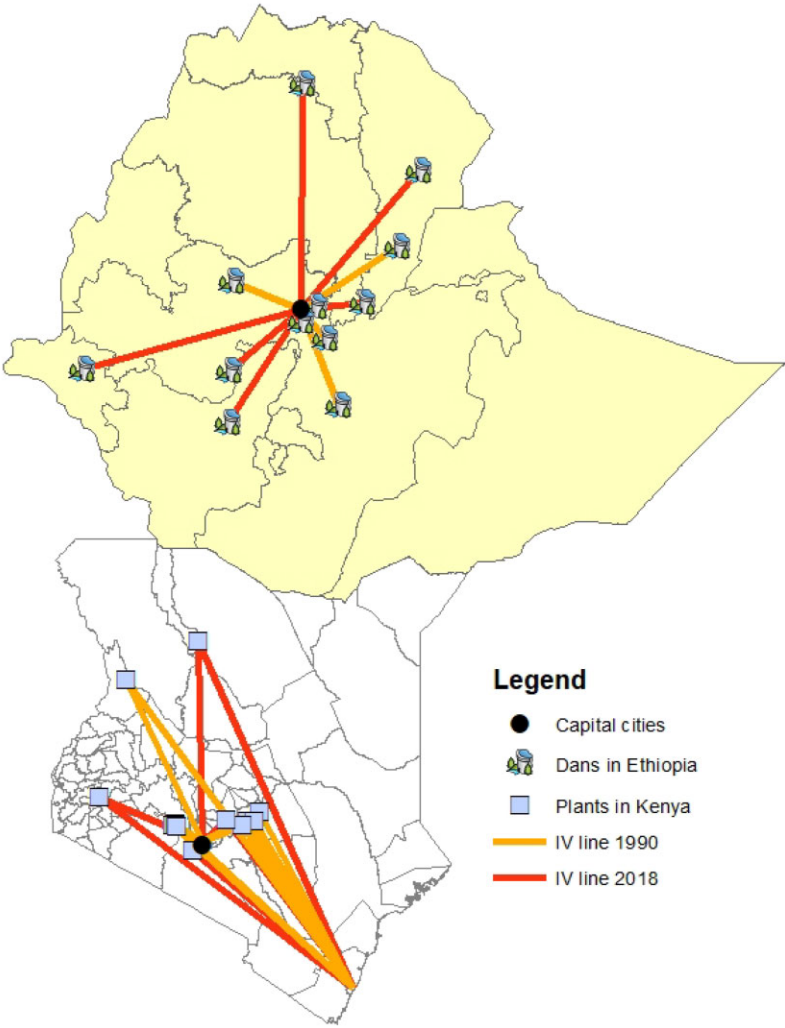
Supplementary Online Appendix
Infrastructure and Structural Change in Africa
Matías Herrera Dappe and Mathilde Lebrand

Supplementary Online Appendix

S1. Data and counterfactuals

S1.1. IV Construction

Figure S1.1. Electrification Instrument: Straight Lines between Cities and Energy Sources for Ethiopia and Kenya (1990 and 2015).

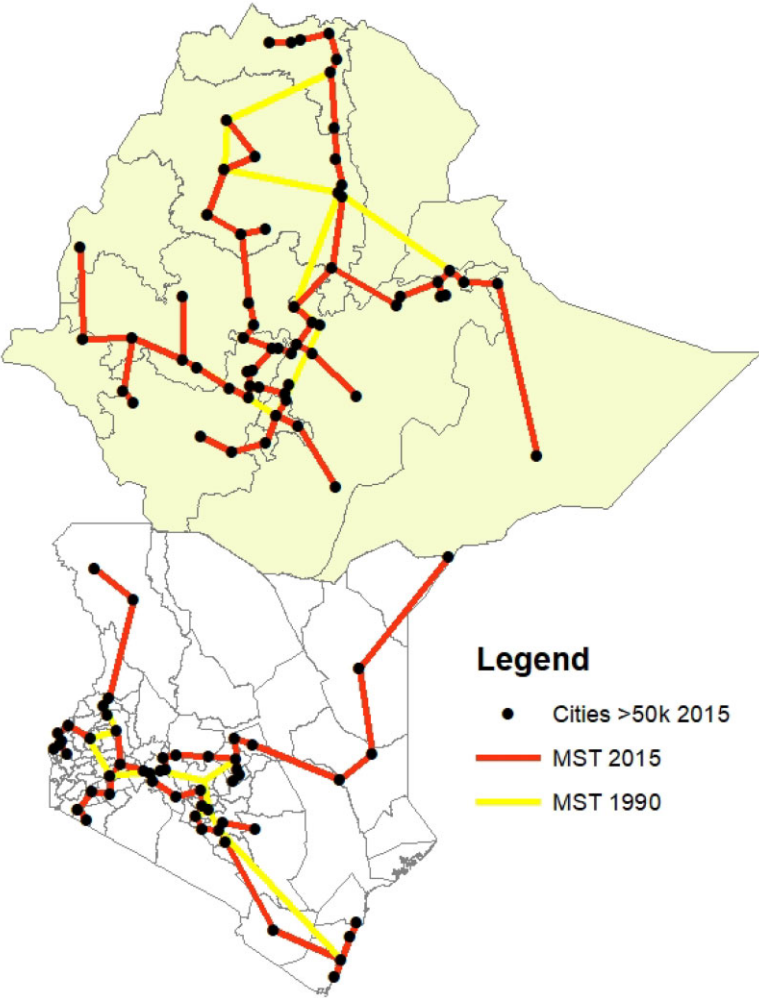


Source: Authors' calculation.

Note: The figures report the location of the main energy sources and cities considered for the construction of the IV. The yellow lines show the lines in 1990 used to build a first IV, the additional red lines show the new connections in 2018 used to build a more recent IV.

S1.2. Calibration

Figure S1.2. Road Instrument: Minimum Spanning Tree Method for Ethiopia and Kenya (1990 and 2015).

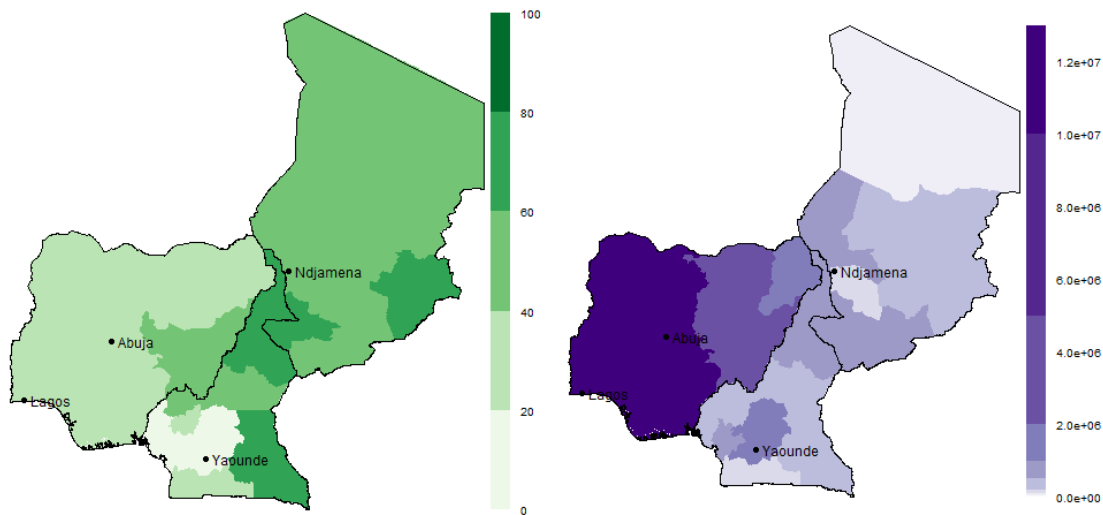


Source: Authors' calculation.

Note: The figures show the minimum spanning trees for 1990 and for 2015 based on the cities considered for their constructions. The yellow line is the path linking the few cities that are considered in 1990. The red line is the path linking the cities with a black dots, which are cities with more than 50,000 inhabitants by 2015.

Figure S1.3. Descriptive Statistics for the 24 Areas in the Lake Chad Region.

(a) Share of employment in agricultural sector (b) Total population per subregion

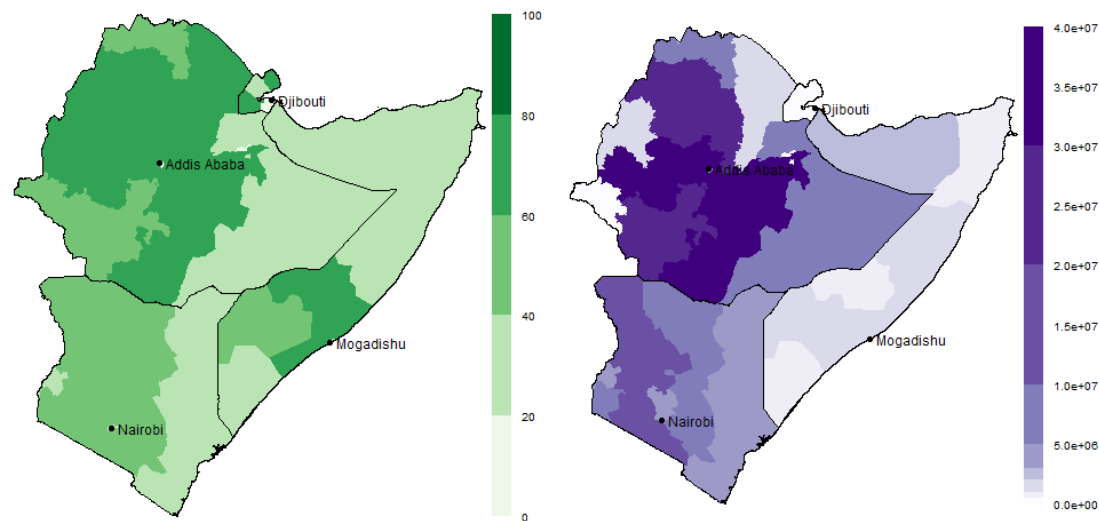


Source: Authors' calculations.

Note: The left map shows the share of employment in the agricultural sector at the subnational level. The right map shows the total population for these same regions.

Figure S1.4. Descriptive Statistics for the 32 Areas in the Horn of Africa.

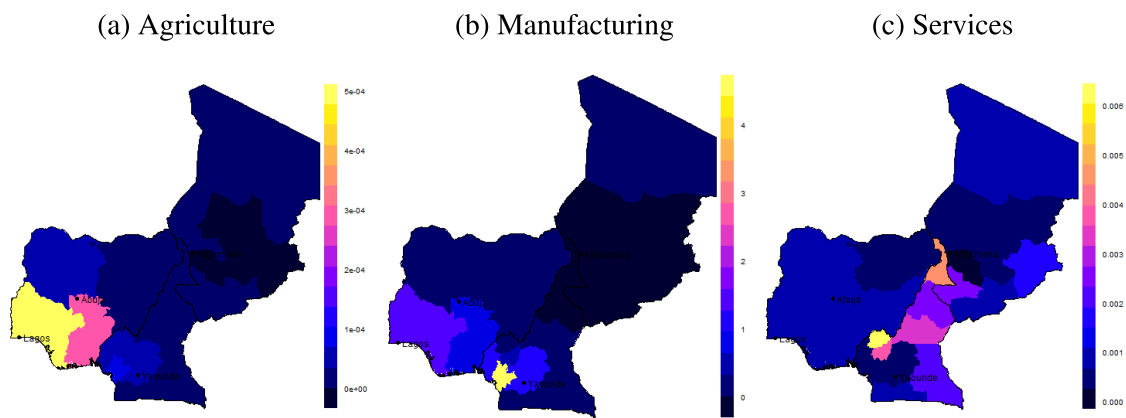
(a) Share of employment in agricultural sector (b) Total population per subregion



Source: Authors' calculations.

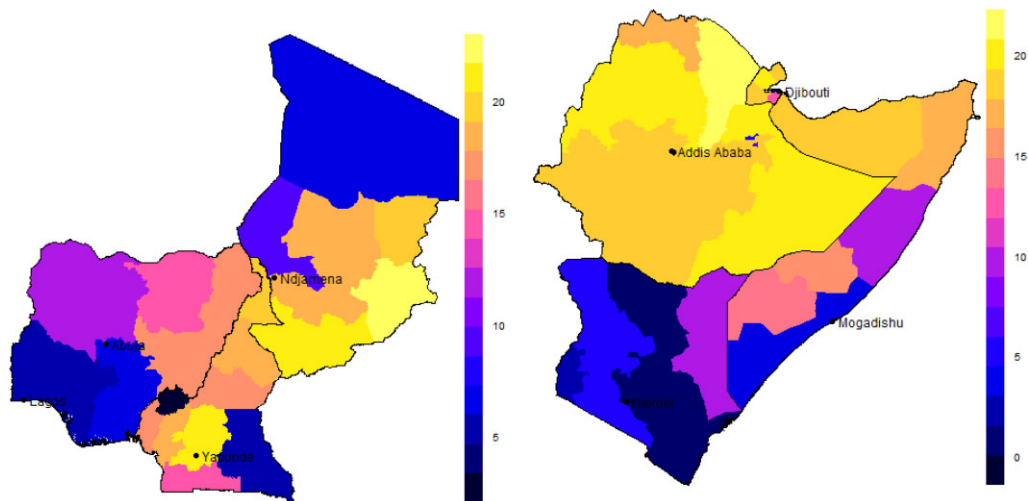
Note: The left map shows the share of employment in the agricultural sector at the subnational level. The right map shows the total population for these same regions.

Figure S1.5. Calibrated Sector Productivities in the Lake Chad Region.



Source: Authors' calculations.
Note: Each map reports the calibrated sector productivity parameter per region for the agriculture sector, the manufacturing sector, and the services sector.

Figure S1.6. Productivity Changes in Manufacturing and Services in Electrification Counterfactual Relative to Baseline in the Lake Chad Region (in Percentage Points).

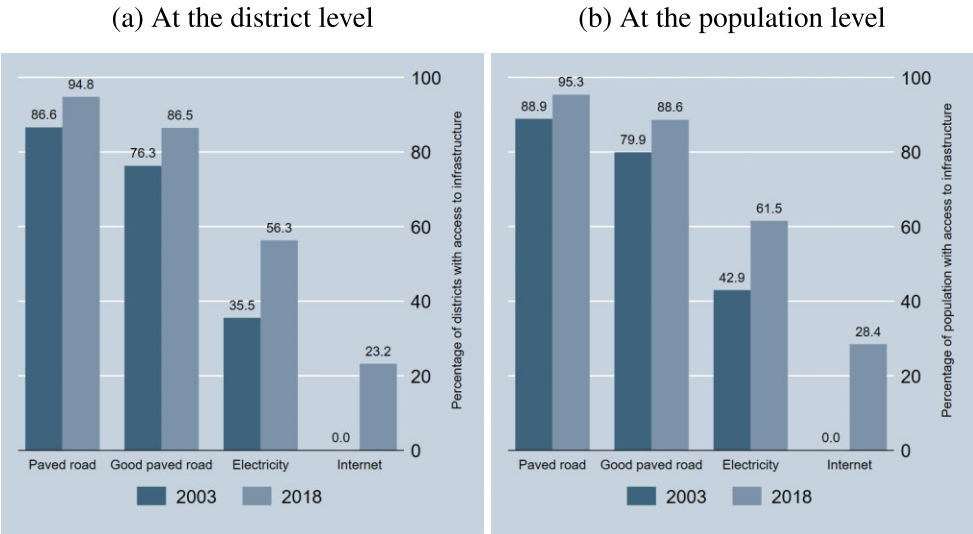


Source: Authors' calculations based on the estimate of the increase in productivity in manufacturing and services sectors from access to electricity.
Note: Each map reports the change in productivity for the manufacturing and services sectors due to a better access to electricity.

S2. Infrastructure Data

S2.1. Data for the Horn of Africa Region

Figure S2.1. Access to Infrastructure in Nigeria, 2003 and 2018.

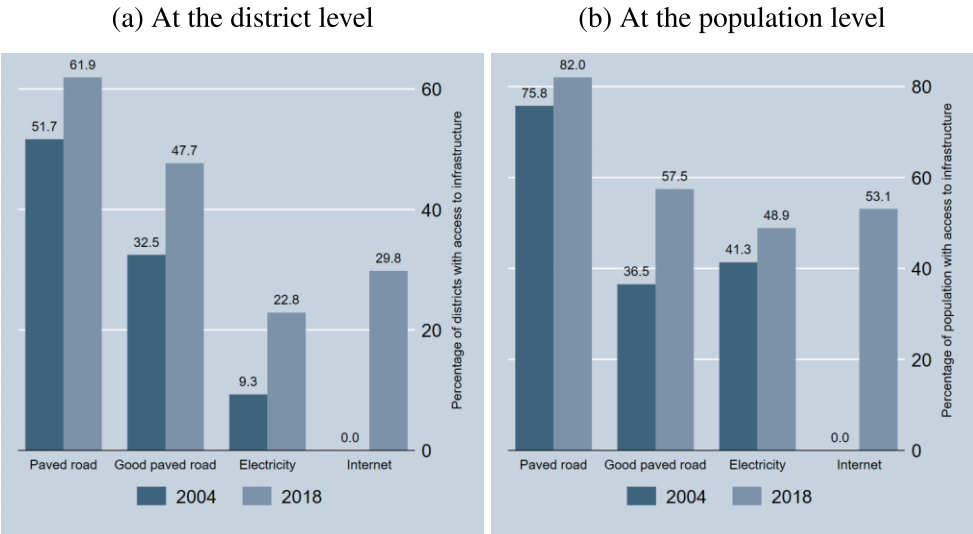


Source: Authors' calculations using data sources listed in the data section.

Note: Good paved roads include roads of fair or good condition. The left graph shows the percentage of districts with access to infrastructure (admin 2 for Nigeria), the right graph the percentage of population using the 2015 district population.

S2.2. Data for the Lake Chad Region

Figure S2.2. Access to Infrastructure in Cameroon, 2004 and 2018.

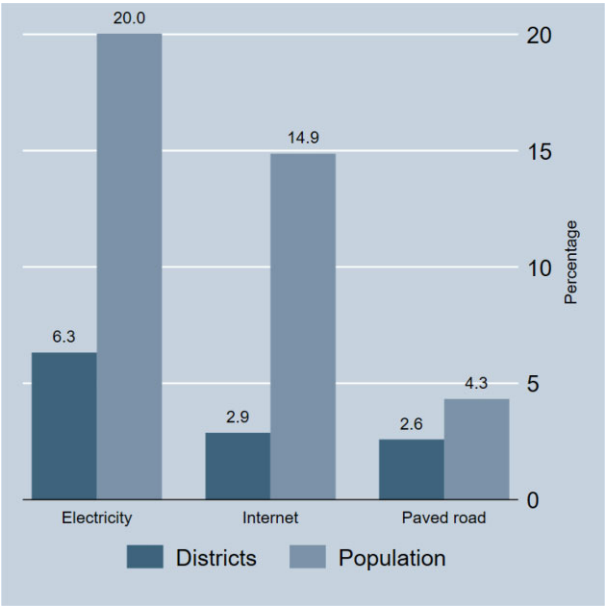


Source: Authors' calculations using data sources listed in the data section.

Note: The left graph shows the percentage of districts with access to infrastructure (admin 3 for Cameroon), the right graph the percentage of population using the 2015 district population.

S2.3. Infrastructure in Nigeria

Figure S2.3. Access to Infrastructure in Chad, 2014.

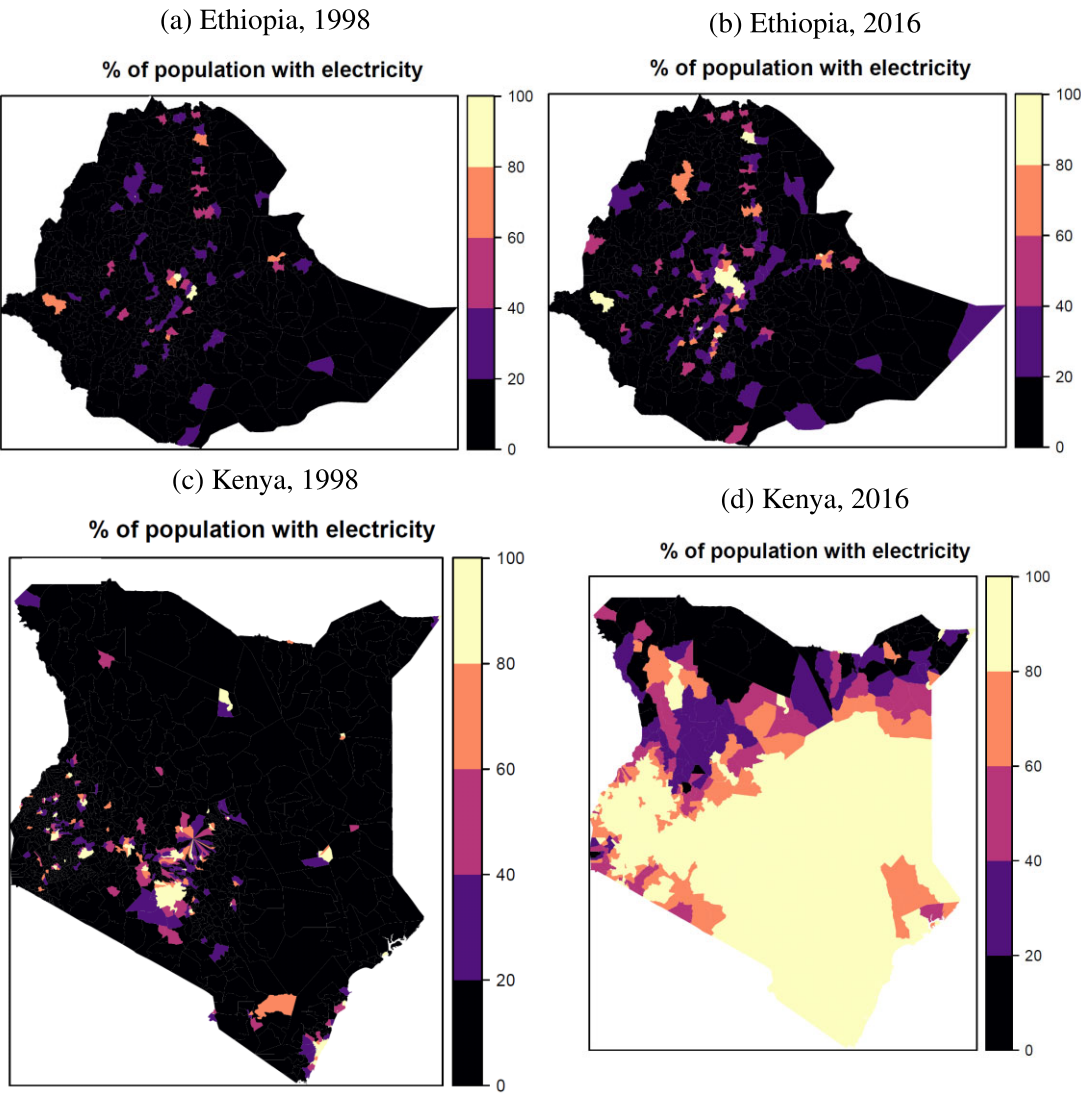


Source: Authors' calculations using data sources listed in the data section.

Note:

S2.4. Cameroon

Figure S2.4. Percentage of Population with Access to Electricity Based on Night-Lights, 1998 and 2016.

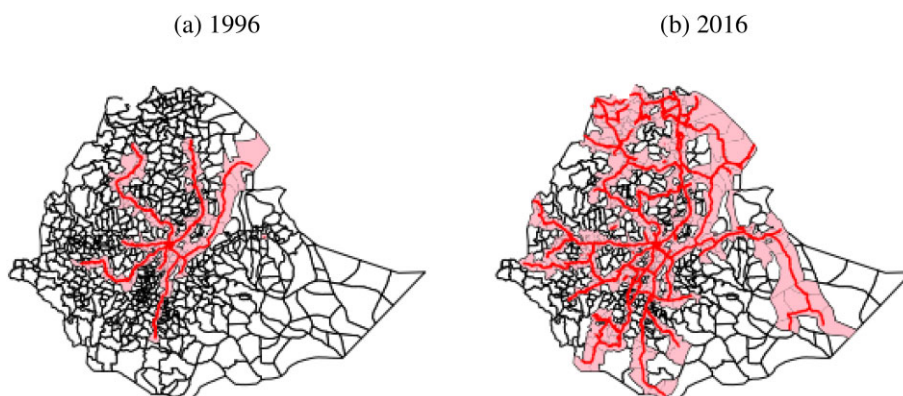


Source: Authors' calculations.

Note: The maps report the percentage of population with electricity in 1998 and 2016 for Ethiopia and Kenya.

S2.5. Chad

Figure S2.5. Paved Road Network in Ethiopia, 1996 and 2016.

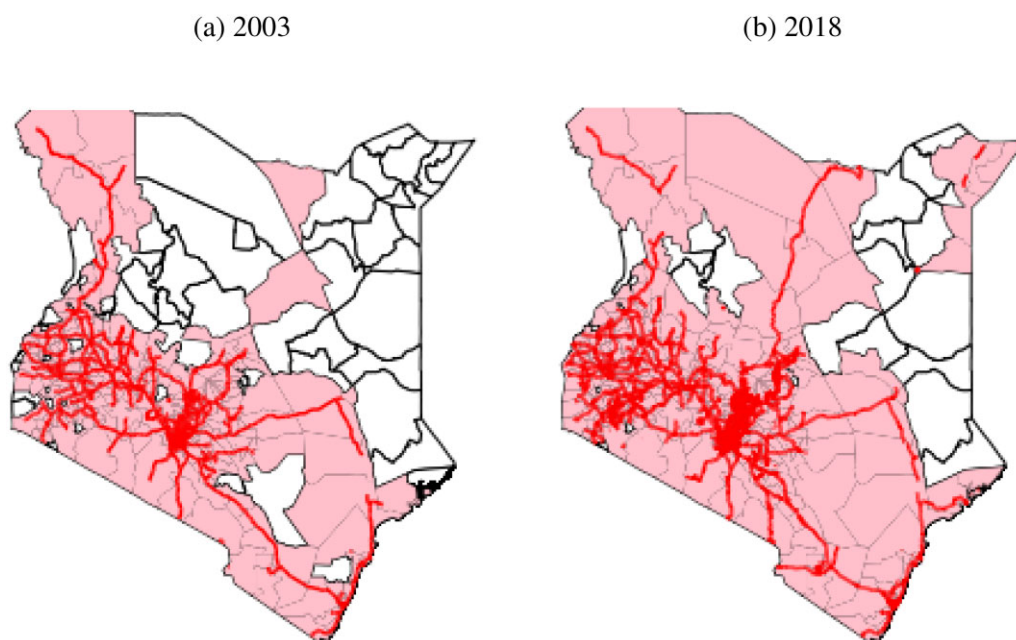


Source: Authors' calculations using data from the Ethiopian Roads Authority (ERA) used in [Croke and Duhaut \(2020\)](#).

Note: The maps show the paved road network in Ethiopia, for the years 1996 and 2016.

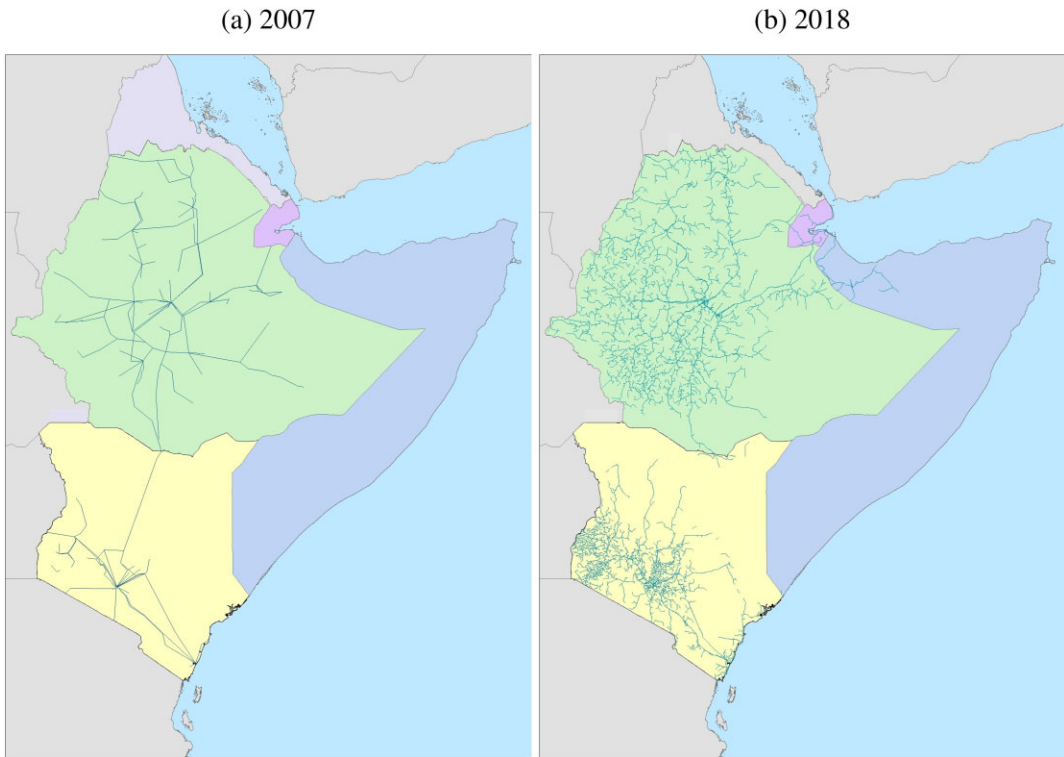
S2.6. Additional Data

Figure S2.6. Paved Road Network in Kenya, 2003 and 2018.



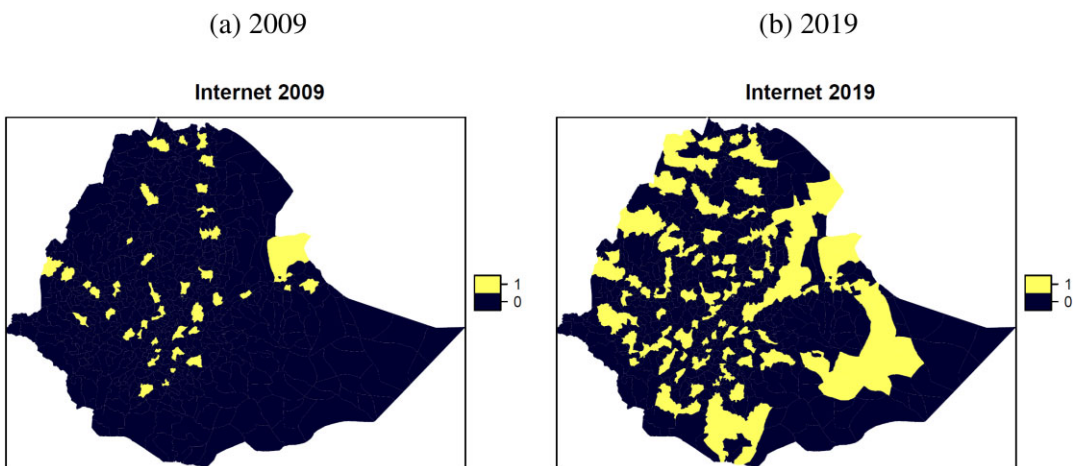
Source: Authors' calculations using data from the Kenya Road Board.

Note: The maps show the paved road network in Kenya, for the years 2003 and 2018.

Figure S2.7. Electricity Grid in Ethiopia and Kenya.

Source: Authors' calculations using data from [Foster and Briceno-Garmendia \(2010\)](#), [gridfinder.org](#), and [Arderne et al. \(2020\)](#).

Note: The left map shows the electricity grid for the Horn of Africa region in 2007. The right map shows the electricity grid for the Horn of Africa region in 2018.

Figure S2.8. Access to Internet Backbone in Ethiopia, 2009 and 2019.

Source: Authors' calculations using Africa Bandwidth Maps data.

Note: The maps show whether a region in Ethiopia is considered as having access to the Internet backbone in 2009 (left) and 2019 (right).

Table S2.1. Isolated versus Bundled Investments Using the 50 Percent Electricity Threshold

Paved road	(a) Roads and electricity		
	Electricity		
	0	1	Total
0	1,823	22	1,845
1	1,237	340	1,577
Total	3,060	362	3,422
Paved road	(b) Roads and Internet		
	Internet		
	0	1	Total
0	1,832	13	1,845
1	1,360	217	1,577
Total	3,192	230	3,422
Internet	(c) Electricity and Internet		
	Electricity		
	0	1	Total
0	2,921	271	3,192
1	139	91	230
Total	3,060	362	3,422

Source: Authors' calculations.

Note: The table reports the number of regions with isolated or bundled infrastructure.

Table S2.2. Isolated versus Bundled Investments Using the 80 Percent Electricity Threshold

Paved road	(a) Roads and electricity		
	Electricity		
	0	1	Total
0	1,842	3	1,845
1	1,380	197	1,577
Total	3,222	200	3,422
Internet	(b) Electricity and Internet		
	Electricity		
	0	1	Total
0	2,028	164	3,192
1	194	36	230
Total	3,222	200	3,422

Source: Authors' calculations.

Note: The table reports the number of regions with isolated or bundled infrastructure.

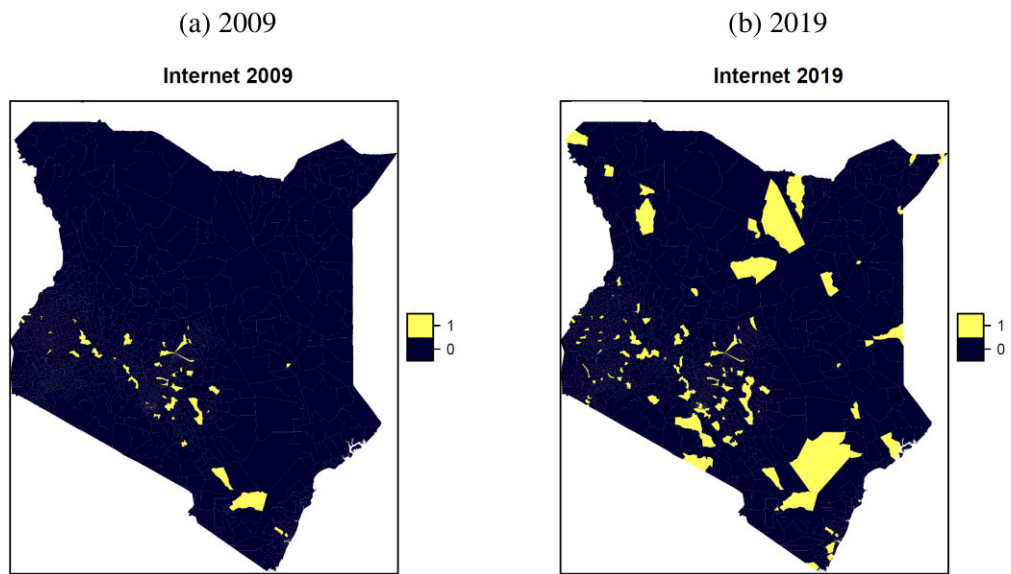
Table S2.3. GADM Administrative Levels

Level	Ethiopia	Kenya	Somalia	Djibouti
Adm1	11	47	18	5
Adm2	79	301	74	11
Adm3	690	1,446		

Source: Authors' calculations.

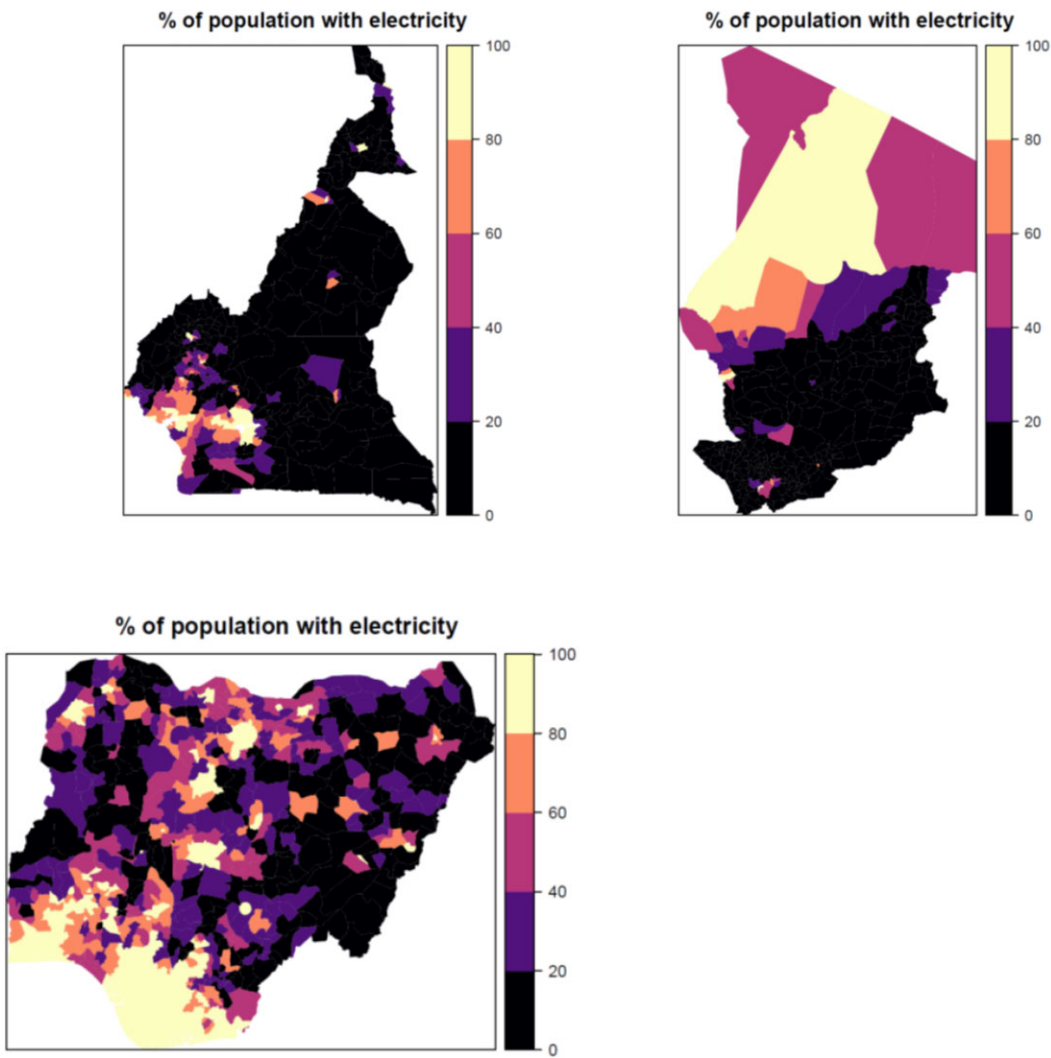
Note: GADM, the Database of Global Administrative Areas, is a high-resolution database of country administrative areas. Adm1 refers to the first-level administrative areas. Adm2 refers to the second-level administrative areas. Adm3 refers to the third-level administrative areas.

Figure S2.9. Access to Internet Backbone in Kenya, 2009 and 2019.



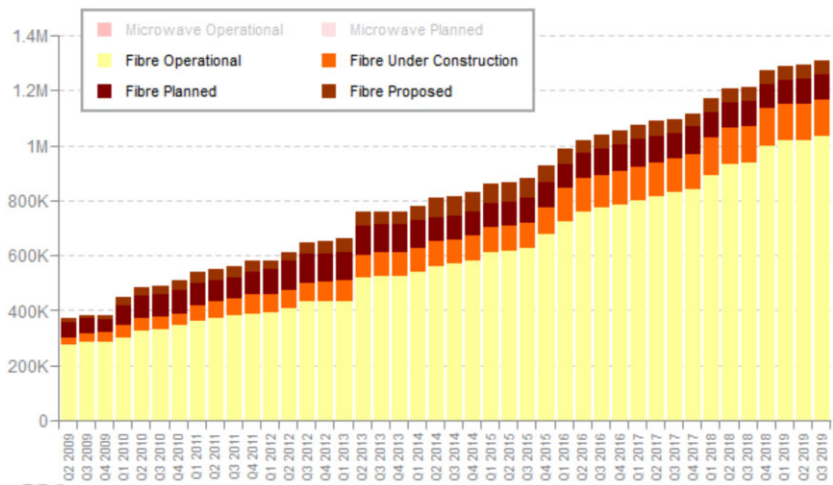
Source: Authors' calculations using Africa Bandwidth Maps data.
Note: The maps show whether a region in Kenya is considered as having access to the Internet backbone in 2009 (left) and 2019 (right).

Figure S2.10. Percentage of Population with Access to Electricity Based on Night-Lights, 2016.



Source: Authors' calculations.
Note: The maps report the percentage of population with electricity in 2016 for Cameroon, Chad, and Nigeria.

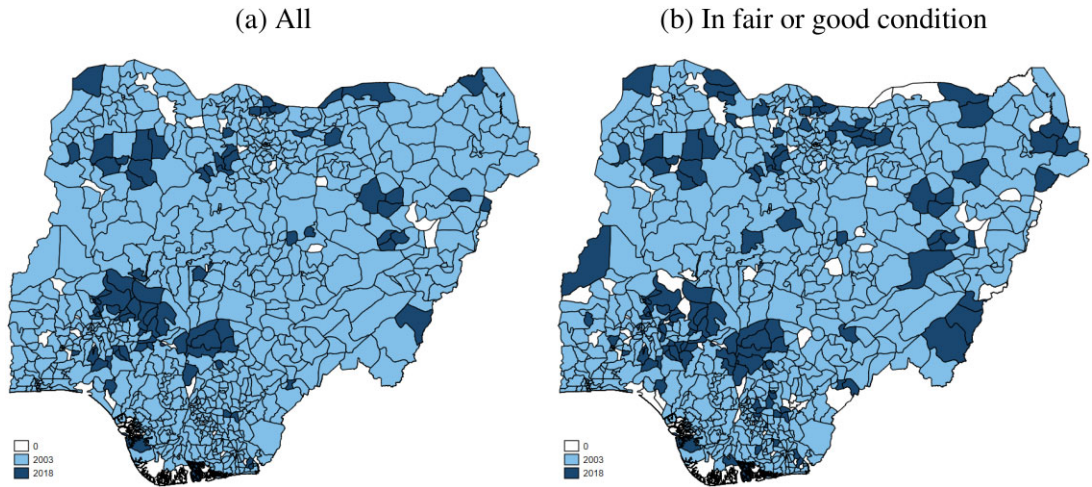
Figure S2.11. Route-Kilometers of Terrestrial Transmission Network, Africa 2009–2019.



Source: <http://www.africabandwidthmaps.com/>.

Note: The figure shows the change in terrestrial transmission network in Africa between 2009 and 2019.

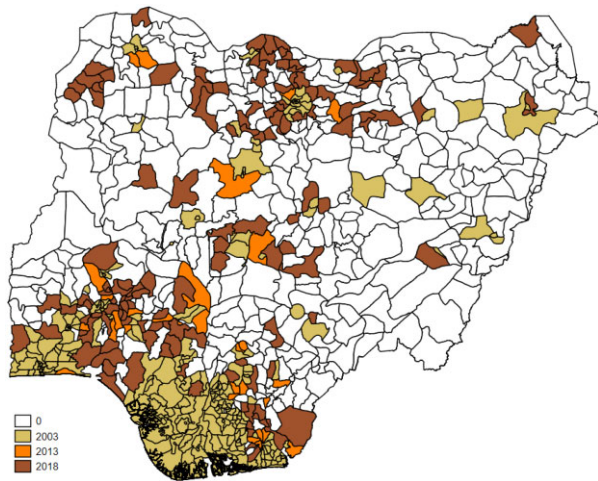
Figure S2.12. Paved Road Network in Nigeria.



Source: Authors' calculations using data from Foster and Briceno-Garmendia (2010) and Ali et al. (2015).

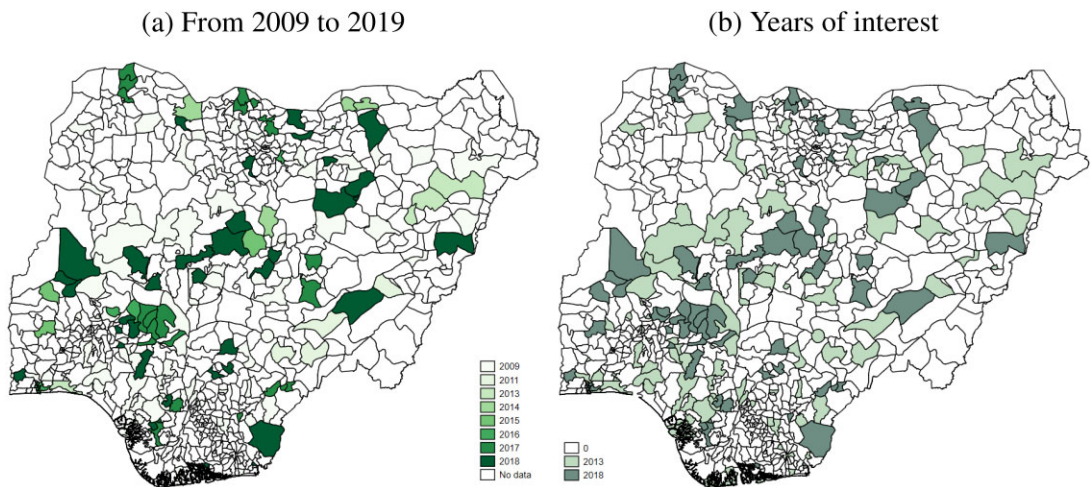
Note: The map represents the year in which access to a paved road is observed. Zero means that no paved road is reported in the latest observed year. "2013" refers to districts with a paved road when observed in 2013 only. "2018" refers to additional districts with a paved road when observed in 2018 compared to 2013.

Figure S2.13. Access to Electricity.

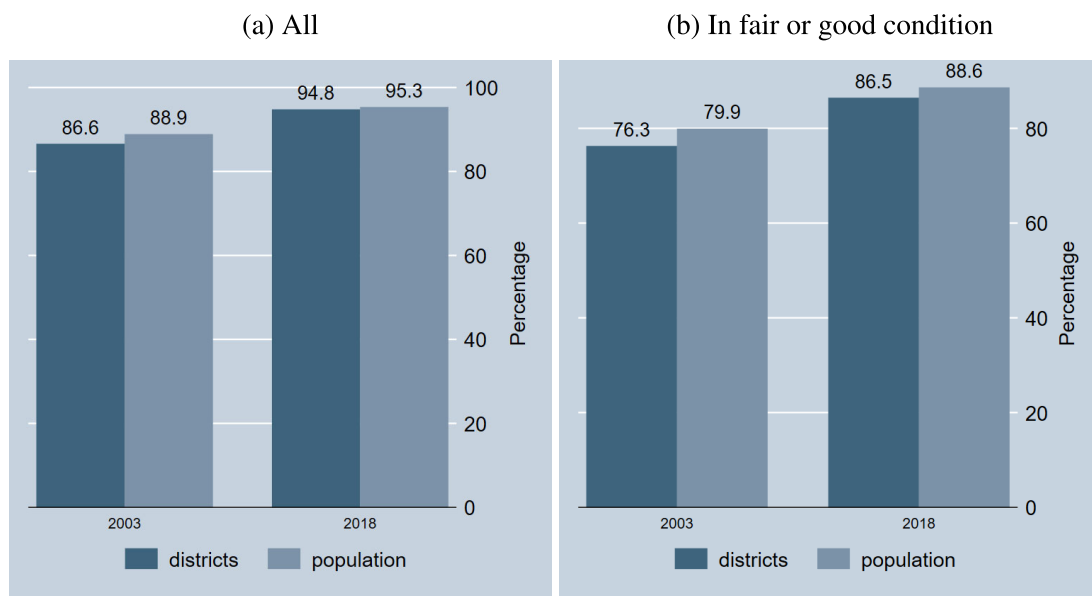


Source: Authors' calculations using nighttime lights.
Note: The map represents the year in which at least 50 percent of the population has access to electricity, measured by lights at night. Zero means that no access to electricity is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

Figure S2.14. Access to Internet Fiber Network.

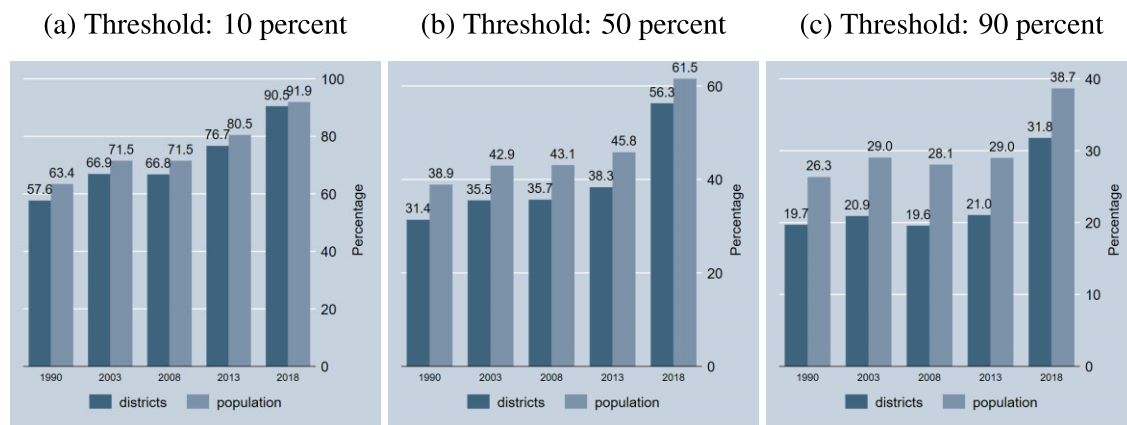


Source: Authors' calculations using Africa Bandwidth Maps.
Note: The maps represent access to the fiber network as measured with a node being present in the district. Zero means that no access is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

Figure S2.15. Percentage of Districts and Population with Access to a Paved Road.

Source: Authors' calculations using data from [Foster and Briceño-Garmendia \(2010\)](#) and [Ali et al. \(2015\)](#).

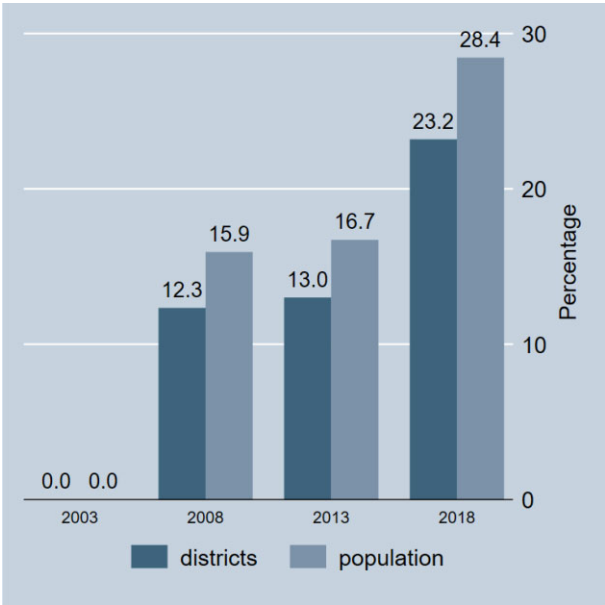
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

Figure S2.16. Percentage of Districts and Population with Access to Electricity for Different Thresholds.

Source: Authors' calculations.

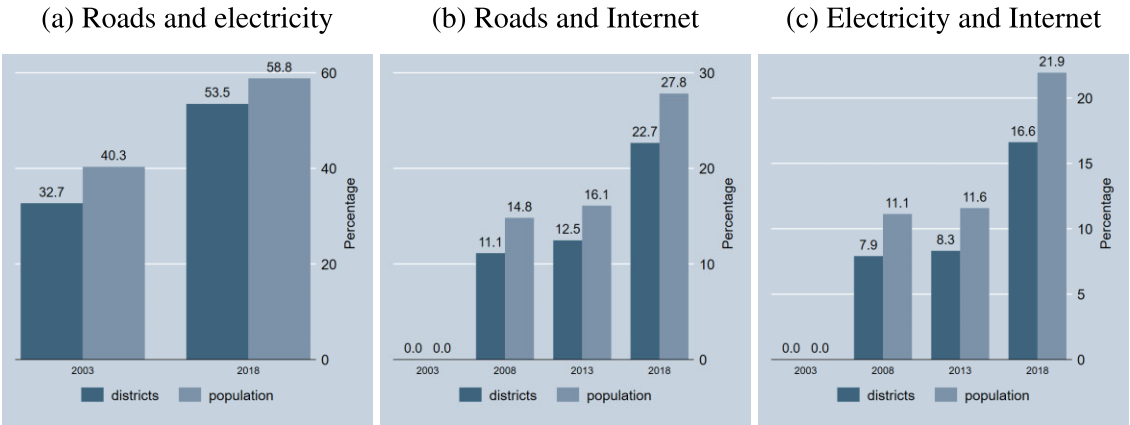
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

Figure S2.17. Access to Internet Broadband.



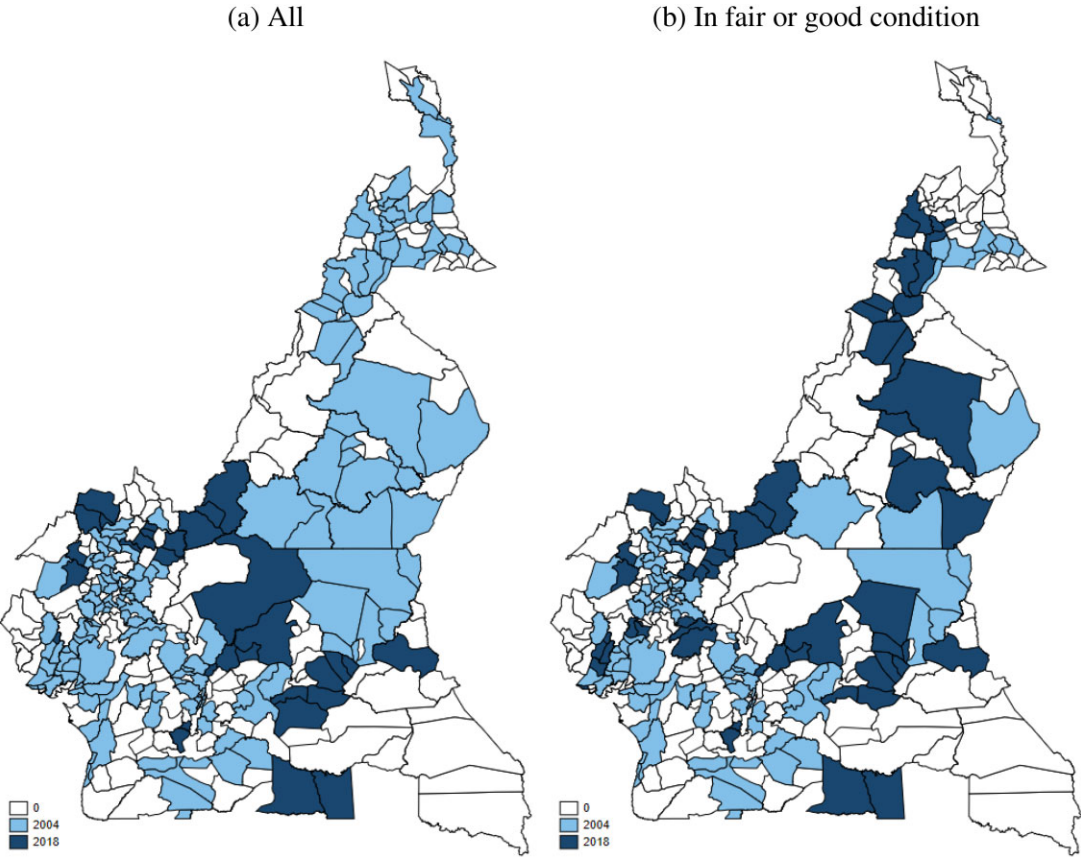
Source: Authors' calculations using Africa Bandwidth Maps.
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

Figure S2.18. Percentage of Districts and Population with Access to Combined Infrastructures.



Source: Authors' calculations.
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

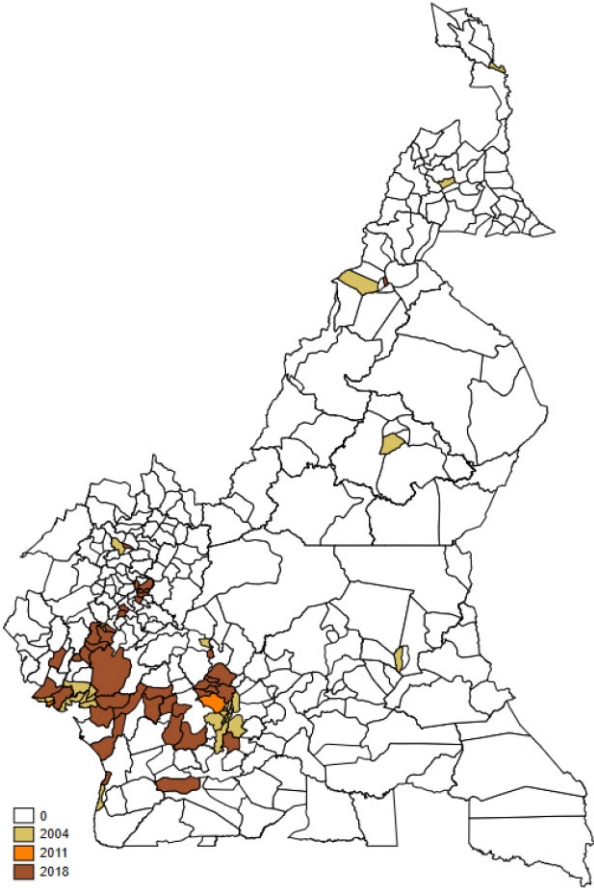
Figure S2.19. Access to Paved Roads.



Source: Data from Foster and Briceno-Garmendia (2010) and government sources.

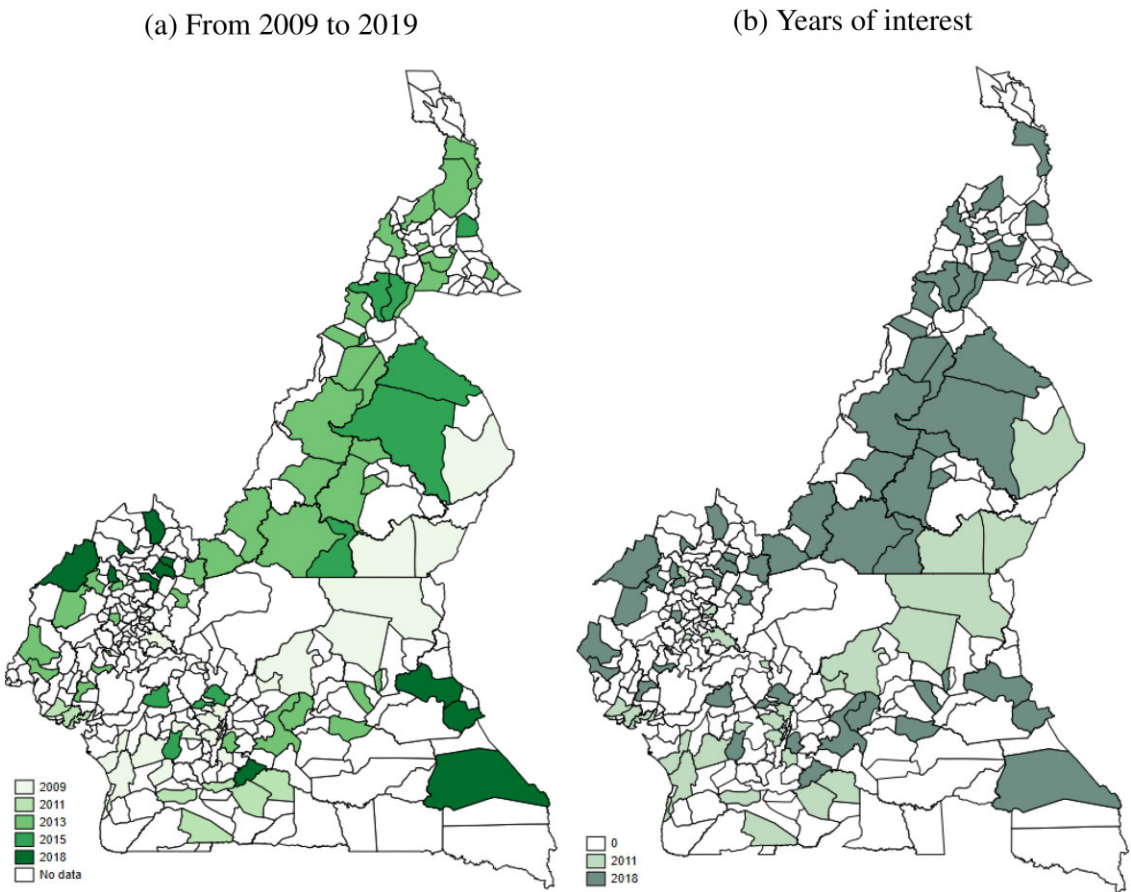
Note: The map represents the year in which access to a paved road is observed. Zero means that no paved road is reported in the latest observed year. “2013” refers to districts with a paved road when observed in 2013 only. “2018” refers to additional districts with a paved road when observed in 2018 compared to 2013.

Figure S2.20. Access to Electricity.



Source: Authors' calculations using nighttime lights.
Note: The map represents the year in which at least 50 percent of the population has access to electricity, measured by lights at night. Zero means that no access to electricity is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

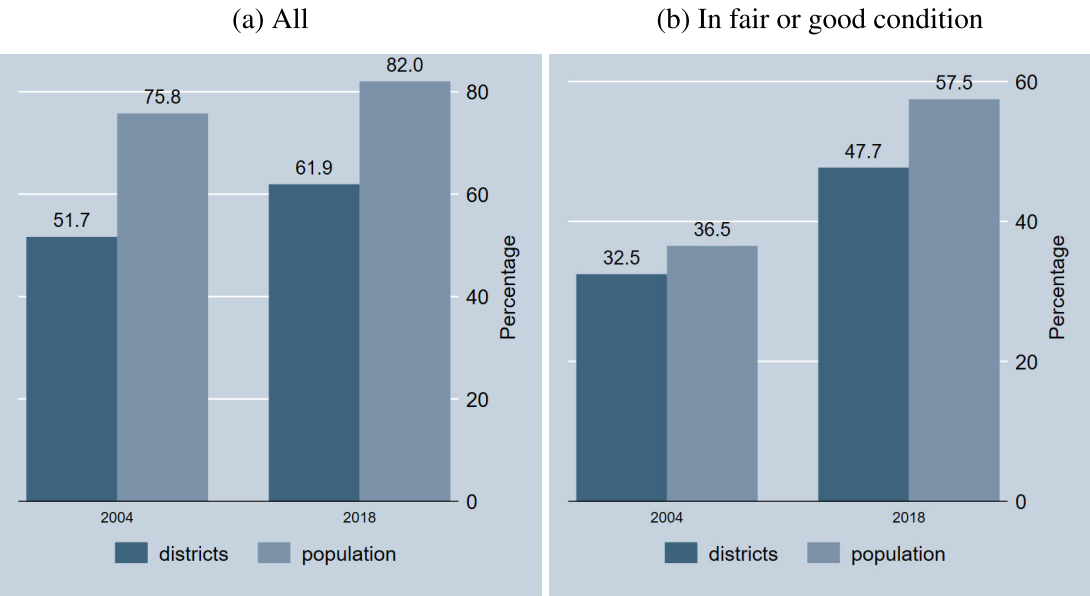
Figure S2.21. Access to Internet Fiber Network.



Source: Authors' calculations using Africa Bandwidth Maps.

Note: The maps represent access to the fiber network as measured with a node being present in the district. Zero means that no access is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

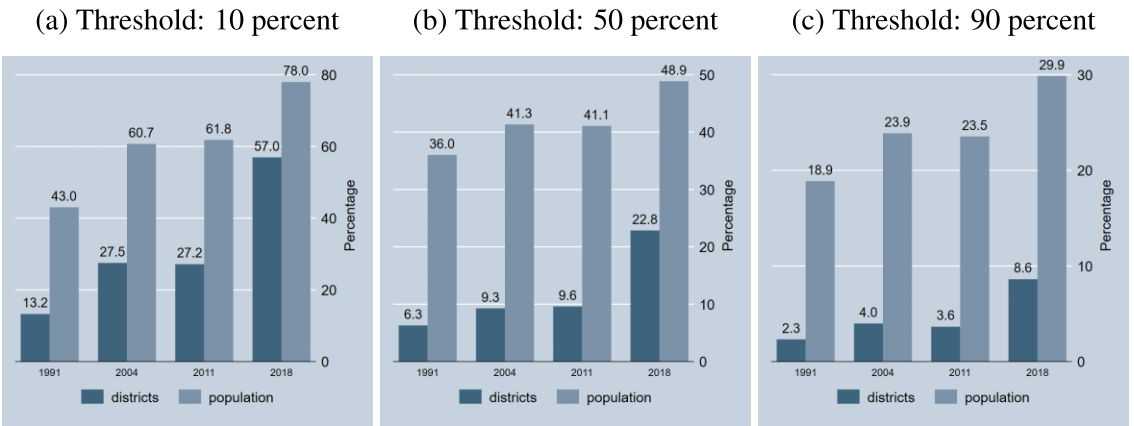
Figure S2.22. Percentage of Districts and Population with Access to a Paved Road.



Source: Data from Foster and Briceno-Garmendia (2010) and government sources.

Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

Figure S2.23. Percentage of Districts and Population with Access to Electricity for Different Thresholds.



Source: Authors' calculations.

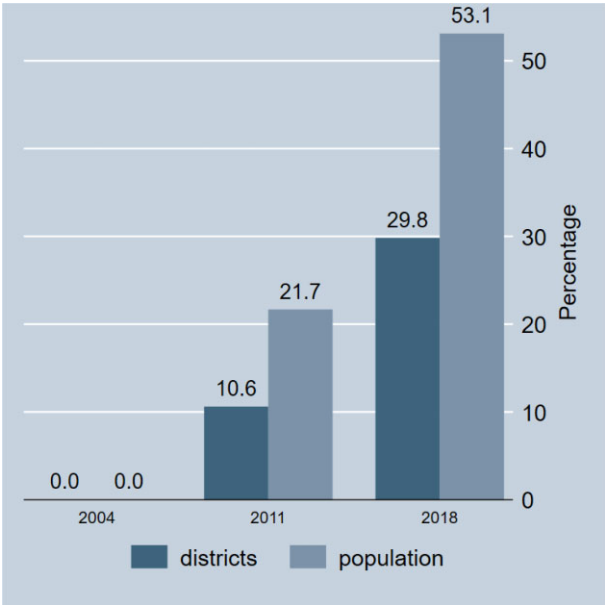
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

S2.7. Transport Counterfactuals

S2.7.1. New Transport Infrastructure in Cameroon and Chad

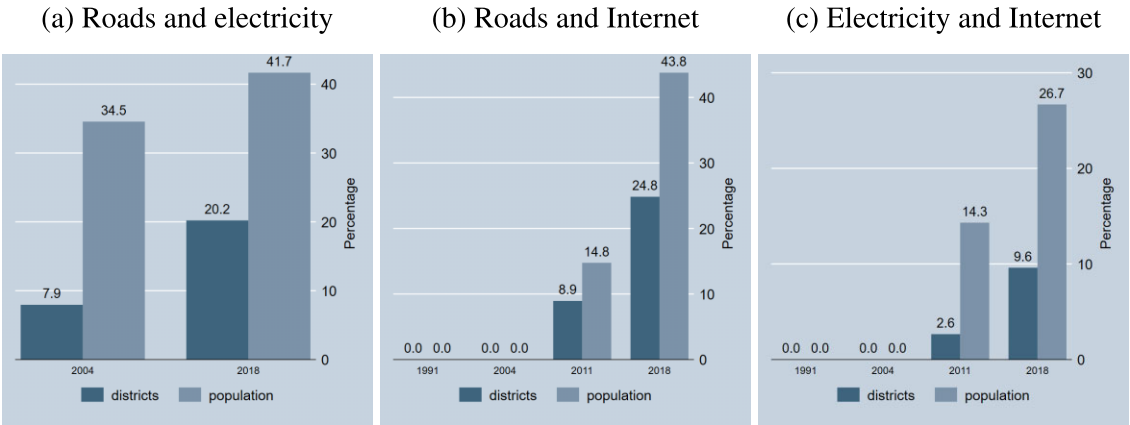
The paper investigates the impact of several transport and trade facilitation projects listed in [table S2.5](#), financed by the World Bank and other donors. These projects are part of an approach to provide a long-term, reliable, safe, and efficient multimodal corridor over the entire 1,800-kilometer-long stretch be-

Figure S2.24. Access to Internet.



Source: Authors' calculations using Africa Bandwidth Maps.
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

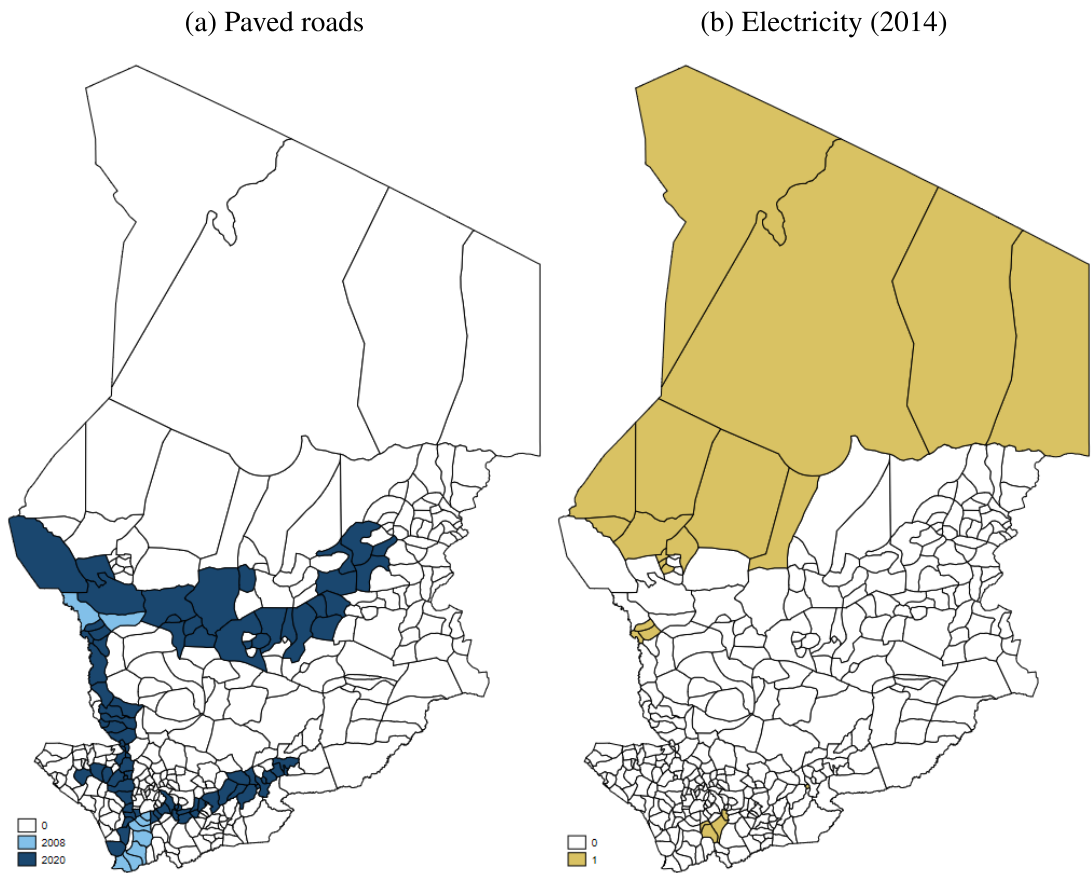
Figure S2.25. Percentage of Districts and Population with Access to Combined Infrastructures.



Source: Authors' calculations.
Note: The population used for weighted average of access is from the Global Human Settlement (GHS) layer of 2015. The figures report the percentage of districts and population with access.

tween Douala–Ngaoundéré–Koutéré–Moundou–Ndjamena (forthcoming World Bank Project Appraisal Document). The corridor contributes to improving domestic, regional, and international connectivity for both countries.

Figure S2.26. Access to Paved Roads and Electricity.



Source: Authors' calculations.
Note: Data using government sources and nighttime lights. Map (b) represents the year when at least 50 percent of the population has access to electricity, measured by lights at night in 2014. Map (a) represents the year when the population of a region is considered as having access to a paved road. Zero means that no access is reported in the latest observed year. Successive years refer to additional districts which gained access when compared to previous years.

Table S2.4. GADM Administrative Levels

Level	NGA	NER	TCD	CMR
Adm1	37	8	23	10
Adm2	775	36	55	58
Adm3	NA	132	348	360

Source: Authors' calculations.
*Note:*GADM, the Database of Global Administrative Areas, is a high-resolution database of country administrative areas. Adm1 refers to the first-level administrative areas. Adm2 refers to the second-level administrative areas. Adm3 refers to the third-level administrative areas. NGA = Nigeria; NER = Niger; TCD = Chad; CMR = Cameroon.

Table S2.5. Summary of Counterfactual Scenarios

Scenario	Country	Infrastructure	Productivity shock	Border policies
1	Cameroon	Baseline	Limited access which varies across regions	Platform in Ngaoundéré to move from rail to road
1	Chad	Corridor (Njamena–Moundou) in bad condition: speed 30 km per hour followed by the segment Moundou to the border in good condition	Limited access	Land border with Cameroon: 30 hours per each border point + administrative costs to trade
2.1 (road)	Cameroon	Transport infrastructure investments		
	Chad	Baseline	Baseline	Baseline
2.2 (road and rail)	Cameroon and Chad	Upgraded road line		
		Upgraded rail line and road corridor	Baseline	Baseline
3	Cameroon and Chad	Electrification and Internet		
		Baseline	Productivity shock in modern sectors from universal access	Baseline
4.1	Cameroon	Transport + border investments		
	Chad	Baseline	Baseline	Half border time
4.2	Cameroon and Chad	Upgraded road corridor		
		Upgraded road corridor and rail line	Baseline	Half border time
5	Cameroon and Chad	Transport + electrification + Internet + border investments		
		Upgraded road corridor and rail line	Productivity shock from universal access	Half border time

Source: Authors' calculations.

Note: The table summarizes the different counterfactuals for the Lake Chad region.

Figure S2.27. Access to Internet Fiber Network.

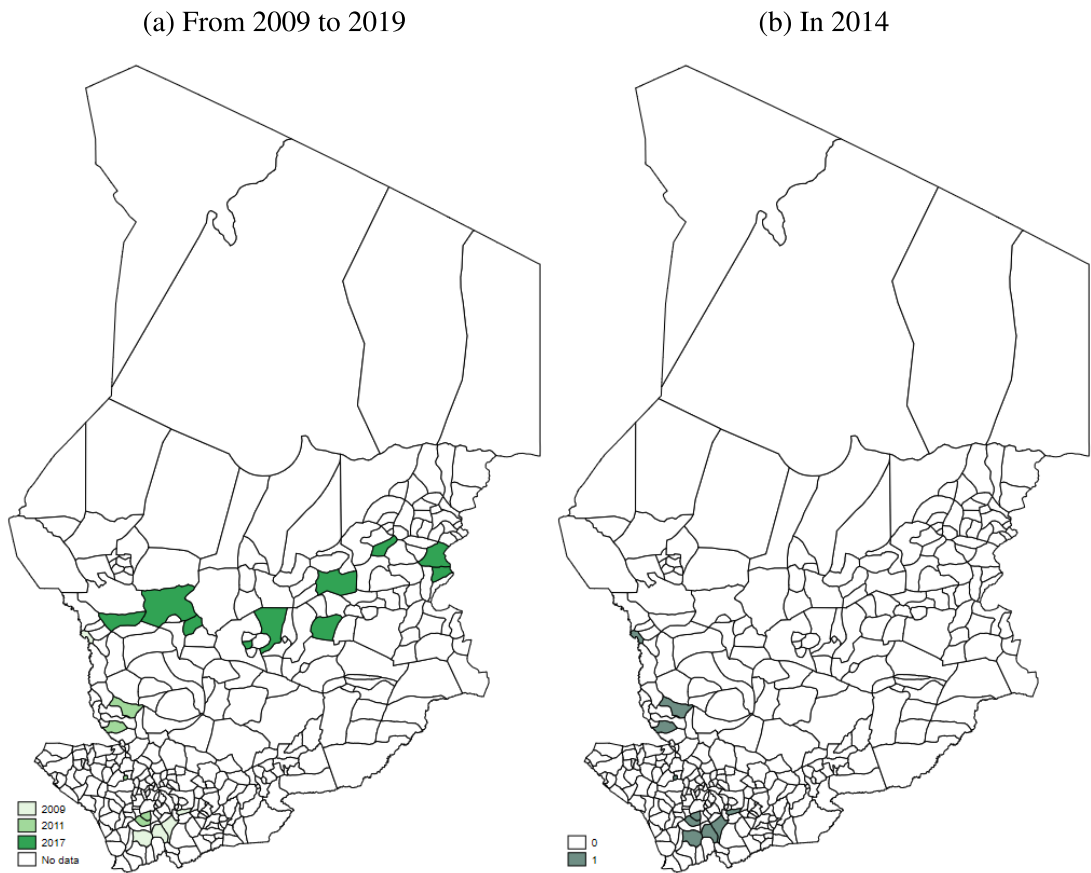


Figure S2.28. Percentage of Districts and Population with Access to Infrastructure (2014).

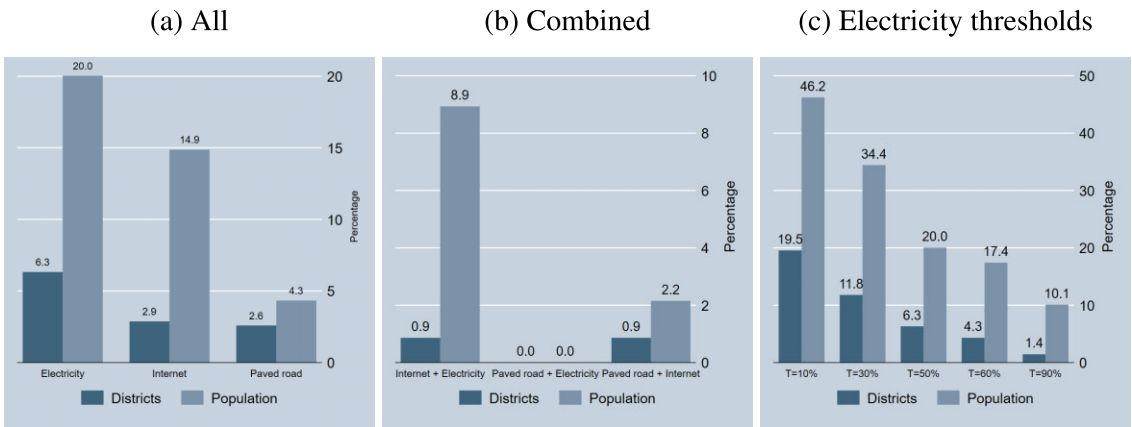


Figure S2.29. Lake Chad Sub-Region.

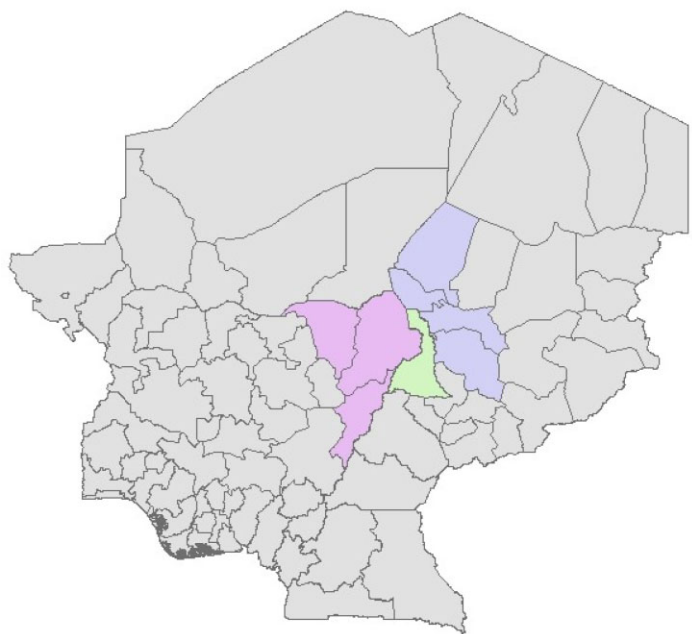


Figure S2.30. Electricity Grids, 2007 and 2018.

(a) 2007

(b) 2018



Source: Electricity grids from [Foster and Briceno-Garmendia \(2010\)](#) and [Arderne et al. \(2020\)](#).
Note: The maps report the electricity grids for the Lake Chad region for 2007 (left) and for 2018 (right).

Table S2.6. Summary of Counterfactual Scenarios for Transport Investments

Scenario	Country	Road infrastructure	Policies
1	Djibouti, Ethiopia, Kenya, Somalia	Baseline Speed and road conditions from latest surveys	High border delays
2.1	Kenya, Somalia, Ethiopia	With transport infrastructure investments Corridor 1: Kismayo, Lamu, and Mogadishu corridor with 3,093 km of rehabilitation or new roads	High border delays
2.2	Djibouti, Ethiopia	Corridor 2: Assab and Djibouti corridor with 649 km of rehabilitation or new roads	High border delays
2.3	Somalia, Djibouti	Corridor 3: Berbera and Djibouti corridor with 1,003 km of rehabilitation or new roads	High border delays
2.4	Djibouti, Ethiopia, Somalia	Corridor 4: Mogadishu, Berbera, and Bossasso corridor with 2,550 km of rehabilitation or new roads	High border delays
3	Djibouti, Ethiopia, Kenya, Somalia	With border infrastructure investments Corridors 1–4	50 percent reduction in border times at border posts along corridors 1–4

Rehabilitation of the Rail Line in Cameroon. The renovation of the rail line between Ngaoundéré, Yaounde, and Douala in Cameroon is going through several steps. The World Bank participates in the financing of the southern part of the project for the segment between Douala and Yaounde, while the Agence Française de Développement (AFD) and the European Investment Bank (EIB) are planning to finance the rehabilitation of the section from Belabo up to Ngaoundéré in North Cameroon in 2022. The counterfactual assumes that the two rehabilitations will happen at the same time. The government is planning to renovate the most-used segment between Yaounde and Douala, whose condition has deteriorated in the last years. After these projects are completed, the whole existing railway network will be rehabilitated, increasing capacity, safety, speed, reliability, and efficiency of rail traffic and therefore improving performance of the corridors. The counterfactual assumes very low speed on the whole line in the baseline.

Rehabilitation of Road Corridors in Chad. There are several historical corridors between Cameroon and Chad. Tensions in the Far North have closed the corridors passing by the northern part of Cameroon and opened the possibilities for other corridors to develop. From Ngaoundéré to Ndjamena, the traditional road corridor crosses the region of North Cameroon, which is under the threat of Boko Haram; for this reason this road section is today considered unsafe and unreliable. An alternative road corridor from Ngaoundéré to Ndjamena crosses the border near Moundou (second largest city in Chad) and then connects Moundou with Ndjamena (about 600 kilometers). The World Bank is currently assessing a project aiming at rehabilitating this section of the corridor with other donors co-financing. As of today the road is totally dilapidated while 100 percent paved. This project would improve connectivity to the port of Douala, increase domestic connectivity between the main two cities of Chad, and improve the regional/international connectivity of Moundou. The proposed project covers the whole corridor between Koutéré–Moundou–Ndjamena under a phased 10-year long-term approach that entails rehabilitation works, reinforcement, maintenance, and axle-load-monitoring facilities management.

S2.7.2. New Transport Infrastructure in the Horn of Africa

The paper investigates the impact of the following regional transport corridors ([table S2.6](#)).

Corridor 1: Kismayo, Lamu, and Mogadishu Corridor. Corridor 1 links population centers in Ethiopia, Kenya, and Somalia with the Somali ports of Mogadishu and Kismayo and the Kenyan port of Lamu. The corridor serves several purposes. It provides an important bilateral artery between the Kenyan and Ethiopian economies, pillars of the regional market that are currently largely disconnected. It also connects three ports that are underutilized for national and regional trade (Lamu, Kismayo, and Mogadishu) with economic centers and hinterland demand. It also establishes connectivity within some of the most remote corners of the three countries.

Corridor 2: Assab and Djibouti Corridor. Corridor 2 complements the trade corridor connecting population centers in Ethiopia with global markets through links with the port of Djibouti. It provides an alternate route between Ethiopia and the coast in Djibouti and complements existing linkages, reestablishing the historically important route to the port of Assab in Eritrea.

Corridor 3: Berbera and Djibouti Corridor. Corridor 3 is a vital import route as well the primary path for export of goods out of Ethiopia. Its Djibouti–Ethiopia segments are already fundamental links between the population centers of landlocked Ethiopia and global markets.

Corridor 4: Mogadishu, Berbera, and Bossasso Corridor. Corridor 4 provides access to the port of Mogadishu in the southeast, through population centers on the Somali agricultural heartland along the Shabeelle river, the trading center of Beledweyne, following the river through Ferfer, and toward the more populated western regions, including Addis Ababa. In the north, it connects to the port of Bossasso, through Garowe, and into Ethiopia, connecting the scattered population of Ethiopia’s Somali region and linking up to Hargessa and corridor 3 in the northwest. The corridor is intended to improve the connectivity of residents of the arid regions at the tip of the Horn of Africa.