Infrastructure and Structural Change in the Lake Chad Region

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Abstract

Access to infrastructure supports economic development through structural transformation. This paper investigates the links between investments in electricity, Internet, and transport infrastructure, in isolation and bundled, and economic development in the Lake Chad Region. Using data on the expansion of the paved road, electricity, and Internet networks over the past two decades and two instruments, it provides reduced-form estimates of the impacts of infrastructure investments on the sectoral composition of employment. Bundled infrastructure investments cause different patterns of structural transformation than isolated infrastructure investments. Bundled paved road and electricity investments is found to have reduced the agricultural employment share by 22 percentage points and increased the share of employment mostly in services. The paper then uses a spatial general equilibrium model to quantify the impacts of future regional transport investments, bundled with a large rural electrification program and trade facilitation measures to reduce border delays, on economic development in Nigeria, Cameroon, and Chad.

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1 Introduction

Infrastructure investments can support economic development through both capital accumulation and structural transformation.[1] 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. However poor infrastructures in low-income countries create transport and information frictions that increase the distance of economic agents relative to one another, limiting the economic specialization within and across neighboring countries. Transport improvements lead to faster journeys, making economic agents closer together, and may also trigger relocation of economic activity, increasing productivity and allowing workers to switch to more productive jobs. 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 whether the combinations of different infrastructures create a big push 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 three neighboring countries, Nigeria, Cameroon, and Chad.

This paper focuses on the impact of infrastructure on economic development for three countries around Lake Chad in north-west Africa, Cameroon, Chad, and Nigeria. The Lake Chad sub-region, an economically- and socially- integrated area that has been undermined by multiple and interrelated drivers of fragility, conflict, and violence, comprises an estimated 17 million to 19 million people, who are primarily involved in agriculture and fishing activities. The sub-region has one of the largest concentrations of extreme poverty in Sub-Saharan Africa. Nigeria, Cameroon, and Chad, while being at different stages of development, all face a similar challenge to generate more and better jobs through economic transformation. Employment in non-agricultural sectors is currently around 55% in Cameroon, 65% in Nigeria, and less than 30% in Chad.[2] The share of employment in agriculture in Cameroon and Nigeria has declined since the 1990s, while it has stagnated at high levels for Chad. Overall, the pace of structural change has remained slower than expected in the region, hence the need to understand the role of infrastructure as a potential driver for structural transformation.

Because the Lake Chad region is characterized by strong historical trade, ethnic, cultural, and political ties, which makes the areas within countries that comprise the region econom-

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[1]There are two approaches for explaining economic growth (McMillan et al., 2017). The first assumes that the accumulation of skills, capital, and broad institutional capabilities are needed to generate sustained productivity growth. The second 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.

[2]World Bank data, see figure A1 in Appendix .

ically interdependent, we study the impact of regional integration and cross-border linkages when assessing the impact of future infrastructure investments. Currently, connectivity across the borders is poor due to a lack of road infrastructure, high border delays, and volatile security situations that make trade or transportation of goods too costly. The paper complements the analysis of key infrastructure investments with additional trade facilitation measures at the borders.

The paper is divided in two parts. The first part uses reduced-form analysis to quantify the impacts of past investments in electricity, internet, and road infrastructure on the structure of employment in Cameroon, Nigeria, and Chad over the past two decades. We show that major past infrastructure investments have had a large impact on the structure of the local economies. The second part uses a spatial general-equilibrium model, based on Moneke (2020), to assess the aggregate and spatial impacts of future infrastructure investments in the region. 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 transport infrastructure. 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 Lake Chad region and generates welfare estimates for the entire region and all its subregions.

We first provide evidence on how past investments and their combinations have impacted structural transformation in Cameroon, Nigeria, and Chad. Geo-identified data on the infrastructure expansion of roads and electricity for Cameroon, Nigeria, and Chad are collected over time and across space, and linked with information on local economic activity based on household-survey data. Two instrumental variables are developed to overcome the endogeneity concerns for road and electricity investments. Following Moneke (2020) and Gaggl et al. (2019), straight transmission lines connecting the main cities with newly opening hydropower dams in Cameroon and power plants in Nigeria are used for electrification, the construction of an hypothetical least-cost network expansion using a minimum spanning tree algorithm is used for road expansion. The paper finds different effects of bundled and isolated infrastructure investments on sectoral employment. Over the last two decades, our IV estimate shows that a combined access to electricity and paved roads led to a 22 percentage-point reduction in agricultural employment, benefiting mostly the services sector. This result is in line with similar work for the Horn of Africa (Herrera Dappe and Lebrand, 2021) and Ethiopia (Moneke, 2020).

As the pace of structural change remains slow in the region, we provide counterfactual evidence of the extent to which a push for more regional integration through the expansion of transport and trade infrastructure as planned by international donors as well as complementary investments in electrification would support economic development and structural transformation. There are several channels to be considered, hence the need for a structural model. Electricity investments increase labor productivity in the non-agricultural sector which can lead to more but also fewer workers in manufacturing or services if the productivity increase exceeds

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the equilibrium impact on demand. Lower transport and border costs reduce trade frictions and might increase regional specialization. New regional corridors may therefore increase structural change in regions with a pre-existing comparative advantage in manufacturing. The use of a general-equilibrium model allows for solving all the different forces and sorting out the final impacts. Overall, the welfare gains from renovating the rail line between Douala and Ngaoudere in Cameroon and upgrading the road between Ndjamena and Moundou in Chad would be magnified when complemented with universal access to electrification and lower border delays. Large gains in purchasing power in poorer areas tend to limit out-migration and the relocation of workers towards non-agricultural regions. As a result, the impact on aggregate structural change at the country level is limited, but the effects vary across subnational regions. The Lake Chad sub-region would benefit from large welfare gains due to lower transport and border costs on tradable goods but remain mostly agricultural. On the contrary, the region of Douala and Yaounde in Cameroon, which has a comparative advantage in manufacturing, would increase its specialization into manufacturing and attract more workers from the rest of the country.

The objective of this work is to extend our understanding on the impact of infrastructure investments within and across neighboring countries in Africa. The novelties of this work are to assess the interactions between different infrastructures and how it affects the sectoral structure of employment at the district level, and to assess the impacts of several planned transport investments, universal access to electricity, and trade facilitation measures in neighboring countries that are at different stages of development. A companion paper undertakes similar work for countries in the Horn of Africa (Herrera Dappe and Lebrand, 2021).

Our paper is related to a number of different strands of research. 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 points decline in the share of agricultural workers and an equivalent rise in wage labor. Gaggl et al. (2019) show that electrification drove 15.7% of the decline in the share of agricultural employment and 28.4% of the increase in the share of manufacturing employment between 1910 and 1940. Electrification was thus a key driver of structural transformation in the U.S. economy. This paper adds to this literature by looking at the district-level impact of infrastructure on sectoral employment in the Lake Chad.

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 et al., 2015). This approach does not allow to isolate the complementarities of different infrastructure. Moneke (2020) shows that transport and electricity

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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, for other African countries.

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 uses to assess the impact of the US interstate highway system. Michaels et al. (2011) look at changes in sectoral employment as an outcome that captures the underlying infrastructure-induced effects.[3] Bustos et al. (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 et al., 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. Section 2 presents the data and descriptive statistics. Section 3 presents the empirical strategy and results. Section 4 develops a spatial general-equilibrium model to produce counterfactuals for more domestic and regional integration through future infrastructure investments. Section 5 concludes.

2   Data and descriptive statistics

2.1   Data

This paper uses household survey data that have been georeferenced, new spatial infrastructure data, and district characteristics in order to study links between access to infrastructure and the structure of local economies as well as the complementarities between types of infrastructure.

Infrastructure   We collected new information on road network expansions, access to the electricity network, and access to Internet fiber backbone from various sources (Table 1).

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[3]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.

Table 1: Summary of Infrastructure data

Infrastructure	Country	Year	Source
Roads	Nigeria Nigeria	1991 2009 around 2013	Jedwab and Storeygard (2020) Foster and Briceno-Garmendia (2010) Ali et al. (2015)
	Cameroon	2009 2018	Foster and Briceno-Garmendia (2010) Road authorities
	Chad	2009 2018	Foster and Briceno-Garmendia (2010) Road authorities
Electricity	All	vary across countries	Nighttime lights / Population raster
Electricity grid	All All	around 2006 most recent	Foster and Briceno-Garmendia (2010) gridfinder.org and Arderne et al. (2020)
Internet	All	2009-2019	Africa Bandwidth Maps 2009-19

We gathered geospatial maps of road expansion using government sources as well as previously harmonized collections of road networks (Foster and Briceno-Garmendia, 2010; Jedwab and Storeygard, 2020). The quality of the network and associated features and the frequency of updates vary across countries. We first used road networks from Foster and Briceno-Garmendia (2010) which relied on surveys and governments sources as a baseline for years between 2000 and 2007. Additional government surveys provided more recent road networks for Cameroon and Chad. We used the road network from Ali et al. (2015) for Nigeria which included road survey data from the Nigeria Federal Roads Maintenance Agency (FERMA) and the World Bank's Fadama project.[4] Panels of roads from the same source are rare. Related works include a similar paper applied to the Horn of Africa (Herrera Dappe and Lebrand, 2021) and Moneke (2020) whose focus on 'all-weather' (i.e. gravel, asphalt or bitumen surface) roads is closer to ours.

We used two methods 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. We used satellite images of annualized nighttime lights (VIIRS for 2016, DMSP for 1992-2013) and population rasters from World Pop to calculate the percentage of the population that was electrified (lived in settlements that produce some light at night). We compared the results for two metrics: a dummy that is equal to one 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.[5] This method assumes that locations that emit lights at night are in settlements that have electricity access and that their electricity is

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[4]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.

[5]An example of mapping rural electrification based on night-time lights can be found at http://india.nightlights.io/.

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. We cross-checked the numbers obtained with country estimates of electrified population from the World Bank.[6] Figure A2 in the Appendix shows the share of the population with access to electricity.

We also collected information on transmission grids based on past efforts to harmonize data for infrastructure from primary sources and recent mapping strategies to infer the electricity grids based on satellite data. For past data, we used 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). To complement these data, we relied on a recent effort by the World Bank; Facebook; and other institutions (the KTH Royal Institute of Technology, the Energy Sector Management Assistance Program [ESMAP], World Resources Institute, and the University of Massachusetts Amherst) to use 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.[7] Figure A22 in the Appendix shows the grid for the Lake Chad region using the AICD grid and using the most recent grid.

Internet infrastructure is proxied by access to the fiber broadband backbone network. We obtained data for all Africa for 2009–20 from Africa Bandwidth Maps, which provides the exact location of fiber nodes along the backbone network. We constructed a proxy for access to the fiber backbone that is equal to one if there is a node of the backbone in the location of interest. Each node has a year attribute, which allows us to build a panel for access to the backbone. We assume that access before 2008 was null everywhere, an assumption that is supported by World Bank data on access to Internet, which reports that less than 4 percent of individuals in Sub-Saharan African countries (including high-income countries) had access to Internet in 2008. We confirmed our figures by cross-checking them against World Bank indicators reporting the percentage of the population using Internet.[8] Figures A9, A13, A19 in the Appendix shows the access to Internet in Nigeria, Cameroon, and Chad.

Employment We are interested in structural transformation, which we interpret as changes in sectoral employment, in line with the literature (Herrendorf et al., 2014). We derive sectoral employment shares from Demographic and Health Surveys (DHSs), which produce harmonized

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[6]The World Bank reports access to electricity (percent of population) for most countries for a long period at https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS.

[7]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)

[8]The World Bank reports access to Internet (percent of population) for most countries for a long time period. See https://data.worldbank.org/indicator/WeT.NET.USER.ZS.

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. 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). Niger did not conduct DHSs for the period of interest.

We use DHS data for which we have access to the occupation of the individuals as well as a proxy for their location. In order to construct the shares of employment per sector, we use respondents' answers to questions about their current occupation. We first compute the shares of nonworking individuals and then group all working individuals into three sectors: agriculture, manufacturing, and services. We aggregate individual responses within each EA and then generate an unbalanced panel of districts that had at least one EA during a survey round. The DHS–provided GPS coordinates for EA locations are not perfectly reliable because of the common random displacement applied to GPS coordinates for anonymity.[9] We aggregate EAs per geographic location.

Use of infrastructure   In addition of access to infrastructure, we consider how uses of roads, electricity and ICT infrastructure impact the structure of employment. We include variables from the DHS surveys that cover use of electricity as reported by households, ownership of cars and motorcycles, ownership of land phone and mobile phone, and use of internet. We aggregate the answers at the subnational level of interest as percentage of households that have access to electricity, own a car, a motorcycle, a land phone, a mobile phone, or use internet. The analysis of use of infrastructure complements the analysis of infrastructure investments. Not all variables are available for the whole period so we restrict our analysis to the period 2008-2018.

District characteristics   We use additional data to control for district heterogeneity. We use population data from the Global Human Settlement Layer (GHSL),[10] land categories from the European Space Agency land cover (see Defourny (2017)), distance from the coast from the Global Self-consistent, Hierarchical,[11] High-resolution Geography Database (GSHHG), distance to the border,[12] access to a city larger than 50,000 inhabitants from the Malaria Atlas Project,[13] temperature from Land Processes Distributed Active Archive Center,[14] and elevation

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[9]DHS coordinates of rural (urban) EAs are randomly displaced within a 0-10 kilometer (0-5 kilometer) radius

[10]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 (250m) grid cells.

[11]Distance to the coast (on land only) is measured in meters. It is derived using World Vector Shorelines (Wessel and Smith, 1996).

[12]Distance to country borders is measured in meters. It is derived using the database of Global Administrative Areas (GADM) 2.8 ADM0 (Country) boundaries.

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

[14]Yearly daytime land surface temperature are from Wan and Hook (2015).

from CGIAR-CSI.[15]

2.2 Descriptive statistics

We compare access to infrastructure for paved roads, electricity, and internet broadband for Nigeria, Cameroon and Chad after 2000. Figures 1, 2, and 3 report summary statistics of the infrastructure variables used in the next sections at the country level, and Figure 4 focuses on the sub-region around Lake Chad.

Nigeria has the highest level of access to paved roads and electricity with more than 90% 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% to 56% of districts having access to electricity between 2003 and 2018.[16] In 2018, 23% of districts are connected to the fiber network as defined by the presence of a node from the fiber backbone.

In Cameroon, 60% of the communes and 80% 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 as the percentage of population is almost twice the percentage of communes. Between 2003 and 2018, the number of communes covered has more than double but the percentage of population covered has increased by only 7% percentage points from 41%. 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% of communes had access to a paved road, 3% to the internet broadband, and 6% to the electricity network. The covered communes are the most populated ones, as 20% of the population has access to electricity and 15% of the population has access to the internet broadband. Recent improvements of the paved road network since 2014 as shown in Figure A18 in the Appendix show that the percentage of communes and population having access to a paved road has largely increased.

The Lake Chad area, which includes The Extreme 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 as depicted on Figure A21 in the Appendix, is characterized by a limited access to infrastructure. Only 30% of the 80 locations - districts in Nigeria, communes in Cameroon and Chad - have a paved road, 16% access to electricity, and 10% access to Internet. Only half of the population has access to a paved road, 20% to electricity, and 30% to the Internet broadband.

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

[16]A district is classified as electrified when at least 50% of its population has access to electricity as monitored with night-time lights.

Figure 1: Access to infrastructure in Nigeria, 2003 and 2018

(a) At the district level

(b) At the population level
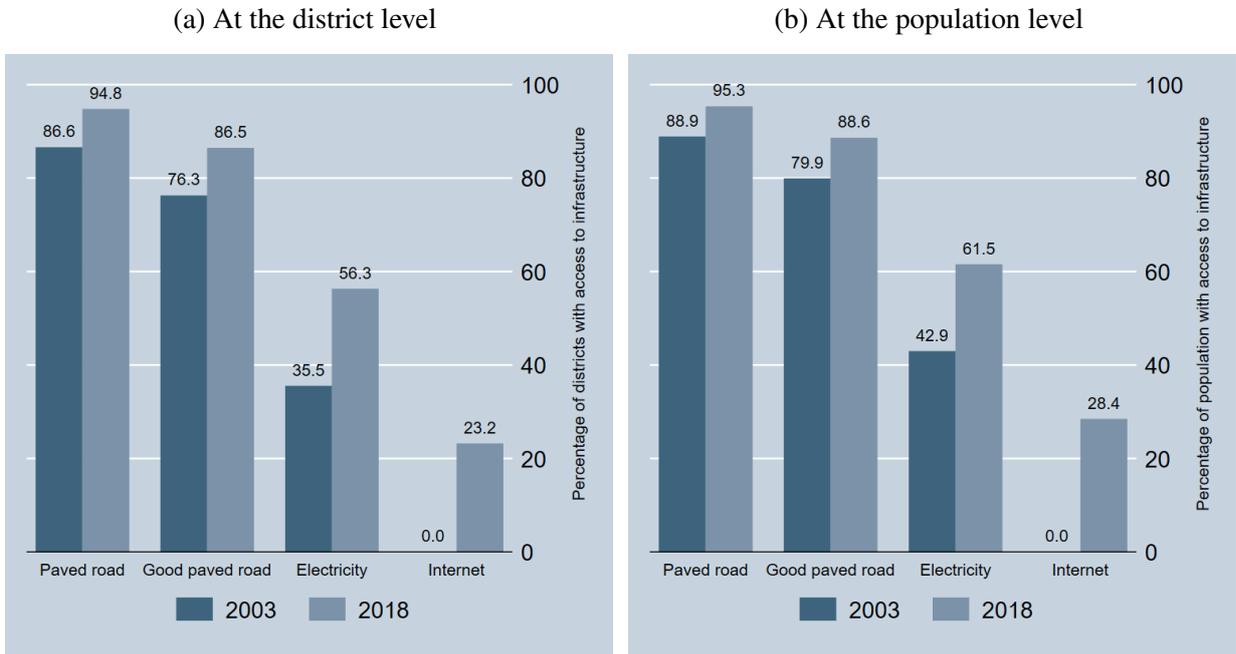
Notes.– Authors' calculations using data sources listed in previous section. Good paved roads include roads of fair or good condition. The left graph shows the percentage of districts with access to infrastructure (admin 2 for Nigeria), the right graph the percentage of population using the 2015 district population.

Figure 2: Access to infrastructure in Cameroon, 2004 and 2018

(a) At the district level

(b) At the population level
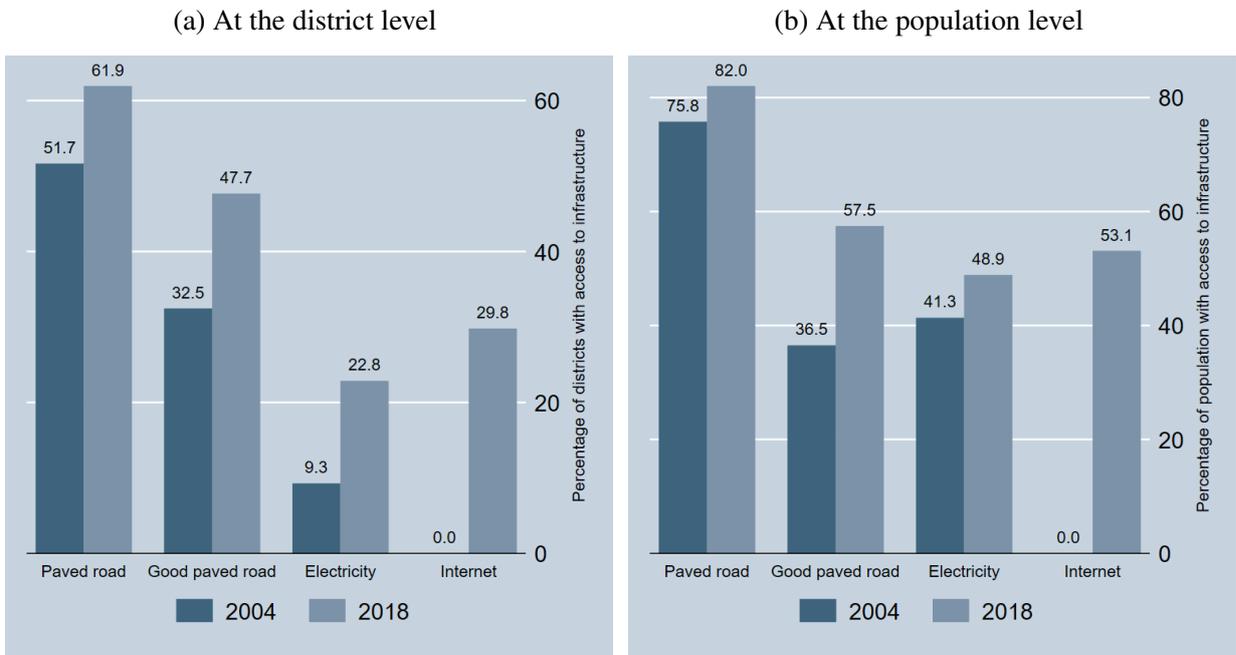
Notes.– Authors' calculations using data sources listed in previous section. The left graph shows the percentage of districts s with access to infrastructure (admin 3 for Cameroon), the right graph the percentage of population using the 2015 district population.

Figure 3: Access to infrastructure in Chad, 2014
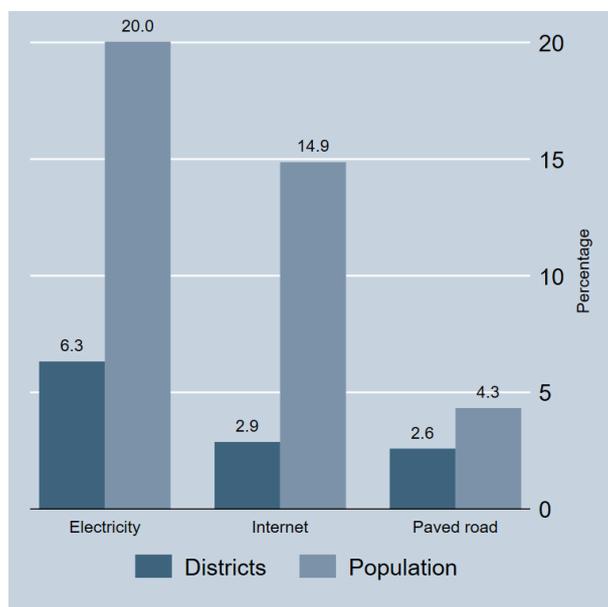
Notes.– Authors' calculations using data sources listed in previous section.

Figure 4: Access to infrastructure in the Lake Chad sub-region

(a) At the district level   (b) At the population level
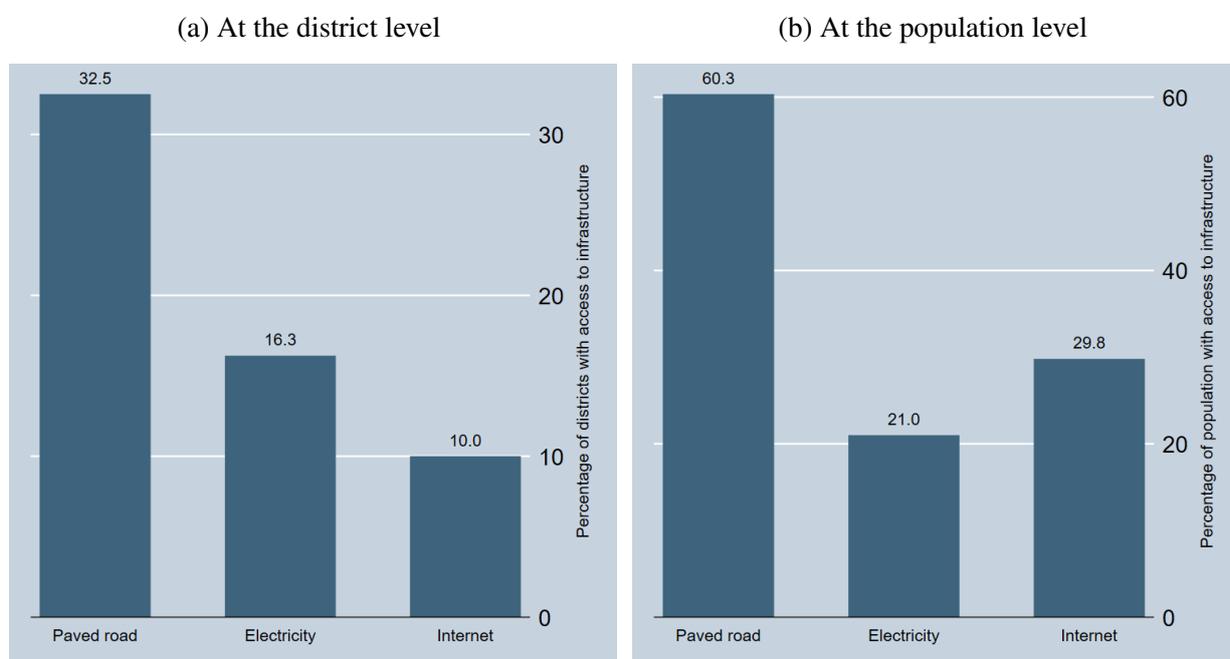
Notes.– Authors' calculations using data sources listed in previous section. The Lake Chad area is defined as the area depicted in Figure A21 around the lake. The left graph shows the percentage of districts s with access to infrastructure (admin 2 for Nigeria, admin 3 for Chad and Cameroon), the right graph the percentage of population using the 2015 district population.

3 Empirical Strategy and Results

3.1 Ordinary Least Squares

3.1.1 Method

Our first empirical strategy uses panel ordinary least squares (OLS) regressions that include year and country fixed effects and a battery of initial district-level controls. The OLS specification is

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\begin{aligned}
Sector_{i,c,t} \;=\; & \alpha + \beta^R Paved\ Road_{i,c,t} + \beta^I Internet_{i,c,t} \\
& + \gamma^{RE} Paved\ Road_{i,c,t} * Electricity_{i,c,t} + \gamma^{IE} Internet_{i,c,t} * Electricity_{i,c,t} \\
& + Controls_{i,c,t} + FE + \varepsilon_{i,c,t}
\end{aligned}
\tag{3.1}
$$

$Sector_{i,c,t}$ is the share of employment in agriculture, manufacturing or services for district i in country c, at year t. $Paved\ Road_{i,c,t}$ is a dummy variable that takes a value of one if location i in country c contains a paved road at year t. $Electricity_{i,c,t}$ is a dummy variable that takes a value of one if location i in country c has more than 50% of its population with lights at night at year t. $Internet_{i,c,t}$ is a dummy variable that takes a value of one if location i in country c has a node on the internet backbone fiber network at year t. We add interaction effects to capture the complementarities between infrastructures. $Paved\ Road_{i,c,t} * Electricity_{i,c,t}$ captures the interaction of road and electricity infrastructure, and $Internet_{i,c,t} * Electricity_{i,c,t}$ the interaction of Internet and electricity infrastructures. We do not include the isolated electricity variable alone and the interaction between Internet and roads.[17] $Controls_{i,c,t}$ represents the additional location-specific controls, which include initial district population, access to a main city, land size, distance to the coast, distance to the border, access to a city of more than 50,000 inhabitants, temperature, and elevation. FE is the year and country fixed-effects. The coefficients β capture the correlation between access to a type of infrastructure on the different sectoral employment shares, while the coefficients γ capture the infrastructure interaction terms.

We run two other specifications. First we include a specification to study labor participation where the dependent variable is not the normalized sectoral share but the share of non-working individuals. Second, we include variables of infrastructure uses rather than presence of infrastructure to compare the results.

$$
\begin{aligned}
Employment_{i,c,t} \;=\; & \alpha + \beta^E Electricity_{i,c,t} + \beta^C Car_{i,c,t} + \beta^M Motorcycle_{i,c,t} + \\
& + \beta^{LP} Land\ Phone_{i,c,t} + \beta^{MP} Mobile\ Phone_{i,c,t} + \beta^I Use\ of\ Internet_{i,c,t} \\
& + Controls_{i,c,t} + FE + \varepsilon_{i,c,t}
\end{aligned}
\tag{3.2}
$$

with $Electricity_{i,c,t}$ the percentage of respondents in location i with access to electricity as indi-

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[17]Too few observations have electricity but no paved road, and Internet but no paved road.

cated by the household, $Car_{i,c,t}$ the percentage owning a car, $Motorcycle_{i,c,t}$ the percentage owning a motorcycle, $Land\ Phone_{i,c,t}$ the percentage owning a land phone line, $Mobile\ Phone_{i,c,t}$ the percentage owning a mobile phone, and $Use\ of\ internet_{i,c,t}$ the percentage using internet. $Employment_{i,c,t}$ can be either the sectoral share or the labor force participation share.

We identify 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 an OLS estimate that is biased toward zero. We consider these issues by providing the results of an IV strategy in the next section.

We first report results for the unbalanced panel of districts that include at least one EA. We estimate local average associations of the three infrastructure investments—roads, electricity, and Internet—and the interaction between these investments on sectoral employment at the district-year level. Then we analyze heterogenous impacts on structural transformation.

3.1.2 OLS results

We start with a regression that includes all countries, Cameroon, Nigeria, and Chad. We then compare the results by country and discuss the existence of heterogeneous effects across sub-national locations. Throughout, standard errors are clustered at the district level, the level of treatment.

All countries A better access to infrastructure is associated with a transformation away from agriculture. Table 2 reports the results of pooling together data from Nigeria, Cameroon, and Chad. Having access to paved roads but no electricity at the district level is significantly associated with a 2 percentage-point increase in the employment share of manufacturing. Having access to Internet at the district level is associated with a 4.6 percentage-point reduction in the employment share of agriculture and a 4.8 percentage-point increase in the employment share of services. Combined investments in paved roads and electrification is associated with larger impacts, a 8.5 percentage-point reduction in the employment share of agriculture, a 5 percentage-point increase in the employment share of manufacturing, and a 4 percentage-point increase in the employment share of services. Table 3 presents the results using the dummy variable that captures electricity access based on the grid expansion for validity check. The results are similar showing a significant association between roads and Internet infrastructure investments and sectoral shares, and the role of complementary electricity investments.

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Table 2: OLS results for Nigeria, Cameroon, Chad

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.0202	0.0211**	0.00165	0.0200**
	(-1.48)	(3.48)	(0.16)	(3.26)
Internet	-0.0462*	-0.00558	0.0480**	-0.00397
	(-2.44)	(-0.74)	(3.00)	(-0.44)
Road + Electricity	-0.0668**	0.0294**	0.0380**	-0.00942
	(-4.39)	(4.30)	(2.99)	(-1.31)
Internet + Electricity	0.00476	-0.00273	0.00576	-0.0158
	(0.21)	(-0.27)	(0.29)	(-1.47)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.447	0.364	0.447	0.142
N. of observations	3041	3041	3041	3041

t statistics in parentheses

[+] $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table 3: OLS results for Nigeria, Cameroon, Chad using the electricity grid

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.0406*	0.0262**	0.0119	0.0184*
	(-2.12)	(3.36)	(0.81)	(2.26)
Internet	-0.130**	0.0196	0.114**	-0.0317**
	(-3.40)	(1.33)	(3.82)	(-2.59)
Road + Electricity grid	-0.0842**	0.0309**	0.0600**	-0.0135[+]
	(-5.11)	(4.70)	(4.37)	(-1.89)
Internet + Electricity grid	0.0233	-0.00907	-0.0184	0.0198
	(0.58)	(-0.59)	(-0.59)	(1.50)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.203	0.240	0.285	0.050
N. of observations	3041	3041	3041	3041

t statistics in parentheses

[+] $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table 4 shows the results of the analysis when including uses as reported by households and ownership of durable goods associated with road, electricity, and ICT infrastructure investments. The presence of infrastructure allows but does not ensure its use by households and represents therefore a lower bound of the impacts of infrastructure. Estimates based on uses permitted by access to services and ownership of durable goods can be interpreted as a higher bound. Estimated coefficients are therefore expected to be higher when considering uses rather then access to hard infrastructures. Variables related to use of infrastructure in Table 4 include the percentage of respondents that own a certain good or use the services allowed by certain infrastructures. Use of electricity by the household requires the presence of the national grid

or other means of providing electricity, a provider for the last-mile service to be linked to the network, and the household to be able to afford this service. Motorcycle and cars are durable goods whose economic impact is greatest with good-quality roads. Use of Internet also requires infrastructure access, the presence of services providers, and affordability.

The associated impacts of use and ownership variables on sectoral shares are large (Table 4). A 10 percentage-point increase in the number of households effectively using electricity is associated with a 3.6 percentage-point decrease in the share of agricultural employment, a 1.1 percentage-point increase in manufacturing employment and a 2.5 percentage-point increase in services employment. Having a car, and to a much lower extent, having a motorcycle have a large impact on sectoral shares. A 10 percentage-point increase in the number of households owning a car is associated with a 3.6 percentage-point decrease in the share of agricultural employment and a 4 percentage-point increase in services. A 10 percentage-point increase in the number of households effectively using Internet is associated with a 7.2 percentage-point increase in the share of services employment. Both the use of mobile and land phones have strong impacts, with a 10 percentage-point increase in the number of respondents using a mobile phone (land phone) associated with a 1.9 (3.3) percentage-point decrease in agricultural employment shares. Finally, the impacts on employment and labor market participation as reported on the last column 'Not working' are mixed.

Table 4: OLS results for Nigeria, Cameroon, Chad based on uses of roads, electricity and ICT, 2008-2018

	Agriculture	Manufacturing	Services	Not working
Electricity (share)	-0.373**	0.114**	0.259**	-0.0485**
	(-25.46)	(16.60)	(21.21)	(-6.69)
Motorcycle (share)	0.0121	-0.0101	0.00669	0.0254*
	(0.55)	(-0.90)	(0.35)	(2.04)
Car (share)	-0.348**	-0.0523*	0.397**	-0.0304
	(-8.49)	(-2.12)	(11.47)	(-1.18)
Use of internet (share)	-0.102*	0.00171	0.124**	-0.123**
	(-2.08)	(0.06)	(2.85)	(-4.12)
Mobile phone (share)	-0.176**	0.0967**	0.0746**	0.0230
	(-6.07)	(7.00)	(2.95)	(1.14)
Land phone (share)	-0.402**	0.00408	0.408**	0.184**
	(-3.86)	(0.06)	(4.36)	(3.19)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.588	0.344	0.547	0.100
N. of observations	2369	2369	2369	2369

t statistics in parentheses

$+$ $p < 0.10$, $*$ $p < 0.05$, $**$ $p < 0.01$

Notes.– All explanatory variables are shares of households with access between 0 and 1.

Around Lake Chad We restrict our analysis to the subnational regions neighboring the lake at the intersection of Chad, Cameroon and Nigeria as shown on Figure A21 in Appendix. These regions are poorer, less developed and more prone to conflicts. Table A2 shows that infrastructure investments in that area are associated with much larger effects on sectoral shares, especially for combined investments in electricity and paved roads. Access to electricity and paved roads is associated with lower sectoral share in agriculture in the districts directly located around Lake Chad. Having access to a paved road but no electricity at the district level is associated with a 11 percentage-point reduction in the employment share of agriculture, a 7 percentage-point increase in the employment share of manufacturing, and a 3 percentage-point increase in the employment share of services. Having access to both paved roads and electricity at the district level is associated with a 42 percentage-point reduction in the employment share of agriculture, a 26 percentage-point increase in the employment share of manufacturing, and a 23 percentage-point increase in the employment share of services.

By country In Cameroon, access to paved roads is associated with a significant reduction in agriculture employment and increase in employment in manufacturing and services (Table A4 in Appendix). Having access to paved roads but no electricity at the district level is associated with a 11 percentage-point reduction in the agriculture employment share, a 6 percentage-point increase in the manufacturing employment share and a 5 percentage-point increase in the employment share of services. Combined investments in roads and electricity are associated with a much larger effect, a 43 percentage-point reduction in the agriculture employment share, an 18 percentage-point increase in the manufacturing employment share and a 25 percentage-point increase in the employment share of services. Reduced-form estimates for the use of infrastructure are reported in Table A6 in Appendix.

Table A5 reports the results for Nigeria. Investments in paved roads alone are associated with a slightly higher share in agricultural employment. Combined access to paved roads and electricity is associated with a large reduction in the share of agriculture employment benefiting both the manufacturing and services sector. Reduced-form estimates for the use of infrastructure are reported in Tables A7 in Appendix .

Heterogenous Effects We finally investigate whether there are heterogenous effects of infrastructure effects depending on the share of agricultural employment and the population-weighted distance to the largest town as in Moneke (2020). Table A8 in Appendix shows that the impact of combined investments in roads and electricity is stronger for locations that are more agricultural. We then test whether the changes in sectoral shares associated with access to infrastructure varies across districts with distance to large towns. We divide the pooled sample of districts in 5 quintiles of distance. The average distances per quintile are 8, 27, 51, 96, and 253 km away from a city with more than 50,000 inhabitants. Tables A9, A10, and A11 in Appendix report the estimation results for each sectoral share. Combined investments in roads and electricity are

associated with slightly higher shares in agricultural employment but lower shares in services for districts whose population is close to a main city (on average 8 km away). The relation is opposite for districts from the second quintile, with a population on average 27 km away from a main city. Combined investments are associated with lower agricultural employment share and higher service employment share. The relation between structural change and infrastructure investments seems to be the strongest for the most isolated districts.

3.2 Instrumental Variables

In this section, we use an instrumental variables identification strategy to deal with the potential endogeneity in the placement of the infrastructure. We instrument both roads and electricity, and the interaction terms.[18]

3.2.1 Method

We instrument electrification and access to a paved road. 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.

We identified two sources of energy generation that can be used for the IV strategy: dams for hydroelectricity, wind farms, gas and geothermal production stations. The main sources of energy supply are hydropower in Cameroon, and gas in Nigeria. Similar to Moneke (2020), we develop an IV which yields a hypothetical electrification status based on a location's proximity to a straight line corridor from electricity generators to the main cities. First, we identify the locations of the electricity generators using two databases, one on dams opening year and another on power plant locations (Platts database). For Cameroon, we use the geolocalized database including all dams in Africa and their year of opening. For Nigeria, we use the global power plant database that includes all power plants per type of energy (hydro, wind, gas, and geothermal) with their capacity and year of commissioning. From the year of dam opening or power plant commissioning onwards, 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. For Nigeria and Cameroon, the main sources of demand vary across time. At the beginning of our panel, all dams in Cameroon have been opened therefore a panel IV is created by varying the sources of demand rather than the supply sources. For Cameroon, we set the threshold of 500,000 inhabitants for a city to be included as a main source of demand for the hydropower supply sources. In 1990, only Douala and Yaounde are included. In 2000, Garoua in the North

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[18]While the previous part also includes Internet investments, this subsection only focuses on finding instruments for paved roads and electricity to keep the IV estimation tractable.

is included, and in 2015, Maroua is also included. For each year, all districts lying along the straight lines connecting the dams to the cities of more than half million inhabitants will be considered hypothetically electrified. We then identify the main sources of demand in each country. For Nigeria, we include the cities with more than a million inhabitants.

Our IV satisfies the main assumptions of an IV strategy. The choice of location of hydro, gas 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 as 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 randomly assigned.

To instrument for the timing of a district's paved road connection, we find the optimal network to connect all cities with more than 50,000 inhabitants in a least-cost fashion by employing 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.

We now run two-stage least squares (2SLS) on the following specifications, with fixed effects and district-level initial values as controls:[19]

$$
\begin{aligned}
PavedRoad_{i,t} \;=\; & \alpha + \gamma^R (PavedRoadIV_{i,t} = 1) \\
& + \gamma^{RE} (PavedRoadIV_{i,t} = 1 \;\&\; ElectricityIV_{i,t} = 1) \\
& + \gamma^I Internet_{i,t} + Controls_i + FE + \varepsilon_{i,t} \quad (3.3)
\end{aligned}
$$

$$
\begin{aligned}
PavedRoad_{i,t} \times Electricity_{i,t} \;=\; & \alpha + \delta^R (PavedRoadIV_{i,t} = 1) \\
& + \delta^{RE} (PavedRoadIV_{i,t} = 1 \;\&\; ElectricityIV_{i,t} = 1) \\
& + \delta^I Internet_{i,t} + Controls_i + FE + \varepsilon_{i,t} \quad (3.4)
\end{aligned}
$$

The second-stage equation is given by:

$$
\begin{aligned}
Sector_{i,t} \;=\; & \alpha + \beta^{R,2SLS} \widehat{PavedRoad}_{i,t} \\
& + \beta^{RE,2SLS} \widehat{PavedRoad_{i,t} \times Electricity}_{i,t} \\
& + \beta^{I,2SLS} Internet_{i,t} + Controls_{i,t} + FE + \varepsilon_{i,t} \quad (3.5)
\end{aligned}
$$

with $Sector_{i,t}$ being the normalized share of employment in agriculture, manufacturing, or services in district i in year t. We also run a similar regression with the share of unemployed workers .

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[19]District level controls variables are interacted with the country dummy such that the effects of distances can only be compared within countries

3.2.2 IV Results

Table 5 reports the results for the 2SLS method for Cameroon and Nigeria which can be compared with the OLS-method regression for Nigeria and Cameroon in Table A13 in Appendix. First-stage results are reported in Table A14 in the Appendix showing a strong and statistically significant relationship between instrumental variables and endogenous regressors. For multiple endogeneous regressors, Sanderson and Windmeijer (2016) provide the most relevant weak instrument F-test statistic. Both Sanderson-Windmeijer and classic F-test statistics indicate non-weak instruments.[20]

Table 5: 2SLS results for Nigeria and Cameroon

	Agriculture	Manufacturing	Services	Not working
Paved road	0.0750*	-0.0687**	-0.00624	0.0468**
	(2.13)	(-4.06)	(-0.22)	(2.76)
Paved road and Electricity	-0.298**	0.123**	0.175**	0.0197
	(-7.87)	(7.16)	(5.45)	(1.15)
Internet	-0.0489**	-0.0195**	0.0683**	-0.0182**
	(-4.32)	(-3.22)	(7.06)	(-3.20)
Controls	Yes	Yes	Yes	Yes
R-squared	0.375	0.138	0.407	0.104
N. of observations	2798	2798	2798	2798

t statistics in parentheses

[+] $p < 0.10$, [*] $p < 0.05$, [**] $p < 0.01$

The IV methodology shows stronger effects, especially for combined investments, than the equivalent OLS regression. The impact of combined investments in paved roads and electricity leads to a 22.3 percentage-point reduction in the agricultural employment share, a 5.4 percentage-point increase in the manufacturing employment share, and a 17.5 percentage-point increase in the services sector. Most of the structural change from agriculture goes to the services sector. Access to paved roads only has a different impact with an increase of 7.5 percentage points in the agricultural employment share, and a decrease of 6.9 percentage-point in the manufacturing sector. The possibility of a negative impact of roads on manufacturing has been documented in other papers (Behrens et al., 2006; Moneke, 2020). Manufacturing activities with no or poor access to electricity might find it difficult to compete with other producers in locations that are increasingly integrated with the rest of the economy. Access to the fiber backbone also has a significant impact on the structure of the local economies and supports employment in the services sector.

Table A15 in Appendix reports the results of the IV specification for Nigeria only, and Table A16 reports the results of the IV specification for Cameroon only. The slightly negative impact

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[20]The final specification is chosen as the specification with the highest Sanderson-Windmeijer statistics. Other specifications including more fixed effects lead to much lower Sanderson-Windmeijer statistics, therefore weak instruments.

of access to paved roads on the manufacturing employment share disappears in Cameroon (Table A16). Investments in infrastructure have mostly benefited the services sector in Nigeria but the manufacturing sector in Cameroon.

As a conclusion, this empirical section shows that infrastructure investments have had an impact on the economic structure of local economies in Nigeria, Cameroon, and Chad. Reduced-form results show that combined investments in paved roads and electricity have a much larger impact than isolated investments on structural change away from the agricultural sector.[21] The size of the impacts and the sector that benefits from the redistribution of employment vary across countries and across locations within country. In order to better understand the different channels through which infrastructure investments can impact local economies, the next section develops a structural model which is then applied to several future investments to study their possible counterfactual impacts on income and sectoral change.

4 Welfare Impacts of Future Infrastructure Investments

This section presents the general equilibrium model we use to assess the welfare impacts of infrastructure investments, including the calibration of the model, and shows the results under several counterfactual scenarios.

4.1 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 et al. (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 et al. (2011) and Eckert and Peters (2018). Compared to Moneke (2020), we consider 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.

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[21]This paper does not provide an IV strategy to study the impacts of internet accessibility.

4.1.1 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, h. 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:

$$U_n = v_n C_n^{\alpha} h_n^{1-\alpha} \tag{4.1}$$

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

$$C_n = [\psi^T (C_n^T)^{\rho} + \psi^M (C_n^M)^{\rho} + \psi^S (C_n^S)^{\rho}] \tag{4.2}$$

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

Consumers exhibit love of variety for both tradeable sectors' goods, C^T and C^M, which we model 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 $j \in [0,1]$:

$$C_n^T = [\sum_{i \in N} \int_0^1 (c_{ni}^T(j))^{\nu} dj]^{1/\nu} \tag{4.3}$$

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:

$$P_n^T = \Big[\sum_{i \in N} \int_0^1 (p_{ni}^T(j))^{1-\sigma} dj \Big]^{\frac{1}{1-\sigma}} \tag{4.4}$$

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.

$$Y_n^i = z^i \Big(\frac{L_n^i}{\mu^i}\Big)^{\mu^i} \Big(\frac{h_n^i}{1-\mu^i}\Big)^{1-\mu^i} \qquad i = T, M \tag{4.5}$$

where $0 < \mu^i < 1$ and, z^K denotes the sector-location-specific realisation 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:

$$F_n^i(z^i) = e^{(-A_n^i z^i)^{-\theta}} \qquad i = T, M \qquad (4.6)$$

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:

$$p_{nm}^i = \frac{\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm}}{z_m^i} \qquad (4.7)$$

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:

$$p_{nm}^i = min\{p_m^i, m \in N\} \qquad (4.8)$$

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:

$$\pi_{nm}^i = \frac{A_m^i (\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm})^{-\theta}}{\sum_{k \in N} A_k^i (\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta}} \qquad (4.9)$$

Production of non-tradeable services also uses labor and land as inputs, but output is a single homogeneous service. We assume 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:

$$\xi_n^K = \frac{(\psi^K)^\kappa (P_n^K)^{1-\kappa}}{(\psi^M)^\kappa (P_n^M)^{1-\kappa} + (\psi^T)^\kappa (P_n^T)^{1-\kappa} + (\psi^S)^\kappa (P_n^S)^{1-\kappa}}, \qquad K \in \{T, M, S\} \qquad (4.10)$$

Given the properties of the Fréchet distribution of productivities, tradeable sectoral price indices

can be further simplified:

$$P_n^i = \gamma \Big[\sum_{k \in N} A_k^i (\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta} \Big]^{-1/\theta} = \gamma (\Phi_n^T)^{-1/\theta} \tag{4.11}$$

To arrive at a spatial equilibrium, we provide conditions for land market clearing, labor market clearing and a labor mobility condition. 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, we assume 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, as well as a location's amenity value, must be equalized across locations of a same country. The welfare in each location of a same country c is given by:

$$V_{n,c} = \bar{V}_c = \frac{\alpha^\alpha (1-\alpha)^{1-\alpha} v_{n,c} \omega_{n,c}}{[P_{n,c}]^{\alpha/(1-\kappa)} r_{n,c}^{1-\alpha}}, \forall n \in \text{ country } c \tag{4.12}$$

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

We follow the specification in Moneke (2020) and Michaels et al. (2011) to include the district specific parameter $v_{n,c}$ in the wage so that the welfare can be interpreted as the real income in each location.

4.2 Calibration of the Model

We calibrate the model by using some parameters from the literature and by recovering the key productivity parameters and wages to obtain an equilibrium for the current situation. Table A17 in the Appendix reports the parameters from the literature to calibrate the model partly taken from Moneke (2020) whose model is calibrated to Ethiopia. To recover the productivity parameters, we use the labor market clearing conditions, the land market conditions, and the labor mobility conditions. For each location, the model admits three equations for the three endogenous variables in each location—land market clearing, labor market clearing, and labor mobility condition—which allows 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 et al. (2011). We obtain a series of $\{A_n^T, A_n^M, A_n^S\}_{n \in N}$ for which the distribution of population, employment, and land is an equilibrium given the current trade costs.

4.3 Counterfactuals

We calibrate the model to assess the welfare and spatial impacts of new infrastructure investments. The counterfactual exercise is done in three steps. First, we calibrate the model to obtain the underlying parameters of the model for the baseline situation, without the new investments. Second, we update the trade costs and sectoral productivity parameters based on the new assumptions. Third, we use the model 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.

We assume that electrification increases productivity in modern sectors and that transport investments increase market access by reducing transport times. To build the electrification counterfactual, we assume that access to electricity increases productivity in modern sectors, being manufacturing and services (see Moneke (2020)). To build the transport counterfactuals, we use the available road networks for each country, making assumptions about speed along the networks 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 build new links between locations. We assume trade costs to be iceberg costs, such that the costs between the origin location o and destination d are given by $d_{od} = max(1, time^\tau)$. Border costs are also added to travel costs, as detailed below.

We calibrate the model using spatial data for land, population, and sectoral shares from the sources used earlier. Because of the complexity of a three-sector model to converge in order to recover the initial sectoral productivities, we reduce the spatial disaggregation to fewer locations. Such aggregation also smoothed measurement issues of sectoral employment based on the DHS data. We divide the Lake Chad region into 24 regions, including 8 first-order administrative divisions in Cameroon, 6 in Nigeria, 8 in Chad. Figure A23 shows the share of agricultural employment and population for each of these subnational regions.

4.3.1 Productivity shocks from rural electrification

The counterfactual consists in providing access to electricity for all in each region based on the current coverage measured by Night Time Lights as described in the Data section. We calibrate the increase in productivity using the estimated productivity increase of 28.4 percent for Ethiopia from Moneke (2020) and the current coverage of electricity per location. The lower the existing coverage, the higher the productivity increase in the counterfactual. The new productivity levels A^* are given by : $A_n^{i*} = A_n^i + A_n^i \times (1 - Elec_n) \times 0.284, \quad n = M, S$ with $Elec_n$ the current ratio of electrified population. Map 5 shows the percent of productivity increase per location.

Figure 5: Counterfactual productivity increase in manufacturing and services from electrification, in percent
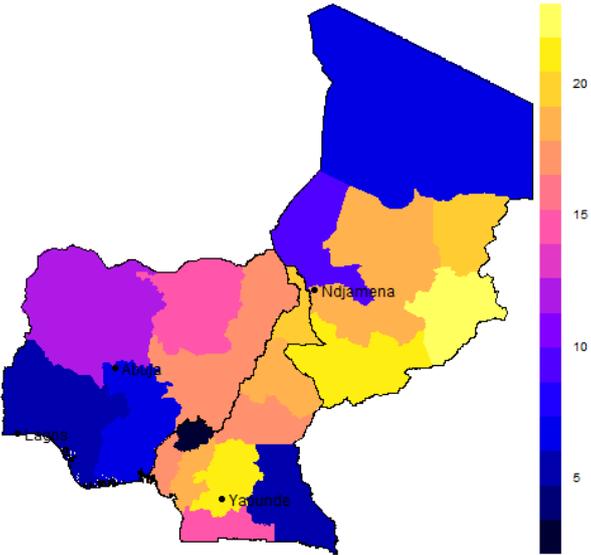
Source: Authors' calculations based on the estimate of the increase in productivity in modern sectors from access to electricity in Ethiopia by Moneke (2020).

4.3.2 New Transport Infrastructure in Cameroon and Chad

We investigate the impact of several transport and trade facilitation projects listed in Table 6 and mapped on Figure 6 and Figure A25 in Appendix as potentially financed by the World Bank and other donors. These projects are part of a approach to provide a long-term, reliable, safe and efficient multimodal corridor over the entire 1800km long stretch between Douala-Ngaoundéré-Koutéré-Moundou-Ndjamena (forthcoming World Bank Project Appraisal Document). The corridor contributes to improve domestic, regional as well as international connectivity for both countries.

Rehabilitation of the rail line in Cameroon The renovation of the rail line between Ngaoundere, 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 Agence Française de Développement (AFD) and European Investment Bank (EIB) are planning to finance in 2022 the rehabilitation of the section from Belabo up to Ngaoundere in the North Cameroun. We assume that the two rehabilitations will happen at the same time so we consider both segments. The government is currently 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. We assume 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 Extreme North have closed the corridors passing by the Northern part of Cameroon and opened the possibilities for other corridors to develop. From Ngaoundére to Ndjamena, the traditional road corridor crosses the region of North Cameroun which is under the threat of Boko Haram, for this reason this road section is today considered as unsafe and unreliable. An alternative road corridor from Ngaoundére to Ndjamena crosses the border near Moundou (second largest city in Chad) and then connect Moundou with Ndjamena (about 600 km). 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% paved. This project would improve connectivity to the port of Douala, increases domestic connectivity between the main two cities of Chad and improves the regional/international connectivity of Moudoun. The proposed project covers the whole corridor between Koutere-Moundou-Ndjamena under a phased 10-year long-term approach that entails rehabilitation works, reinforcement, maintenance and axle load monitoring facilities management.

Complementary policies: Border frictions We assume that trade across locations from a same country only face transport costs while traders across countries have to wait an additional 30 hours to be able to cross the borders. Given the lack of data, we assume a level of 30 hours by default. In the forthcoming counterfactuals, we reduce border time by two as a complement to the transport investments.

Table 6: Summary of counterfactual scenarios

Scenario	Country	Infrastructure	Electrification	Border Policies
Baseline				
1	Cameroon	Rail line that is less and less competitive with the road: speed 40km per hour	Limited access which varies across regions	Platform in Ngadoundere to move from rail to road
1	Chad	Corridor (Njamena-Moundou) in bad conditions: speed 30km/h 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
Transport infrastructure investments				
2.1 (road)	Cameroon Chad	Baseline Upgraded road line	Baseline	Baseline
2.2 (road and rail)	Cameroon and Chad	Upgraded rail line and road corridor	Baseline	Baseline
Electrification				
3	Cameroon and Chad	Baseline	Productivity shock in modern sectors from universal access	Baseline
Transport + Border investments				
4.1	Cameroon Chad	Baseline Upgraded road corridor	Baseline	Half border time
4.2	Cameroon and Chad	Upgraded road corridor and rail line	Baseline	Half border time
Transport + Electrification + Border investments				
5	Cameroon and Chad	Upgraded road corridor and rail line	Productivity shock from universal access	Half border time

Figure 6: Planned road and rail investments
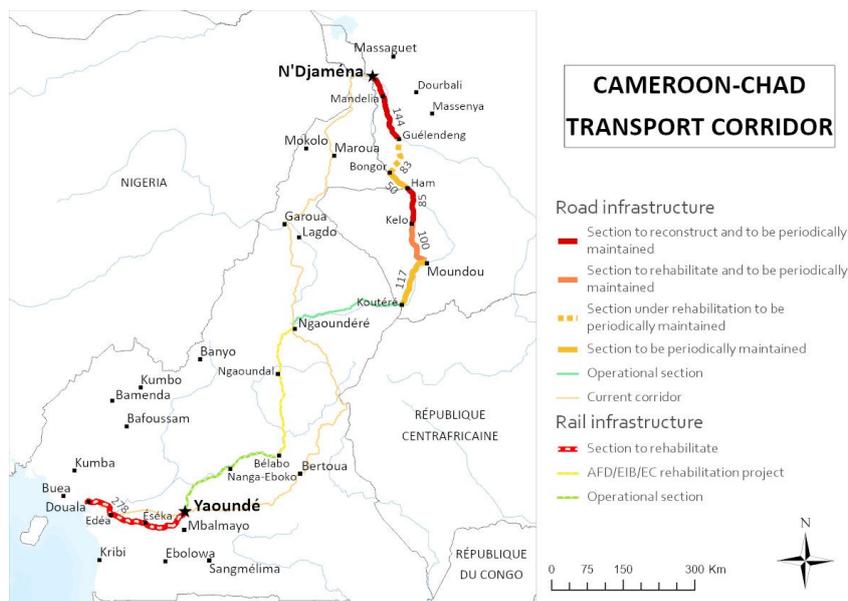
We create counterfactuals using the transport networks from each country described in Section 2. We assume a new speed for the new road corridor and reduce border delays in some scenarios. For the rail corridor, we keep the road network as it is and assume a new direct transport line between Ngaoundere, Yaounde and Douala. New transport times are computed assuming that the previous roads can be used as well as the new rail line, which is more efficient. Stops between the main cities are not permitted. The first section between Ngaoundere and Yaounde is assumed to be 627 km with an average speed of 70km/h.[22] The second section between Yaounde and Douala is assumed to be 261 km with an average speed of 70km/h.

4.3.3 Aggregate Impacts

Employment impacts Table 7 reports the change in employment share for all sectors at the national level from the combined road and rail investments, complemented with universal access to electricity and lower border delays. The proposed transport investments are expected to have a marginal impact on structural change at the national level for most countries. Rural electrification tends to increase employment in sectors of tradable goods (agriculture and manufacturing). Better regional integration through lower transport and border costs will increase manufacturing employment in Cameroon, and agricultural employment in Chad. Nigeria benefits from a better access to its neighbors to specialize slightly more in the services sector. When combining all interventions, structural changes are marginal in Nigeria but larger for Chad and Cameroon. Cameroon specializes more in traded goods, both agricultural and manufacturing

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[22]Distance assumptions come from the website rome2rio.com which reports distance per transport mode.

production, and Chad increases its employment share in agriculture. However most changes are expected to happen between subnational regions within country through worker reallocation across sectors and between regions. In this case, the aggregate changes from relocation between sectors across regions are limited because of large welfare gains from lower prices in poorer places reducing the incentives of workers to move out of the most agricultural places.

Table 7: Change in share of sectoral employment in counterfactual scenarios relative to baseline (in percentage points)

Agricultural sector				
Scenarios	Total	Cameroon	Nigeria	Chad
Transport (Road and Rail)	0	0.3	0	-0.1
Rural Electrification	0.9	0.8	0.7	2.5
Transport + Electrification	0.9	1.5	0.7	2
Transport + Border	-0.4	0.1	-0.6	1.8
Transport + Electrification + Border	0.5	1.3	0	4.8
Manufacturing sector				
Scenarios	Total	Cameroon	Nigeria	Chad
Transport (Road and Rail)	0	-0.1	0	-0.1
Rural Electrification	0.1	0.6	0.1	-0.2
Transport + Electrification	0.1	0.5	0.1	-0.2
Transport + Border	-0.3	0.5	-0.3	-1.6
Transport + Electrification + Border	-0.2	1.3	-0.2	-2
Services sector				
Scenarios	Total	Cameroon	Nigeria	Chad
Transport (Road and Rail)	0	-0.2	0	0.1
Rural Electrification	-1	-1.5	-0.9	-2.2
Transport + Electrification	-1	-2	-0.8	-1.8
Transport + Border	0.7	-0.6	0.9	-0.2
Transport + Electrification + Border	-0.3	-2.6	0.2	-2.8

Welfare impacts   First we compute the nominal GDP impacts measured as the total nominal incomes.

$$\Delta NominalGDP_c = \Delta[Population_{n,c} \times Nominal\ Income_{n,c}] \tag{4.13}$$

with $Income_{n,c}$ the total nominal income in location n of country c. Change in national incomes do not include gains in purchasing power from lower prices.

Welfare is defined as the real income available for 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. We then compute the total welfare impact in each counterfactual and compare it to the baseline welfare:

$$\Delta Welfare_{n,c} = \Delta[Population_{n,c} \times V_{n,c}] \tag{4.14}$$

with $V_{n,c}$ the welfare or real income in location n of country c defined in equation 4.12.

Table 8 shows the change in nominal income and Table 9 the change in welfare for the three countries and the sub-region around Lake Chad. The welfare gains are overall much larger than the gains in nominal GDP indicating that lower prices and the reallocation of workers towards places with high real incomes or better amenities are two main sources of welfare gains.

Transport investments have significant spillover effects and benefit the most the sub-region around Lake Chad. While the road upgrade only benefits Chad, improvements of the rail line in Cameroon have strong spillover effects on Chad which benefits from a 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 Lake Chad sub-region experiences larger increase in welfare than the whole region with a welfare increase of 0.8 percent from transport investments compared to 0.13 for the three countries (Table 9). The sub-region benefits directly from better access to richer and more populated places through the road corridor in Chad and the rail line. Additional reductions in border delays disproportionately benefit the sub-region which has the most to gain given its geography. Additionally, universal access to electricity brings large increase in welfare, especially for the Lake Chad sub-region. Given the assumptions of the model, there is no additional benefit from combining investments in electrification and transport. The gains from bundled investments equal the sum of each taken in isolation.

Table 8: Change in nominal GDP in counterfactual scenarios relative to baseline (in percentage)

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 + Road and Rail	0.9	0.2	0.8	1
Road and Rail + Border	0	0	0.6	0
Electrification + Road and Rail + Border	0.7	0.5	0.8	0.7

Table 9: Change in welfare in counterfactual scenarios relative to baseline (in percentage)

Scenarios	Total	Cameroon	Chad	Nigeria	Lake Chad
Road (Chad)	0.03	0.0	0.23	0.02	0.1
Road and Rail	0.13	0.5	0.7	0.03	0.8
Electrification	4.4	5.7	5.2	4.2	5.6
Electrification + Road and Rail	4.6	6.1	6	4.3	6.3
Road and Rail + Border	2.5	2.8	3.7	2.3	4.8
Electrification + Road and Rail + Border	7.1	8.7	9	6.8	10.7

4.3.4 Spatial Impacts of Infrastructure Investments

New infrastructure investments have different impacts across regions within country. The comparative advantage of each region in producing agricultural or manufacturing goods and exporting to other regions, the attractiveness of each region, its distance to other places, and the land surface that can be used are key factors that determine the final impacts of such investments.

Structural change   While small at the national level, structural changes from infrastructure investments are larger at the sub-national level and vary across regions. Table 7 reports the change in employment in non-agricultural employment, and Table 8 the change in manufacturing employment. Electrification of all, which leads to a productivity increase in the manufacturing and services sectors, does not reduce the share of non-agricultural employment in any of the region. Higher labor productivity in non-agricultural sector tends to push workers in the sector whose productivity remains the same at the equilibrium. However, the least agricultural regions experience the smallest increase in agricultural employment, and most of them experience an increase in the share of manufacturing employment (Figure 8). On the contrary, better connectivity through lower transport costs or/and lower border delays leads to higher share in non-agricultural employment in the regions with a comparative advantage in non-agricultural activities. The effects of better connectivity on manufacturing employment are similar to the productivity increase from electrification. Overall, new infrastructure investments will not push for structural change in the regions of Chad and Northern Cameroon. The share of manufacturing employment will increase in the region of Douala and Yaounde which will benefit from higher connectivity to trade and a productivity shock. Manufacturing employment might also increase in Northern and Eastern Nigeria due to better access to electricity.

Migration in and out   New investments lead to migration in and out across regions. Figure 9 reports the change in population for each counterfactual scenario. 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 region of Yaounde and Douala attracted the most new workers from other regions.

Welfare gains   New investments lead to absolute and relative winners and losers across regions. Figure 9 reports the change in sub-national welfare for each counterfactual scenario. Better connectivity and lower border delays lead to very high welfare gains for the Lake Chad regions that move from being isolated to a central region, and therefore benefit from better access to goods and lower prices. Electrification brings the largest welfare gains for the regions with a comparative advantage in non-agricultural production. North-Eastern Nigeria, Southern Chad, and the region of Yaounde benefit from the largest welfare gains.

Figure 7: Change in share of employment in non-agricultural sectors from universal access to electricity, transport and reduction in border delays compared to baseline - in percentage points

(a) Road and rail
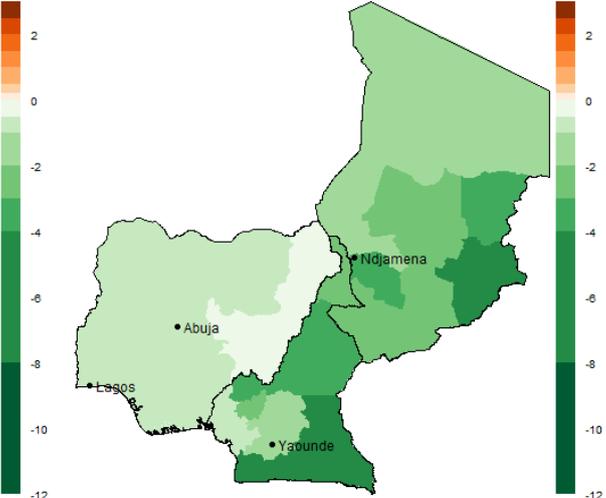
(b) Electrification

(c) Road and rail, and borders

(d) Transport, borders and electrification
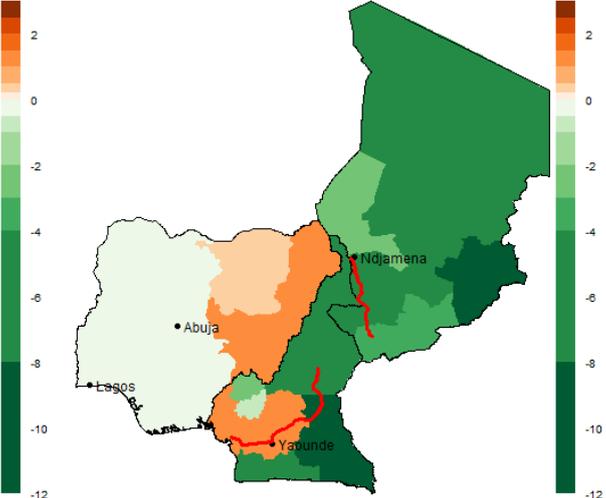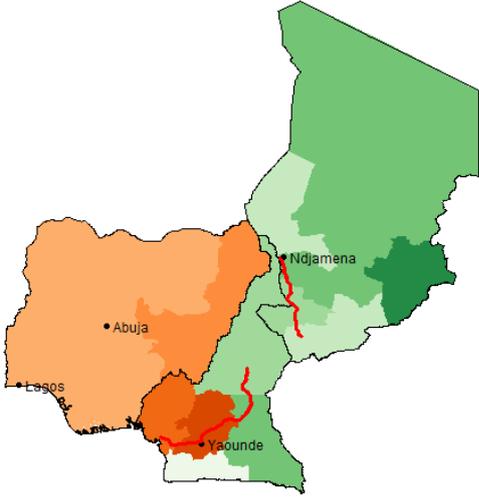
Figure 8: Change in the share of employment in manufacturing sectors from universal access to electricity, transport and reduction in border delays compared to baseline - in percentage points

(a) Road and rail

(b) Electrification

(c) Road and rail, and borders

(d) Transport, borders and electrification
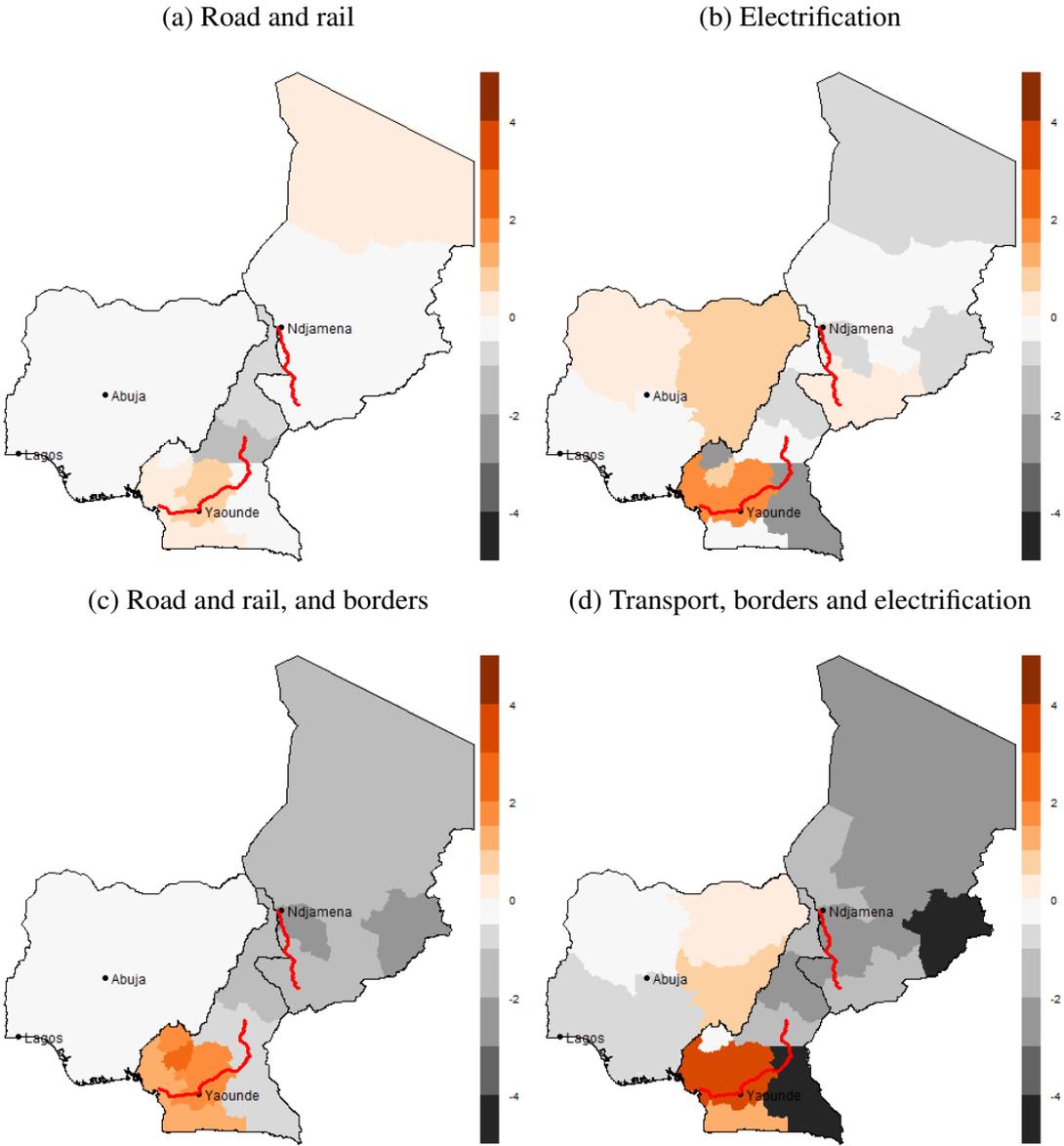
Figure 9: Change in share of population from universal access to electricity, transport and reduction in border delays compared to baseline - in percentage points

(a) Road and rail

(b) Electrification

(c) Road and rail, and borders

(d) Transport, borders and electrification
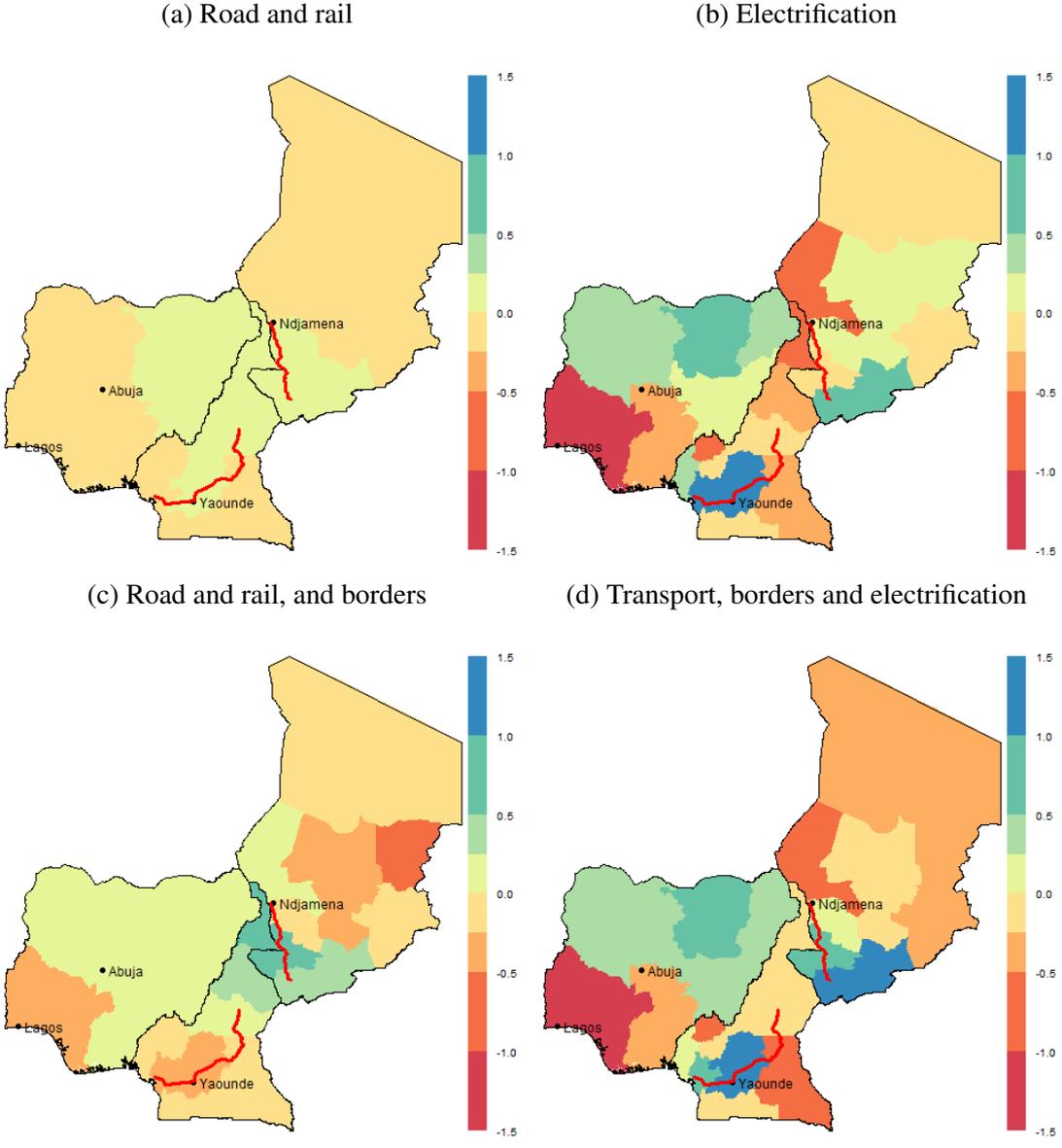
5   Conclusion

This paper investigates how infrastructure—transport, electricity and Internet—affects economic development through the channels of sectoral employment and structural change. It first estimates the impacts of past transport, electricity, and Internet investments and their interactions in Nigeria, Cameroon and Chad on sectoral employment for the last two decades. The empirical analysis shows that a combined access to paved roads and electricity triggered a large shift in employment from agriculture to services and that access to Internet led to an increase in the share of service employment.

The paper's spatial general equilibrium model estimates the potential impacts of future regional transport corridor projects in countries neighboring Lake Chad and universal access to electricity. 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.

This paper also opens several directions for future research. First, the spatial general equilibrium model does not consider investments in Internet. The plan for future research is to include this sector in the model and to link it with the empirical analysis. Second, 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.

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A Appendix

Figure A1: Employment in agriculture in countries neighboring Lake Chad
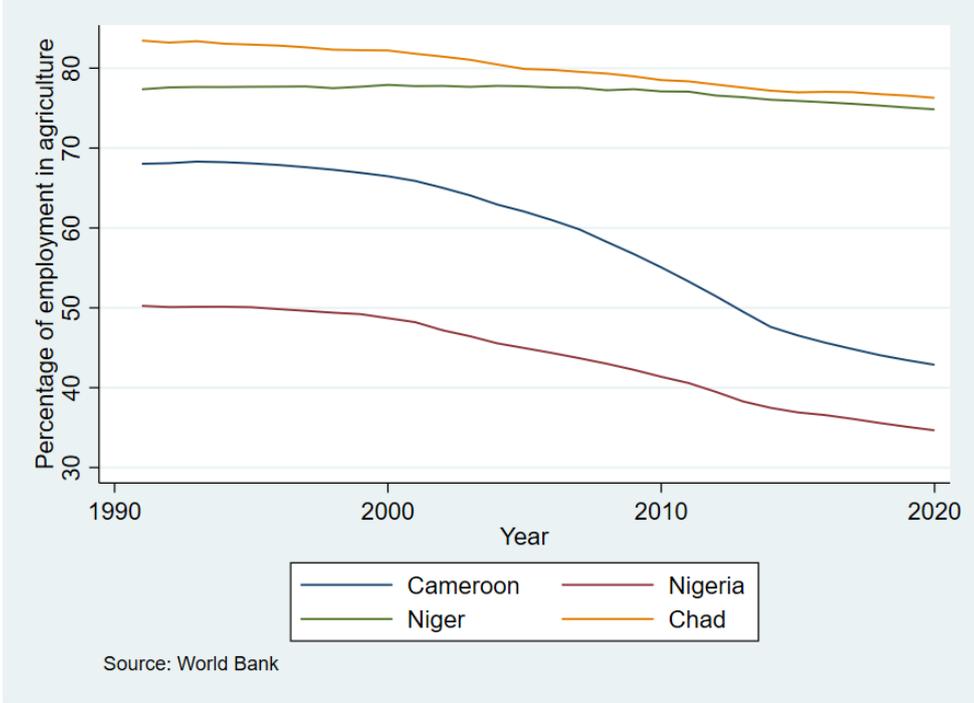
Figure A2: Percentage of population with access to electricity based on nightlights, 2016
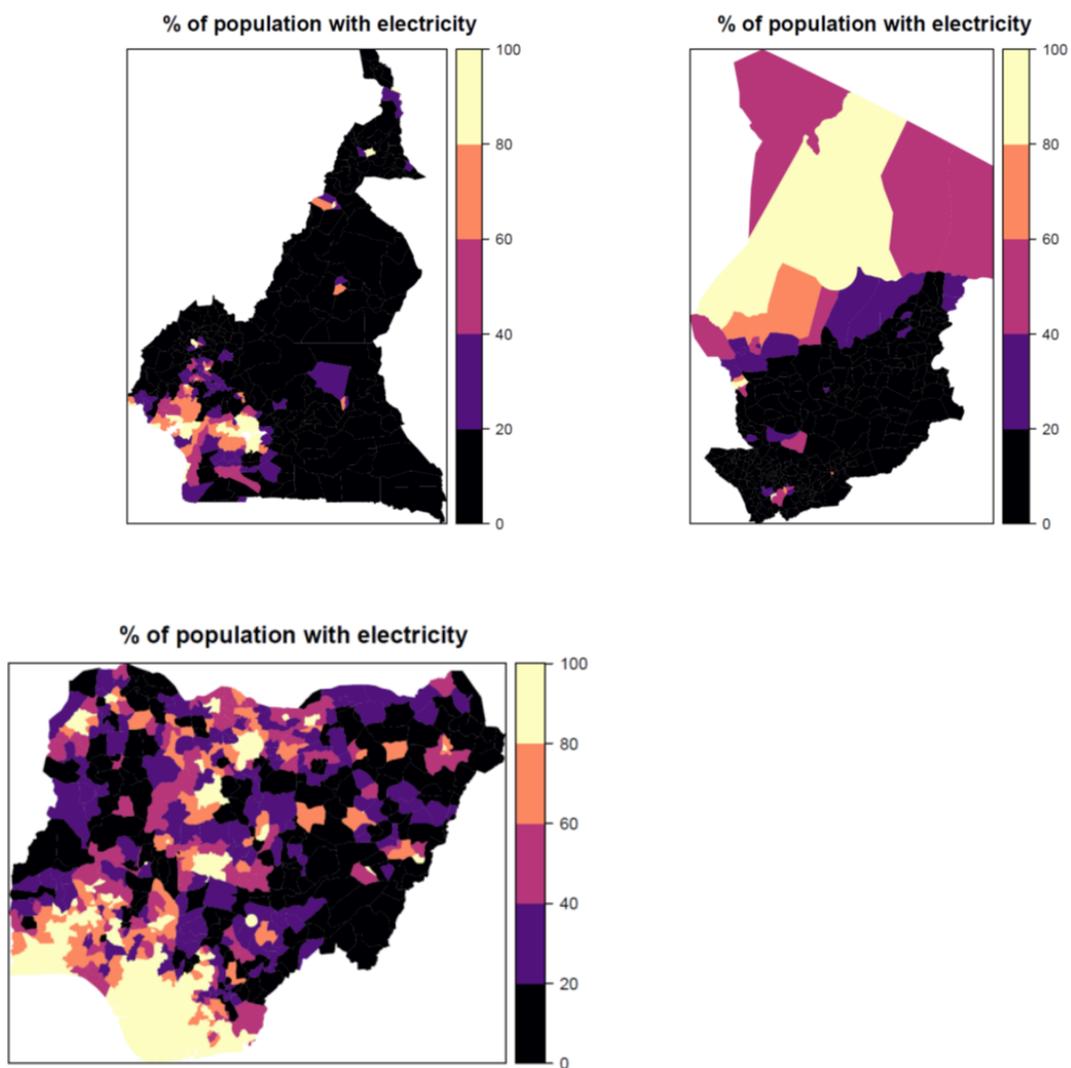
Figure A3: Route-Kilometers of Terrestrial Transmission Network, Africa 2009 - 2019

Source: http://www.africabandwidthmaps.com/
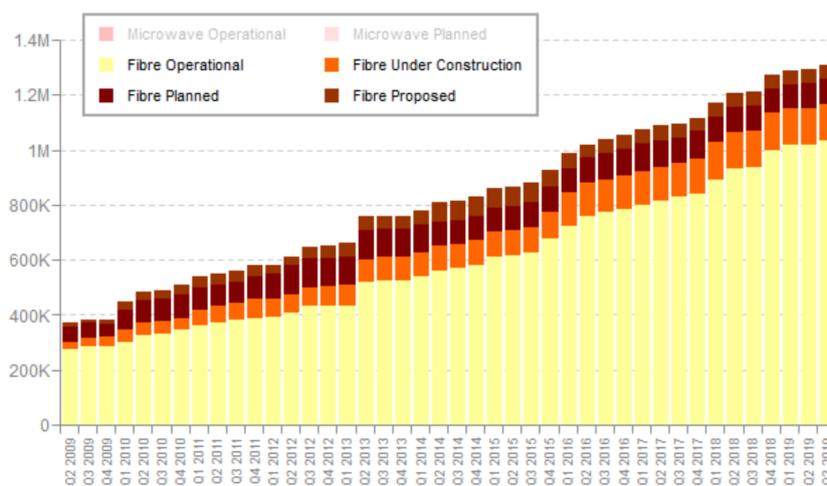
A.1 Infrastructure in Nigeria

Figure A4: Paved road network in Nigeria

(a) All   (b) In fair or good condition
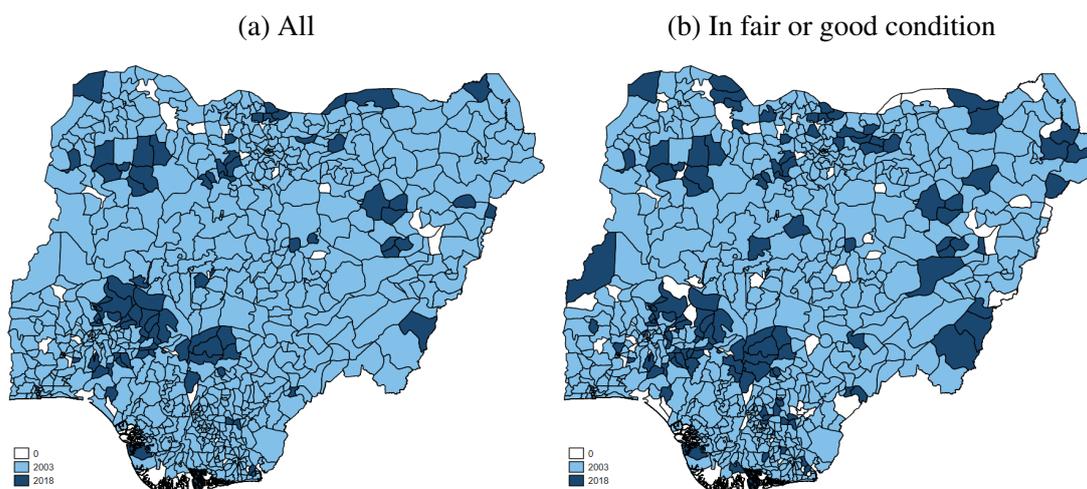
Notes.– Data from Foster and Briceno-Garmendia (2010) and Ali et al. (2015). The map represents the year at which access to a paved road is observed. 0 means that no paved road is reported in the latest observed year. 2013 refers to districts with a paved road when observed in 2013 only. 2018 refers to additional districts with a paved road when observed in 2018 compared to 2013.

Figure A5: Access to electricity
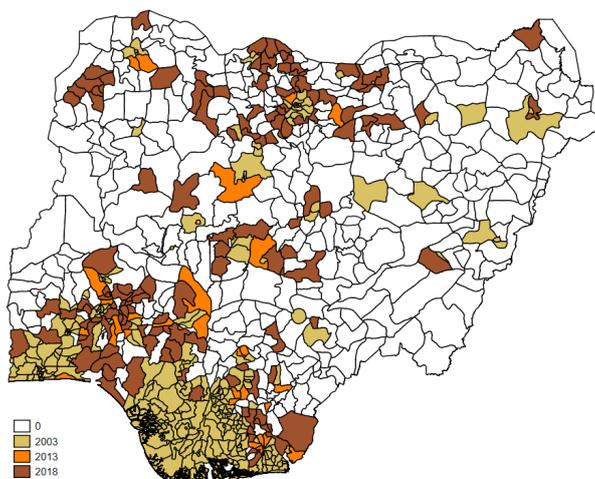
Notes.– Authors' calculations using Night Time Lights. The mapap represents the year at which at least 50 percent of the population has access to electricity, measured by lights at night. 0 means that no access to electricity is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

Figure A6: Access to Internet Fiber network
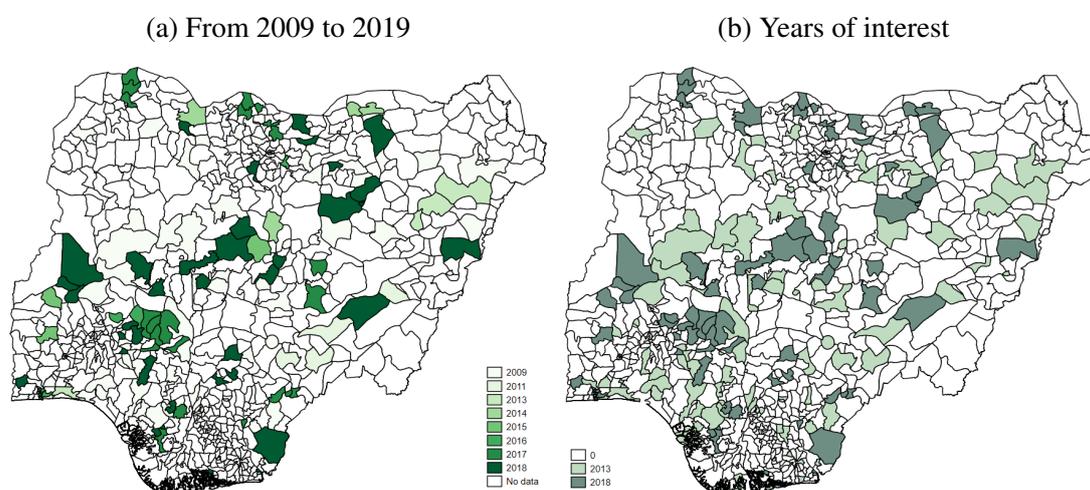
(a) From 2009 to 2019

(b) Years of interest

Notes.– Authors' calculations using Africa Bandwidth Maps. The maps represent access to the fiber network as measured with a node being present in the district. 0 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 A7: Percentage of districts and population with access to a paved road

(a) All

(b) In fair or good condition
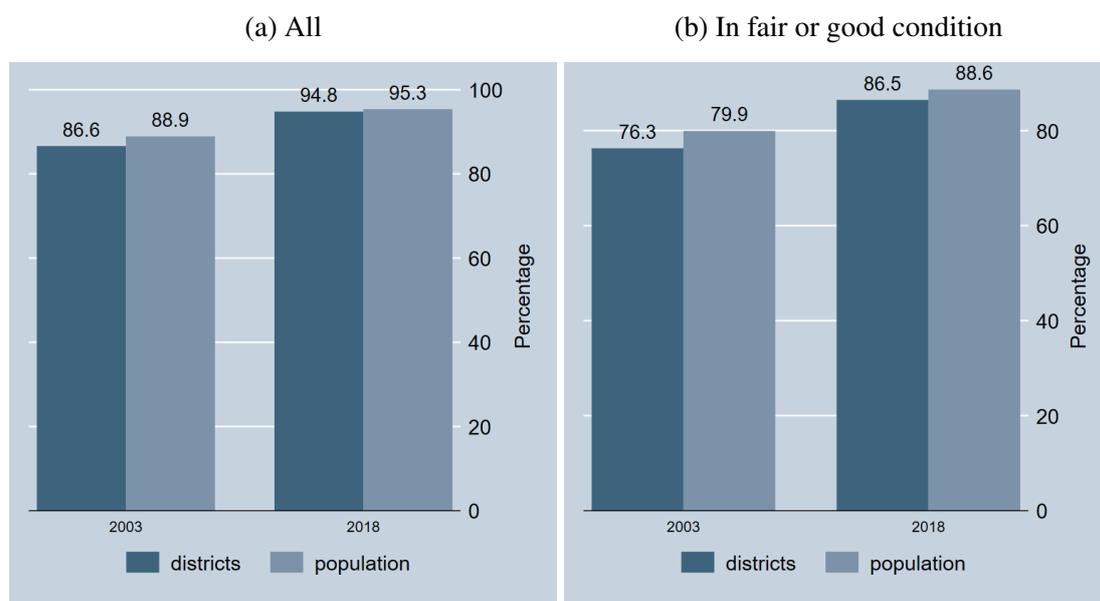
Notes.– Data from Foster and Briceno-Garmendia (2010) and Ali et al. (2015). The population used for weighted average of access is from GHS 2015.

Figure A8: Percentage of districts and population with access to electricity for different thresholds

(a) Threshold=10%

(b) Threshold=50%

(c) Threshold=90%
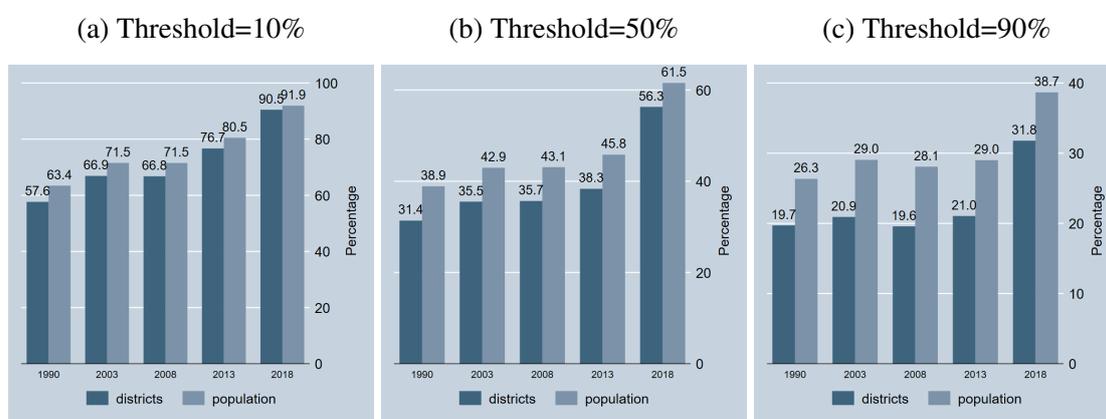
Notes.– Authors' calculations.

Figure A9: Access to internet broadband
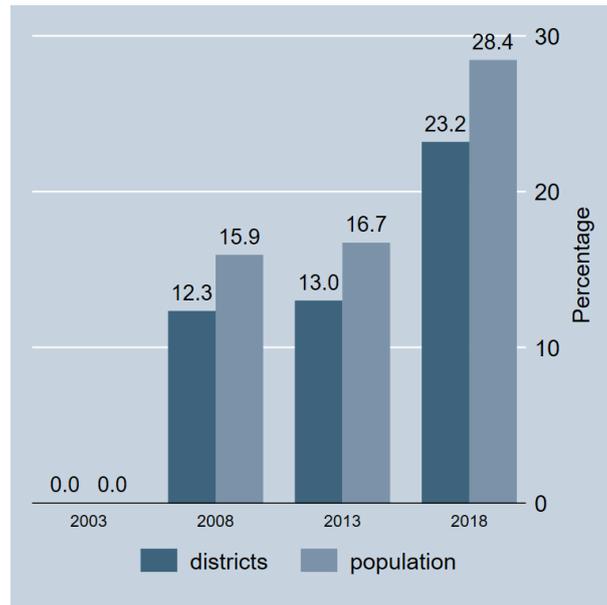
Figure A10: Percentage of districts and population with access to combined infrastructures

(a) Roads and electricity   (b) Roads and internet   (c) Electricity and internet
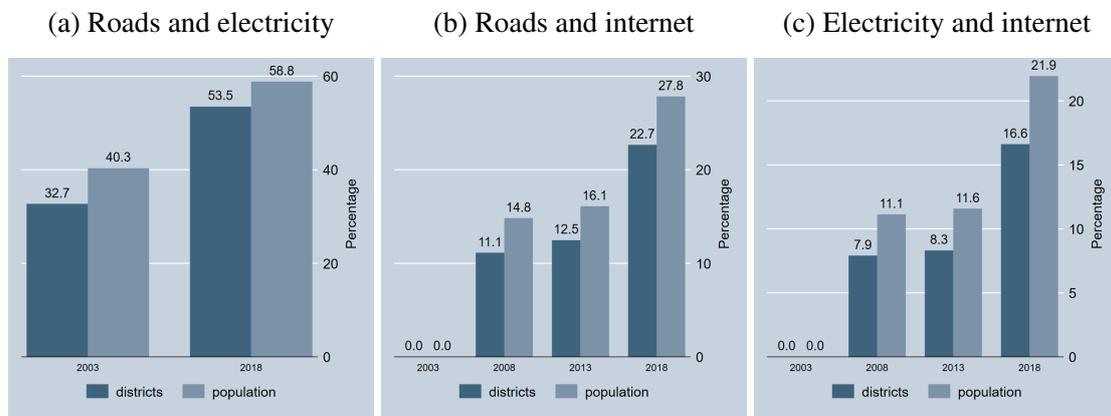
A.2   Cameroon

Figure A11: Access to paved roads

(a) All   (b) In fair or good condition
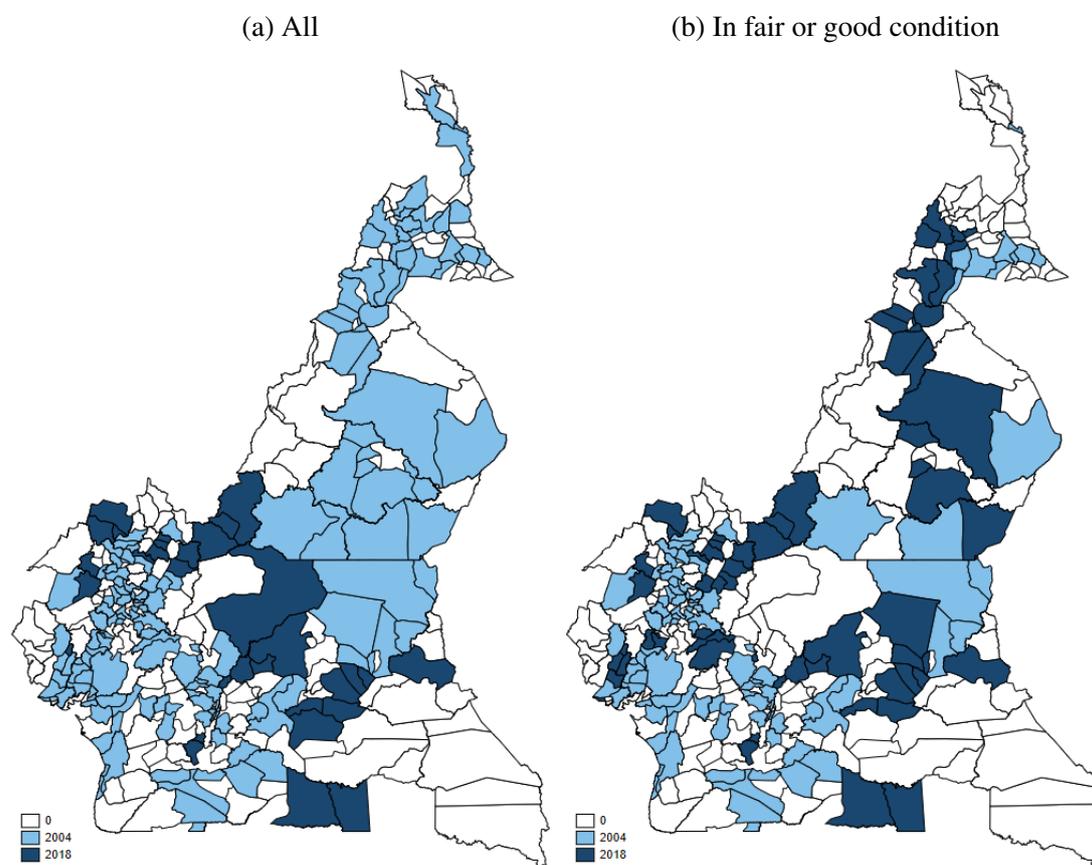

Notes.– Data from Foster and Briceno-Garmendia (2010) and government sources. The map represents the year at which access to a paved road is observed. 0 means that no paved road is reported in the latest observed year. 2013 refers to districts with a paved road when observed in 2013 only. 2018 refers to additional districts with a paved road when observed in 2018 compared to 2013.

Figure A12: Access to electricity
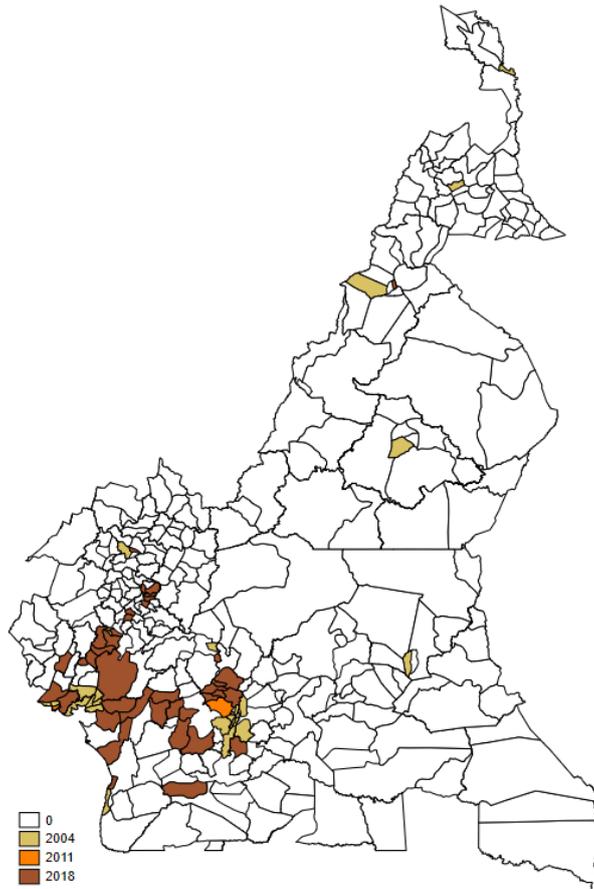
Notes.– Authors' calculations using Night Time Lights. The mapap represents the year at which at least 50 percent of the population has access to electricity, measured by lights at night. 0 means that no access to electricity is reported in the latest observed year. The earliest year refers to districts with access when observed in that year only. Successive years refer to additional districts which gained access when compared to previous years.

Figure A13: Access to Internet Fiber network
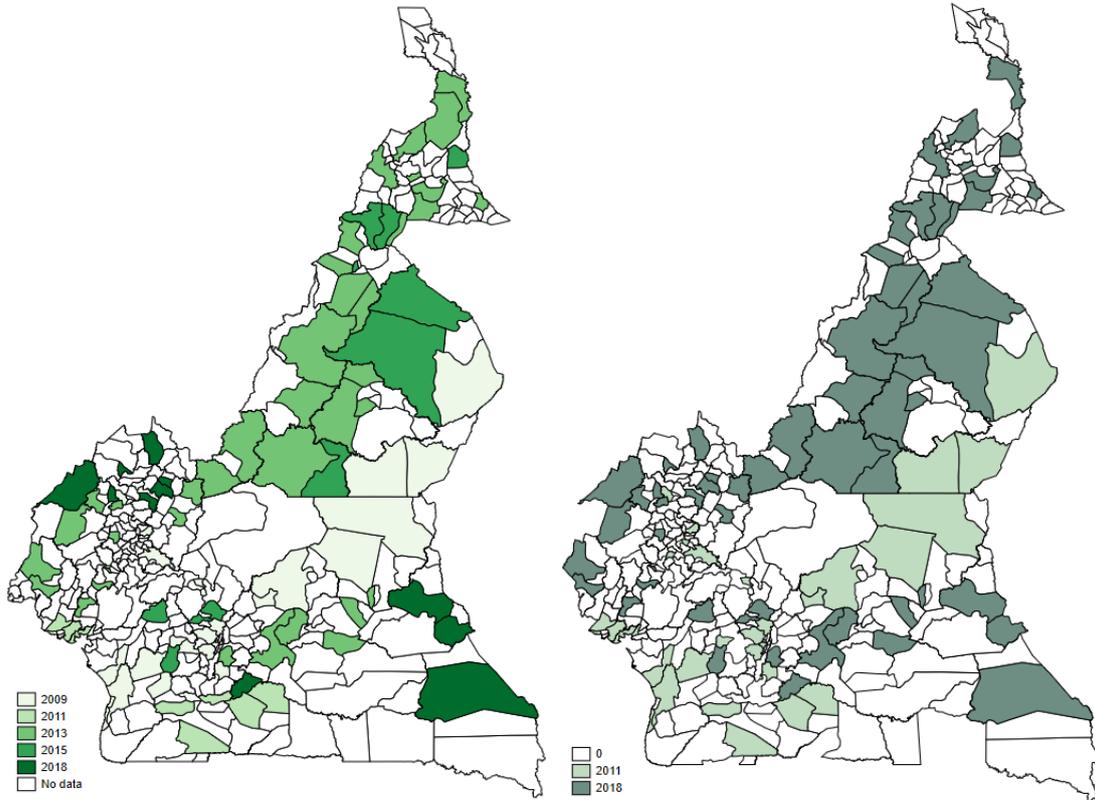
(a) From 2009 to 2019

(b) Years of interest

Notes.– Authors' calculations using Africa Bandwidth Maps. The maps represent access to the fiber network as measured with a node being present in the district. 0 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 A14: Percentage of districts and population with access to a paved road

(a) All

(b) In fair or good condition
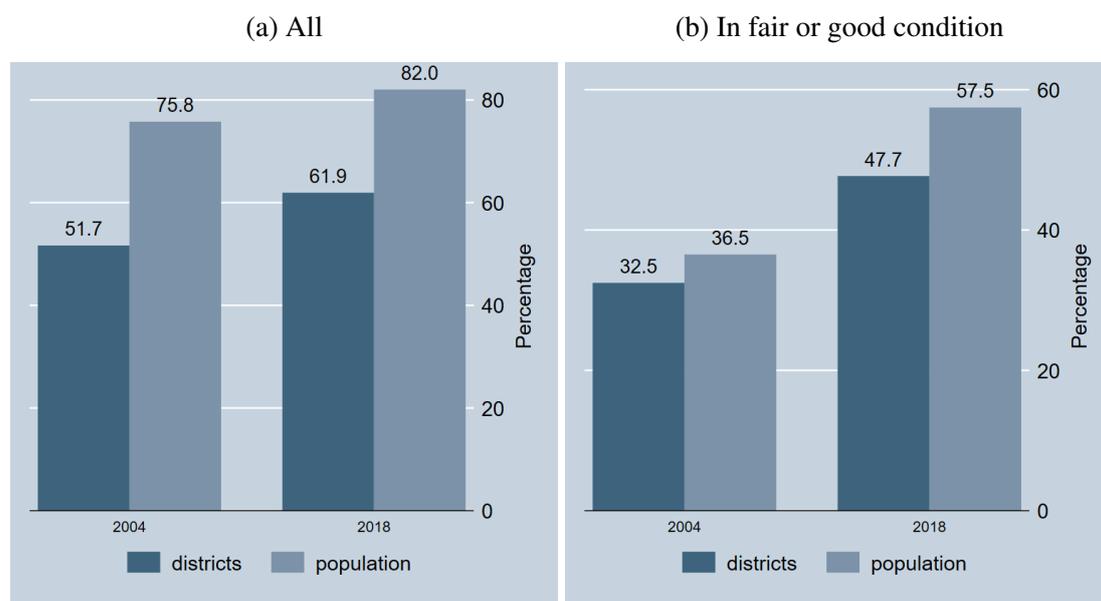
Notes.– Data from Foster and Briceno-Garmendia (2010) and government sources. The population used for weighted average of access is from GHS 2015.

Figure A15: Percentage of districts and population with access to electricity for different thresholds

(a) Threshold=10%

(b) Threshold=50%

(c) Threshold=90%
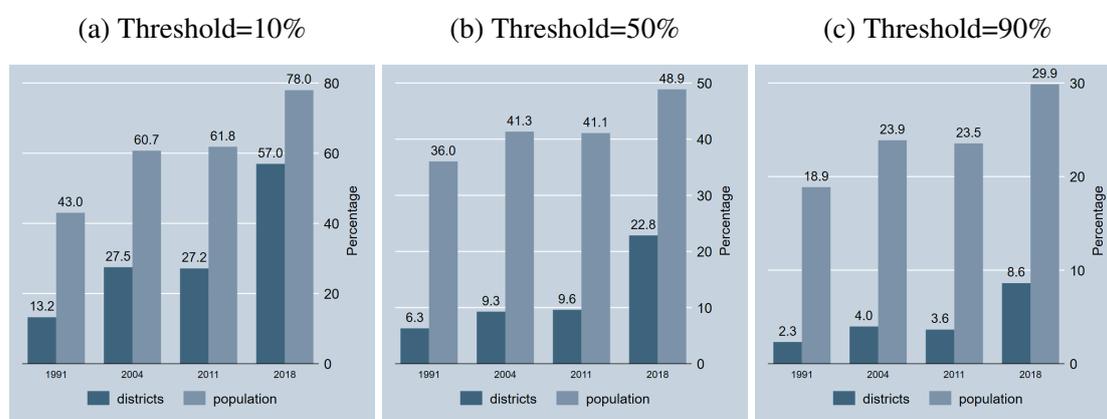
Notes.– Authors' calculations.

Figure A16: Access to internet
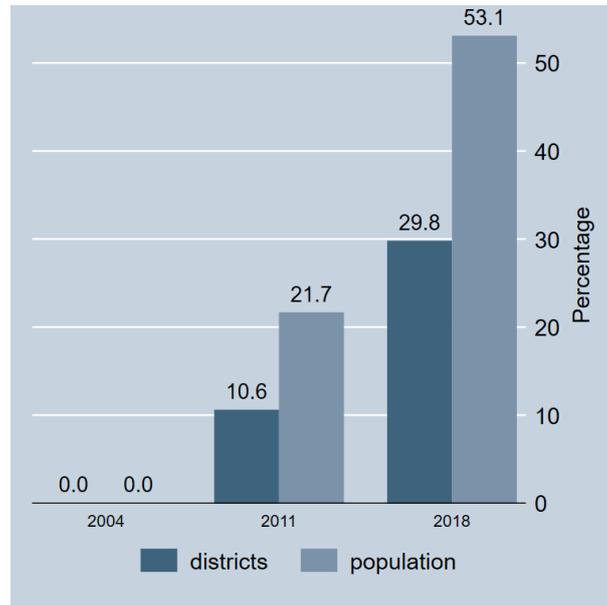
Figure A17: Percentage of districts and population with access to combined infrastructures

(a) Roads and electricity   (b) Roads and internet   (c) Electricity and internet

49
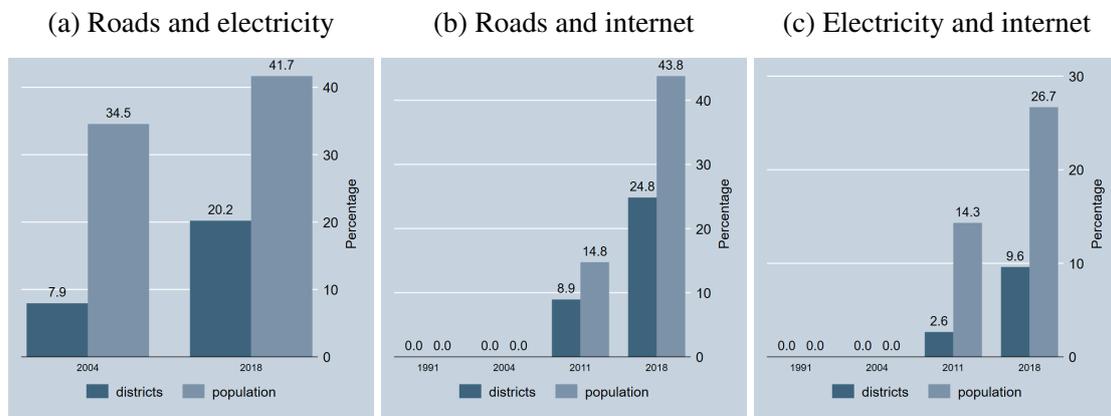
A.3 Chad

Figure A18: Access to paved roads and electricity

(a) Paved roads
(b) Electricity (2014)
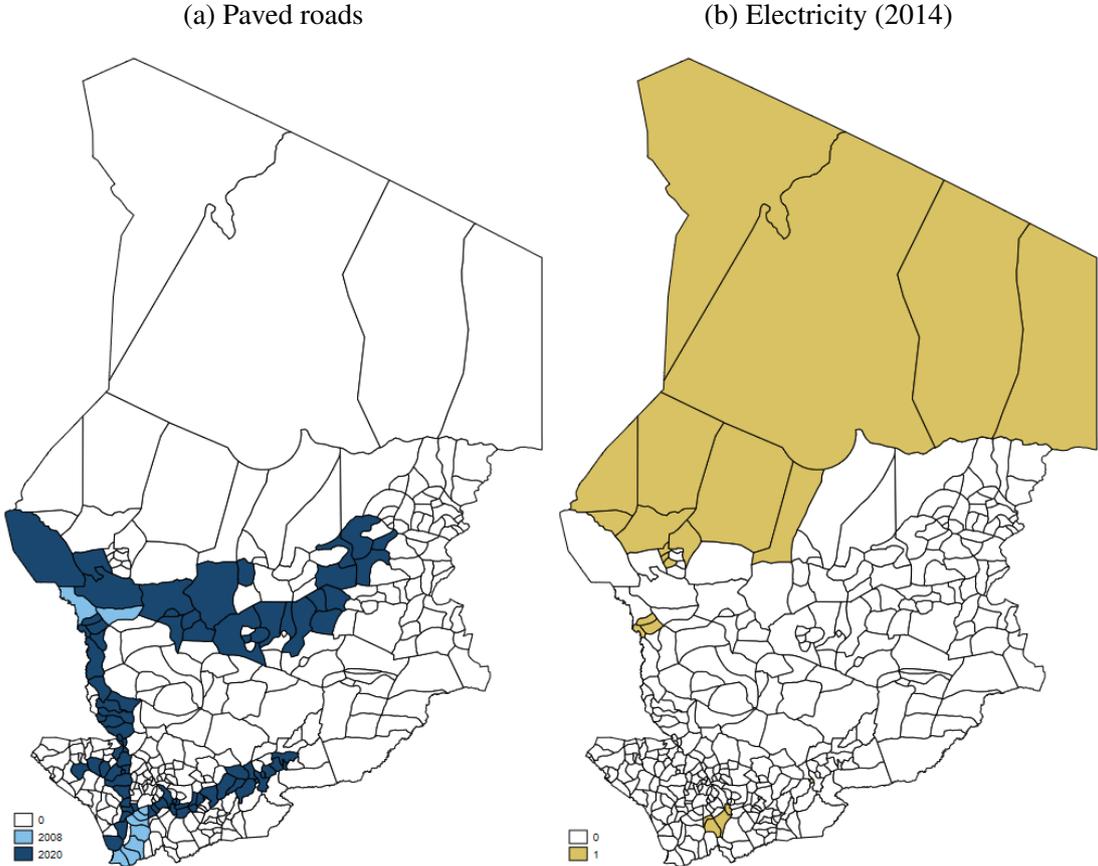
Notes.– Data using government sources and Night Time Lights. The map (b) represents the year at which at least 50 percent of the population has access to electricity, measured by lights at night in 2014. The map (a) represents the year at which at the population has access to a paved road.The map represents the year at which access is observed. 0 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.

Figure A19: Access to Internet Fiber network
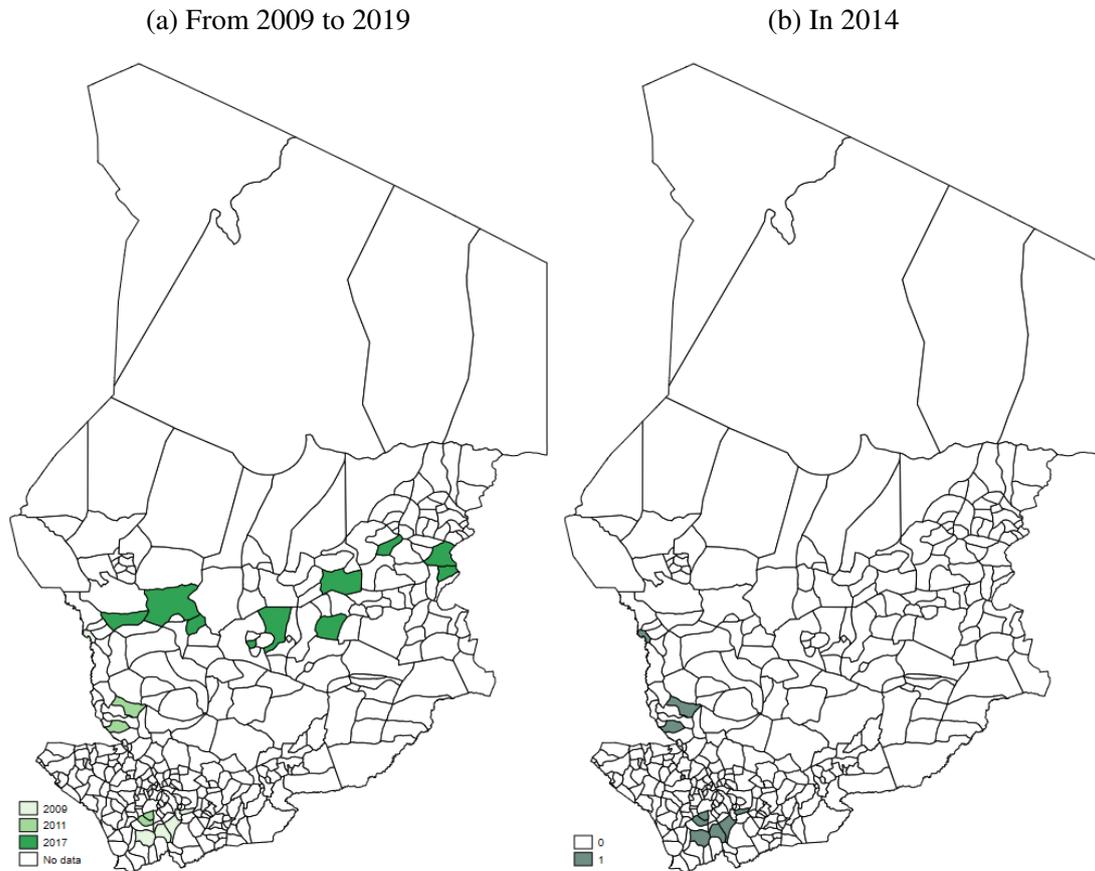
(a) From 2009 to 2019

(b) In 2014

Notes.– Authors' calculations using Africa Bandwidth Maps. The maps represent access to the fiber network as measured with a node being present in the district. 0 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 A20: Percentage of districts and population with access to infrastructure (2014)

(a) All

(b) Combined

(c) Electricity thresholds
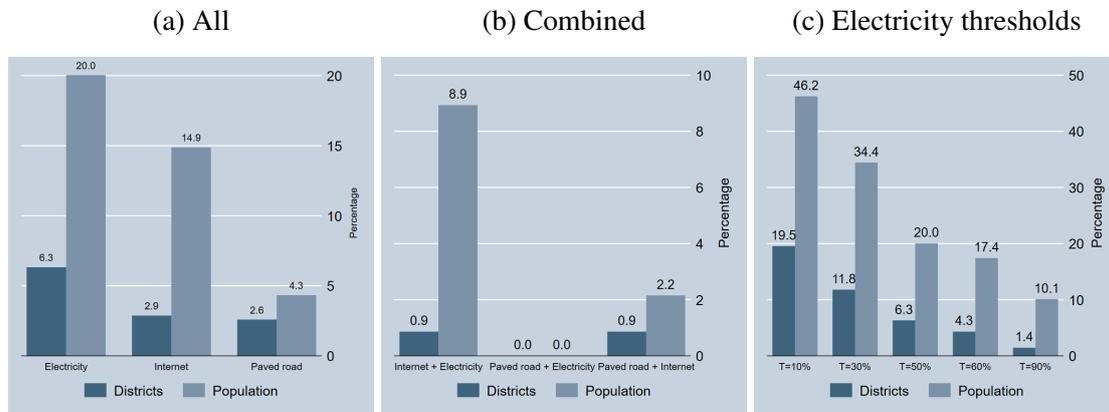
Notes.– Authors' calculations. The population used for weighted average of access is from GHS 2015.

A.4 Additional Data

Table A1: GADM administrative levels

Level	NGA	NER	TCD	CMR
adm1	37	8	23	10
adm2	775	36	55	58
adm3	NA	132	348	360

Figure A21: Lake Chad sub-region
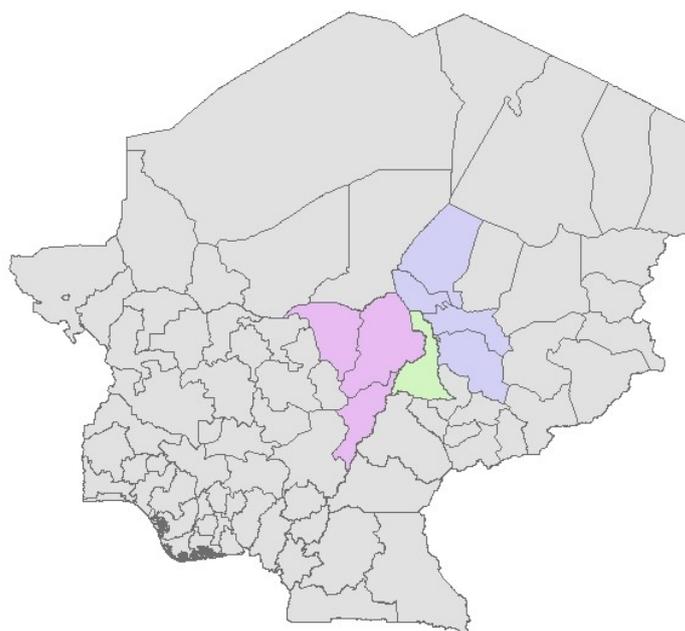
Figure A22: Electricity grids, 2007 and 2018

(a) 2007	(b) 2018
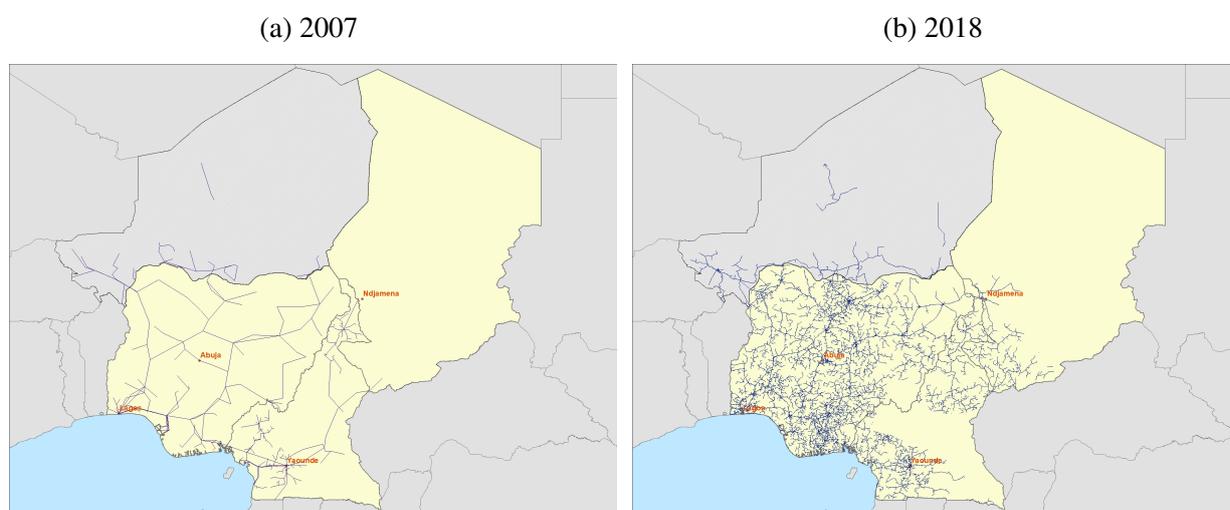
Notes.– Electricity grids from Foster and Briceno-Garmendia (2010) and Arderne et al. (2020).

A.5 Regression tables

Table A2: OLS results for locations around Lake Chad

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.108[+]	0.0725*	0.0327	-0.0162
	(-1.84)	(2.31)	(0.85)	(-0.83)
Internet	-0.0601	0.0554*	0.0300	0.0464*
	(-1.07)	(2.09)	(0.73)	(2.16)
Road + Internet	-0.132	-0.0605	0.189[+]	-0.00452
	(-1.17)	(-1.33)	(1.92)	(-0.14)
Road + Electricity	-0.418**	0.192**	0.230**	0.0585[+]
	(-5.48)	(4.91)	(5.55)	(1.78)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.381	0.465	0.508	0.637
N. of observations	123	123	123	123

t statistics in parentheses

[+] $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A3: OLS results for Nigeria, Cameroon, Chad in the period 2008-2018

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.0461**	0.0188**	0.0270*	0.0318**
	(-2.72)	(2.60)	(1.98)	(3.97)
Road + Electricity	-0.0571**	0.0298**	0.0268[+]	-0.0277**
	(-3.23)	(3.80)	(1.79)	(-3.00)
Internet	-0.0405*	0.00199	0.0421*	-0.00670
	(-1.97)	(0.26)	(2.46)	(-0.63)
Internet + Electricity	-0.00606	-0.00726	0.0105	-0.00862
	(-0.25)	(-0.66)	(0.50)	(-0.67)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.495	0.365	0.443	0.159
N. of observations	1817	1817	1817	1817

t statistics in parentheses

[+] $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A4: OLS results for Cameroon

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.116**	0.0606**	0.0551**	0.0224*
	(-4.50)	(4.54)	(3.43)	(2.15)
Internet	-0.0548	0.000550	0.0542*	0.0162
	(-1.58)	(0.04)	(2.09)	(1.10)
Road + Electricity	-0.314**	0.117**	0.198**	0.0520**
	(-7.83)	(6.28)	(7.22)	(3.84)
Internet + Electricity	-0.0659	-0.000399	0.0663	-0.0315
	(-0.86)	(-0.01)	(1.27)	(-1.41)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.290	0.271	0.388	0.066
N. of observations	661	661	661	661

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A5: OLS results for Nigeria

	Agriculture	Manufacturing	Services	Not working
Paved road	0.0537**	-0.00909	-0.0446**	0.0179*
	(2.76)	(-1.29)	(-2.86)	(2.15)
Internet	-0.0666**	0.00310	0.0635**	-0.00916
	(-2.60)	(0.31)	(2.89)	(-0.78)
Road + Electricity	-0.260**	0.0829**	0.177**	-0.0558**
	(-19.74)	(15.44)	(15.50)	(-9.20)
Internet + Electricity	0.0115	-0.0113	-0.000159	-0.00437
	(0.39)	(-0.93)	(-0.01)	(-0.32)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.274	0.282	0.210	0.064
N. of observations	2137	2137	2137	2137

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A6: OLS results for Cameroon: the use perspective, after 2008

	Agriculture	Manufacturing	Services	Not working
Electricity (share)	-0.416**	0.159**	0.257**	0.0447**
	(-12.60)	(8.25)	(10.48)	(2.81)
Motorcycle (share)	-0.143*	0.0267	0.116*	0.0326
	(-2.41)	(0.80)	(2.49)	(0.97)
Car (share)	-0.410**	0.114	0.296**	-0.0285
	(-3.17)	(1.44)	(2.91)	(-0.31)
Use of internet (share)	-0.389**	0.0991$^+$	0.289**	-0.0385
	(-4.77)	(1.82)	(3.89)	(-0.73)
Mobile phone (share)	-0.169**	0.0271	0.142**	0.0985*
	(-2.76)	(0.74)	(2.73)	(2.54)
Land phone (share)	-0.325	-0.220	0.545**	-0.125
	(-1.34)	(-1.18)	(2.76)	(-0.93)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.646	0.389	0.577	0.095
N. of observations	442	442	442	442

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A7: OLS results for Nigeria: the use perspective, after 2008

	Agriculture	Manufacturing	Services	Not working
Electricity (share)	-0.356**	0.104**	0.252**	-0.0738**
	(-22.18)	(14.13)	(18.43)	(-9.48)
Motorcycle (share)	0.0804**	-0.0291*	-0.0513*	0.00655
	(3.26)	(-2.27)	(-2.43)	(0.49)
Car (share)	-0.355**	-0.0573*	0.413**	-0.00349
	(-8.47)	(-2.18)	(11.32)	(-0.15)
Use of internet (share)	0.0748	-0.0722*	-0.00268	-0.245**
	(1.43)	(-2.38)	(-0.06)	(-8.15)
Mobile phone (share)	-0.189**	0.115**	0.0745**	0.0155
	(-6.07)	(7.78)	(2.70)	(0.70)
Land phone (share)	-0.384**	-0.0164	0.401**	0.189**
	(-3.26)	(-0.22)	(3.65)	(3.20)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.538	0.274	0.492	0.127
N. of observations	1684	1684	1684	1684

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A8: Heterogenous effects on agricultural employment, by share of agricultural employment, in Cameroon, Nigeria and Chad

	Agriculture q0.25	Agriculture q0.5	Agriculture q0.75
main			
Paved road	-0.00135	-0.0363	-0.0247
	(-0.07)	(-1.54)	(-1.02)
Internet	-0.0810**	-0.0484	-0.0787**
	(-2.92)	(-1.37)	(-2.59)
Road + Electricity	-0.224**	-0.295**	-0.322**
	(-19.11)	(-19.07)	(-16.70)
Internet + Electricity	0.0582*	0.000243	-0.0104
	(2.08)	(0.01)	(-0.25)
Country-Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared			
N. of observations	3041	3041	3041

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A9: Heterogenous effects on agricultural employment, by the distance to a main city, in Cameroon, Nigeria and Chad

	Agriculture Q1	Agriculture Q2	Agriculture Q3	Agriculture Q4	Agriculture Q5
Paved road	0.115**	0.0452$^+$	-0.0253	-0.0612*	-0.0574
	(3.42)	(1.70)	(-0.95)	(-2.06)	(-1.56)
Internet	-0.0587	-0.0874**	-0.0568	-0.00215	-0.0574
	(-1.20)	(-2.96)	(-1.29)	(-0.07)	(-1.08)
Road + Electricity	-0.0769**	-0.0934**	-0.0278	0.00465	-0.182*
	(-2.93)	(-3.01)	(-0.79)	(0.11)	(-2.14)
Internet + Electricity	0.0446	0.0881*	-0.0321	-0.135*	0.0739
	(0.87)	(2.31)	(-0.61)	(-2.50)	(0.89)
Country Year FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
R-squared	0.441	0.273	0.323	0.242	0.298
N. of observations	744	691	671	543	392

t statistics in parentheses

$^+$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A10: Heterogenous effects on manufacturing employment, by the distance to a main city, in Cameroon, Nigeria and Chad

	Manufacturing Q1	Manufacturing Q2	Manufacturing Q3	Manufacturing Q4	Manufacturing Q5
Paved road	-0.0517**	-0.000957	0.0143	0.0238*	0.0425**
	(-2.87)	(-0.07)	(1.36)	(2.04)	(2.83)
Internet	0.0190	-0.00931	0.0118	-0.0214+	-0.00208
	(0.36)	(-0.49)	(0.93)	(-1.88)	(-0.13)
Road + Electricity	0.0424**	0.0236+	0.0146	-0.000445	0.0407
	(3.42)	(1.74)	(0.98)	(-0.03)	(1.00)
Internet + Electricity	-0.0384	0.0195	-0.0124	0.0218	-0.0243
	(-0.70)	(0.82)	(-0.60)	(1.21)	(-0.83)
Country Year FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
R-squared	0.402	0.304	0.323	0.377	0.403
N. of observations	744	691	671	543	392

t statistics in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A11: Heterogenous effects on services employment, by the distance to a main city, in Cameroon, Nigeria and Chad

	Services Q1	Services Q2	Services Q3	Services Q4	Services Q5
Paved road	-0.0634*	-0.0442*	0.0110	0.0374+	0.0148
	(-2.02)	(-2.18)	(0.48)	(1.71)	(0.54)
Internet	0.0398	0.0967**	0.0450	0.0235	0.0595
	(1.03)	(3.77)	(1.20)	(0.88)	(1.31)
Road + Electricity	0.0345	0.0697**	0.0132	-0.00420	0.141**
	(1.46)	(2.78)	(0.42)	(-0.10)	(2.67)
Internet + Electricity	-0.00624	-0.108**	0.0444	0.114*	-0.0496
	(-0.15)	(-3.15)	(0.95)	(2.08)	(-0.72)
Country Year FE	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes
R-squared	0.440	0.310	0.332	0.341	0.336
N. of observations	744	691	671	543	392

t statistics in parentheses
$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

A.6 Regression tables: IV strategy

Table A12: Energy sources in electricity production (in %)

	1990		2015	
	Cameroon	Nigeria	Cameroon	Nigeria
Hydro	99%	42%	75%	18%
Renewable, excluding hydro	NA	NA	1%	NA
Oil, gas and coal	1%	58%	25%	82%

Table A13: OLS results for Nigeria and Cameroon (comparison table)

	Agriculture	Manufacturing	Services	Not working
Paved road	-0.00841	0.0136*	-0.00276	0.0205**
	(-0.61)	(2.23)	(-0.26)	(3.26)
Road + Electricity	-0.0579**	0.0189**	0.0408**	-0.00685
	(-3.76)	(2.80)	(3.18)	(-0.97)
Internet	-0.0400**	-0.00724	0.0482**	-0.0145**
	(-3.59)	(-1.31)	(4.86)	(-2.62)
Year + Country FE	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
R-squared	0.446	0.353	0.458	0.103
N. of observations	2798	2798	2798	2798

t statistics in parentheses

[+] $p < 0.10$, [*] $p < 0.05$, [**] $p < 0.01$

Table A14: First Stage: Roads IV and Electricity IV for Nigeria and Cameroon

	Dependent variable:	
	Paved Roads	Paved Roads × Electricity
Paved Road IV	0.1385 ***	0 .0934***
	(7.62)	(3.36)
Paved Road IV × Elec IV	0.0087 ***	0.0637***
	(0.49)	(2.81)
Subnational FE	Yes	Yes
Controls	Yes	Yes
Windmeijer cond. F.	8.51	9.73
F-test statistic	9.08	10.08
N. of observations	2798	2798

t statistics in parentheses

[+] $p < 0.10$, [*] $p < 0.05$, [**] $p < 0.01$

Table A15: 2SLS results for Nigeria

	Agriculture	Manufacturing	Services
Paved road	0.135**	-0.0844**	-0.0505
	(3.30)	(-4.67)	(-1.50)
Paved road and Electricity	-0.331**	0.124**	0.207**
	(-8.44)	(7.26)	(6.21)
Internet	-0.0430**	-0.00745	0.0505**
	(-3.37)	(-1.13)	(4.55)
Controls	Yes	Yes	Yes
R-squared	0.274	0.067	0.238
N. of observations	2137	2137	2137

t statistics in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Table A16: 2SLS results for Cameroon

|	Agriculture	Manufacturing	Services
Paved road	-0.130*	0.0260	0.104*
	(-2.03)	(0.62)	(2.05)
Paved road and Electricity	-0.111	0.134	-0.0227
	(-0.54)	(0.95)	(-0.14)
Internet	-0.0290	-0.0774**	0.106**
	(-1.03)	(-4.48)	(4.42)
Controls	Yes	Yes	Yes
R-squared	0.455	0.227	0.345
N. of observations	661	661	661

t statistics in parentheses

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Figure A23: Descriptive statistics for the 24 regions for the model

(a) Share of employment in agricultural sector

(b) Total population per subregion
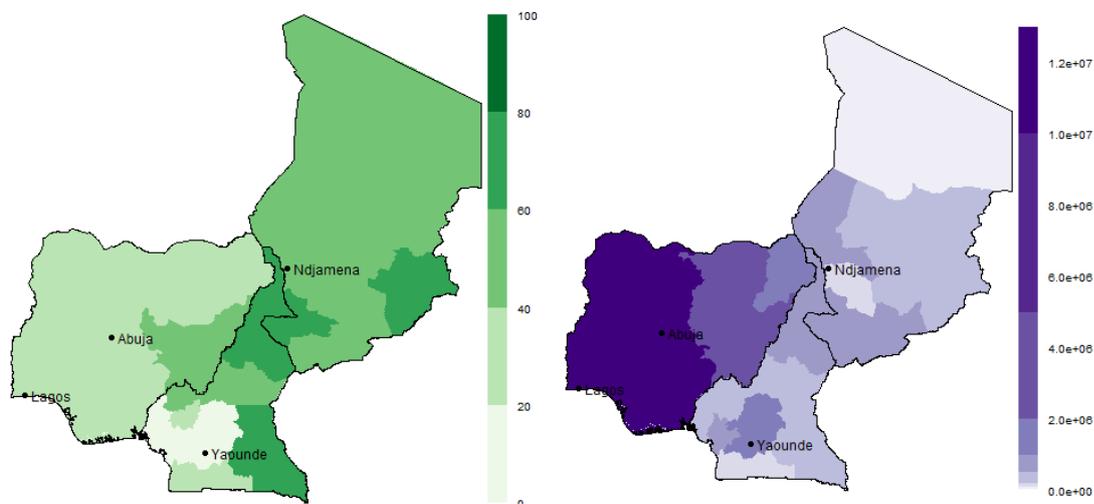
Source: Authors' calculations.

A.7   Counterfactuals

Table A17: Parameters for Structural Estimation

Parameter	Value	Source	Description
σ	4	Bernard et al. (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

Figure A24: Calibrated sector productivities

(a) Agriculture

(b) Manufacturing

(c) Services

Notes.– Authors' calculations.

60
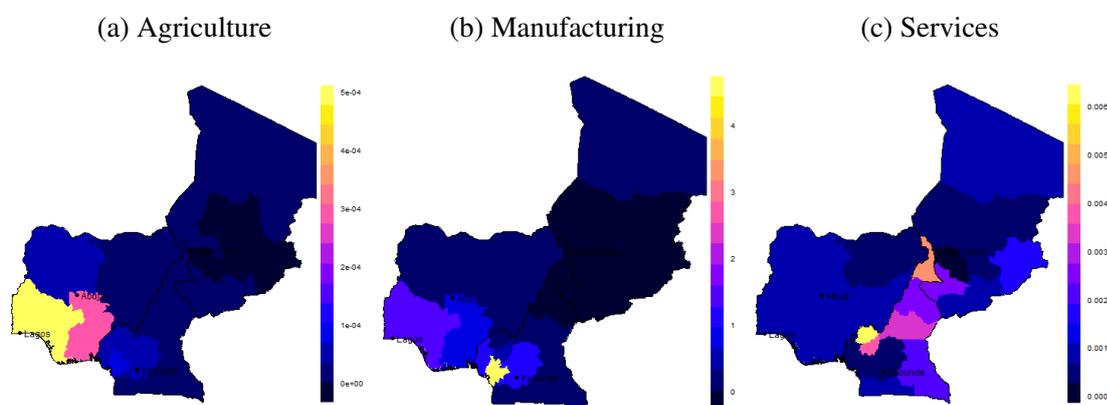
Figure A25: Rail and road investments in Cameroon (left) and Chad (right)
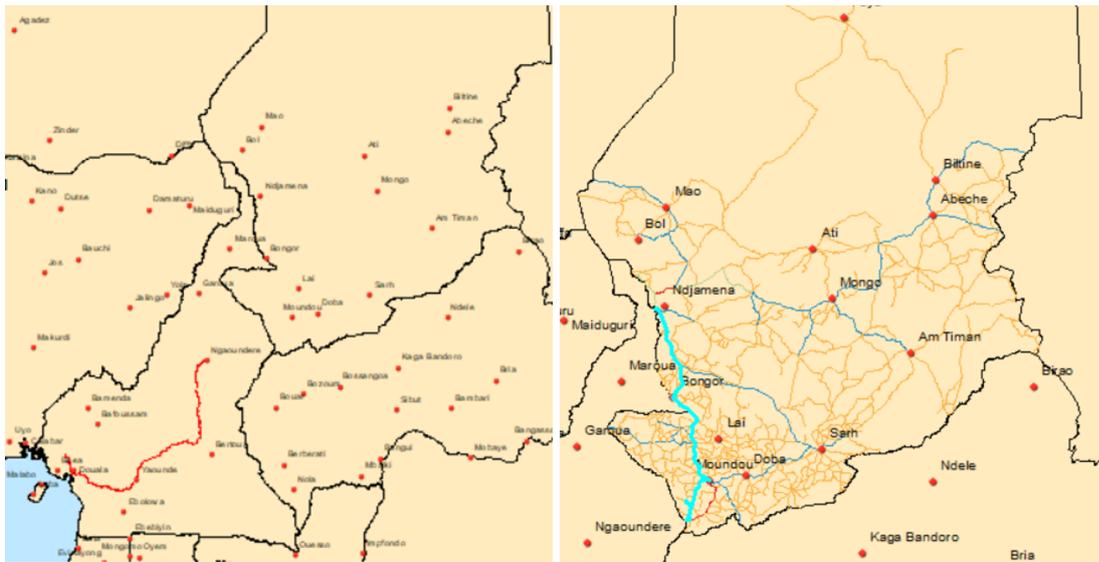
Figure A26: Regional welfare impacts from universal access to electricity, transport and reduction in border delays compared to baseline - percentage change in regional welfare

(a) Road and rail

(b) Electrification

(c) Road and rail, and borders

(d) Transport, borders and electrification