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Infrastructure and Structural Change in the Horn of Africa

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Abstract

Access to infrastructure supports economic development through both capital accumulation and structural transformation. This paper investigates the links between investments in electricity, Internet, and road infrastructure, in isolation and bundled, and economic development in the Horn of Africa, a region that includes countries with different levels of infrastructure and economic development. Using data on the expansion of the road, electricity, and Internet networks over the past two decades, 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. The impact of bundled road and electricity investments on reducing the sectoral employment share in agriculture is found to be 2.5 times larger than the impact of roads alone. The paper then uses a spatial general equilibrium model to quantify the impacts of future regional transport investments, bundled with electricity and trade facilitation measures, on economic development in countries in the Horn of Africa.

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Infrastructure and Structural Change in the Horn of Africa

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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 in countries in the Horn of Africa.

This paper first uses reduced-form analysis to understand the relationship between past investments in electricity, Internet, and road infrastructure and sectoral structure of employment in Ethiopia and Kenya. Geo-identified data on the infrastructure expansion of roads and electricity for Kenya and Ethiopia 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), straight transmission lines connecting themain cities with newly opening hydropower dams in Ethiopia and all power plants in Kenya are used for electrification, the construction of an hypothetical least-cost network expansion using a minimum spanning tree algorithm is used for road expansion. Reduced-form results capture the localized effects in the areas that have been affected, but do not capture the general-equilibrium effects and spillovers due to the network nature of infrastructure such as roads. The paper then uses a spatial general-equilibrium model, based on Moneke (2020), to assess the aggregate and spatial impacts of planned infrastructure investments in the region. The general-equilibrium model captures the spillover effects that a localized investment has on the rest of the country and all the countries in the Horn of Africa and generates welfare estimates for the entire region and all its subregions.

[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.

A companion paper undertakes similar work for countries around Lake Chad.

The paper finds different effects of bundled and isolated infrastructure investments on sectoral employment. The empirical analysis finds that investments in roads alone have a large impact on sectoral change, moving workers from agriculture to manufacturing and services. The impact is found to be 2.5 times larger in the case of bundled road and electricity investments. Internet access is associated with moving workers from agriculture to services.

Simulations using a spatial general equilibrium model show that bundled infrastructure investments cause different patterns of structural transformation and welfare gains than isolated infrastructure investments. Simulations quantify the structural change and welfare gains from future regional corridors, when built in isolation and when bundled with additional investments in electrification. At the local level, we show that planned regional road investments in the Horn of Africa will have a larger impact on structural change when complemented with better access to electricity. Simulations show that better regional market access could bring large welfare gains, especially when complemented with lower border delays. Lower transport costs reduce spatial frictions and increase specialization within and across countries. Better regional integration is predicted to yield the largest reduction in agriculture employment in Kenya, where several regions have a comparative advantage in manufacturing, and the smallest in Ethiopia and Somalia. However, Somalia enjoys the largest welfare gains from lower border and transport frictions because of access to cheaper goods and a wider variety of goods.

Several papers have examined the impact of infrastructure investment on sectoral employment at the micro-level. Gertler et al. (2016) find that lower transport costs empower women by opening up labor market opportunities and increasing their employment in the nonagricultural 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. This paper adds to this literature by looking at the district-level impact of infrastructure on sectoral employment in the Horn of Africa.

Most of the literature studying the impact of infrastructure considers the gains from energy, transport, and digital investments in isolation or bundled in a unique infrastructure index. The aggregate impact of infrastructure has been measured through the elasticity of output with respect to a synthetic infrastructure index, which includes transport along with electricity and telecommunications (Calderon et al., 2015). This approach does not allow to isolate the complementarities of different infrastructure. Moneke (2020) shows that transport and electricity investments are complementary and that they increased economic development in Ethiopia. He finds starkly different patterns of bundled infrastructure investments on sectoral employment compared with only road investments. Roads alone cause service sector employment to increase at the expense of agriculture and, especially, manufacturing employment. In contrast, the interaction of roads and electrification causes a strong reversal in manufacturing employment. This paper adds to the strand of literature initiated by Moneke (2020) by studying the impact of internet, electricity and transport, and their complementarities, for both Ethiopia and

Kenya.

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.[2] 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.

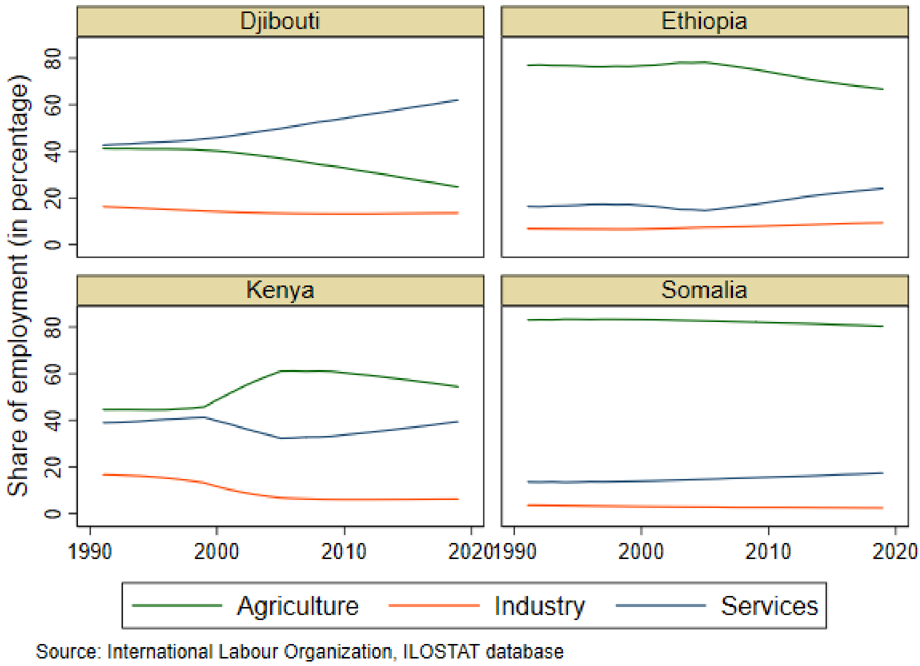
The paper is structured as follows. Section 2 provides an overview of the background in the Horn of Africa. Section 3 includes details of the data used in our analysis. Section 4 presents the empirical strategy and results. Section 5 develops a spatial general-equilibrium model to produce counterfactuals for more domestic and regional integration. Section 6 concludes.

2 Background

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

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

Figure 1: Employment per sector in Horn of Africa countries, 1990–2020



Economic activity has been converging across the Horn of Africa, but not in the borderlands, which are lagging (World Bank, 2021). Evidence from nightlights points to faster growth in economic activity in less built-up and less well-lit areas (1992–2018), consistent with shared economic development and "catch-up" dynamics. However, a critical exception to this pattern is that border areas show slower growth relative to more developed, core areas. Little development is taking place in these areas, extending their historical marginalization and character as lagging, peripheral regions. Whether regional integration through improved connectivity and lower frictions at the borders will lead to stronger development in the lagging areas remains to be seen.

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

3 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).

Table 1: Summary of Infrastructure data

Infrastructure	Country	Year	Source
Roads	Ethiopia	1996, 2006, 2016	Ethiopian Roads Authority (ERA)
	Kenya	2003, 2009, 2016-18	Kenya Road Board
Electricity	All	vary across countries	Nighttime lights / Population raster
Electricity grid	All	around 2006	Foster and Briceno-Garmendia (2010)
	All	most recent	gridfinder.org and Arderne et al. (2020)
Internet (fiber backbone)	All	2009-2019	Africa Bandwidth Maps 2009-19

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. For Ethiopia and Kenya, we used a rich panel of data on road network expansions complemented by details on road conditions (a panel of GIS data and maps for 1996, 2006, and 2016 for Ethiopia and 2003, 2009, and 2018 for Kenya that rely at least partially on actual road surveys).[3] Panels of roads from the same source are rare. Figures A.2 and A.3 show the extensions of the paved road network for Kenya and Ethiopia. Related papers studying the expansion of the Ethiopian road network are Adamopoulos (2019), Gebresilasse (2019) and Kebede (2019), all of which focus on the feeder roads from the 2016 Ethiopian Roads Authority survey.[4].

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

[3] Data for Ethiopia are used in Croke and Duhaut (2020)

[4] The study by Moneke (2020), which focuses on all-weather (gravel, asphalt, or bitumen surface) roads, is closer to this study

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 10 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 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 in Ethiopia and Kenya 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, 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 A5 in the appendix shows the grid for the Horn of Africa 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 (see Figure A1). 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

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

[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)

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 A6 and A7 in the appendix show the access to Internet in Ethiopia and Kenya.

Isolated vs Bundled investments Tables A1 reports the number of districts for Ethiopia and Kenya with bundled and isolated investments for all years. Given that the small number of districts with electricity but no paved road, we assume that there is no district with electricity but no paved road.[9]

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 survey data with GPS coordinates for most surveys and are available for several rounds per country. The DHS is a repeated cross-section of enumeration areas (EA), with approximately 20–30 households enumerated per EA. Four rounds of survey data are covered in Ethiopia (2000, 2005, 2011, 2016) and four in Kenya (1991, 2003, 2009, 2018). For Ethiopia, the DHS rounds included 12,751 individuals in 2000, 14,052 in 2005, 21,080 in 2011, and 19,157 in 2016, from approximately 650 EAs, which differ per round. Djibouti and Somalia did not conduct DHSs.

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.[10] We aggregate EAs per geographic location.

[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.

[9] Table A2 shows that increasing the electricity threshold to 80% leaves only one district with electriciy but no paved road, the charter city of Dire Dawa in Ethiopia, which is connected to the road network. Removing the electricity alone indicator reduces the risk of capturing data errors.

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

District Characteristics We use additional data to control for district heterogeneity. We use population data from the Global Human Settlement Layer (GHSL),[11] land categories from the European Space Agency land cover (see Defourny (2017)), distance from the coast from the Global Self-consistent, Hierarchical,[12] High-resolution Geography Database (GSHHG), distance to the border,[13] access to a city larger than 50,000 inhabitants from the Malaria Atlas Project,[14] temperature from Land Processes Distributed Active Archive Center,[15] and elevation from CGIAR-CSI.[16]

4 Empirical Strategy and Results

4.1 Ordinary Least Squares

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

$$\begin{aligned} Sector_{i,c,t} &= \alpha + \beta^R Paved\ Road_{i,c,t} + \beta^I Internet_{i,c,t} \\ &+ \gamma^{RE} Paved\ Road_{i,c,t} * Electricity_{i,c,t} + \gamma^{RI} Paved\ Road_{i,c,t} * Internet_{i,c,t} \\ &+ Controls_{i,c,t} + FE + \varepsilon_{i,c,t} \end{aligned} \tag{4.1}$$

$Sector_{i,c,t}$ 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. $Paved\ Road_{i,c,t} * Electricity_{i,c,t}$ captures the interaction of the road and electricity infrastructure, and $Paved\ Road_{i,c,t} * Internet_{i,c,t}$ the interaction of the road and internet infrastructures. We add interaction effects between the dummies to better understand the complementarities between infrastructures. We do not include an interaction effect for electricity and internet as access to internet is assumed to rely on electricity access. $Controls_{i,c,t}$ 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,

[11] GHSL: Population count from the Global Human Settlement Layer. Based on population data from Gridded Population of the World v4.10 polygons, distributed across cells using the Global Human Settlement Layer global layer. Source data provided in 9 arc-second (250m) grid cells.

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

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

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

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

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

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 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 report results for the unbalanced panel of districts that include at least one EA. We first 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 within-country heterogeneity in structural transformation across districts. All regressions exclude the Somali region of Ethiopia, because coverage of this region in the DHS data is poor.

Average Effects in Ethiopia and Kenya We start with a regression that includes Ethiopia and Kenya, and then compare the results by country. Throughout, standard errors are clustered at the district level, the level of treatment. Access to roads, especially when complemented with access to electricity, is associated with a transformation away from agriculture in the Horn of Africa. Table 2 reports the results of pooling data from Ethiopia and Kenya for all years. Having access to a paved road at the district level is associated with a 4 percentage-point reduction in the employment share of agriculture and a 2 percentage-point increase in the employment share of manufacturing. Combined investments in roads and electricity are associated with a major shift from agriculture to manufacturing and services. Having access to the combined access to roads and electricity at the district level is associated with a 27 percentage-point reduction in the employment share of agriculture, a 10 percentage-point increase in the employment share of manufacturing, and a 18 percentage-point increase in the employment share of services. Results by country reported in Tables A4 and A5 in the appendix show that the impacts are similar at the country level. The combination of roads and electricity access has a large impact on structural change.

We then analyze the within-country heterogeneity in structural transformation across districts, focusing on the share of agricultural employment and the population-weighted distance to the largest town.

Table 2: OLS results for Horn of Africa

	Agriculture	Manufacturing	Services
Paved road	-0.0398*	0.0221**	0.0188
	(-2.24)	(2.87)	(1.34)
Internet	-0.0135	0.0247	-0.0313
	(-0.21)	(0.50)	(-0.67)
Road + Internet	-0.0134	-0.0230	0.0622
	(-0.20)	(-0.45)	(1.29)
Road + Electricity	-0.232**	0.0758**	0.161**
	(-9.63)	(6.07)	(8.68)
Year + Country FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared	0.459	0.326	0.398
N. of observations	1887	1887	1887

t statistics in parentheses

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

By share of agricultural employment Table A6 in the appendix confirms the spatial heterogeneity of outcomes across districts in Ethiopia. Results are reported for the first quartile of employment in agriculture (49 percent of employment in agriculture), the second quartile (75 percent of employment in agriculture), and the third quartile (90 percent of employment in agriculture). Access to roads reduces the share of employment in agriculture only in the districts with an existing low level of agricultural employment. The combined impacts of road and electricity in reducing the share of agricultural employment is the largest for the second quartile, districts with around 75% of employment in agriculture.

By distance to a main city Changes in the shares of manufacturing and services employment associated with access to infrastructure vary with distance to large towns. Tables A7 and A8 in the appendix report the estimation results for the share of manufacturing employment across quartiles of distance to a town of at least 50,000 inhabitants for Ethiopia. They show that a combined access to roads and electricity is associated with a reduction in manufacturing employment share but a large increase in services employment in the most isolated locations.

4.2 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.

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 and wind farms. The main sources of energy supply are hydropower in Ethiopia and hydropower and wind in Kenya (Table A9). Similar to Moneke (2020), we developed an IV that yields a hypothetical electrification status based on a location's proximity to a straight-line corridor from electricity generators to the main cities. We identified the locations of the electricity generators using two databases, one on the opening year of dams and another on the locations of power plants (Platts database). For Ethiopia, we used a database including all dams in Africa, their location, and their year of opening. For Kenya, we used the global power plant database, which includes the capacity and year of commissioning of all power plants by type of energy (hydro, wind, gas, and geothermal). From the year of the dam opening or power plant commissioning onward, all districts lying along the straight lines connecting the dams or power plants to the main demand centers are considered as having access to electricity. We then identified the main sources of demand in each country (Addis Ababa in Ethiopia and Nairobi and Mombasa in Kenya). Map A8 in the appendix shows the results of the construction of the electrification instrument around 1990 and 2015.

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

To instrument for the timing of a district's paved road connection, we find the optimal network to connect all cities with more than 50,000 inhabitants in a least-cost fashion by using common minimum spanning tree algorithms, such as Kruskal's and Boruvka's algorithms. The list of cities with more than 50,000 inhabitants varies over time because of changes in population, which creates a panel of roads for each country. Map A9 in the appendix shows the results of the construction of the road instrument around 1990 and 2015.

We run a two-stage least squares (2SLS) regression on the following specifications, with province and year fixed effects and district-level initial values as controls:[17]

$$\begin{aligned} Road_{i,t}\#Electricity_{i,t} \quad = \quad & \alpha + \beta^{R}(RoadIV_{i,t} = 1 \ \& \ ElectricityIV_{i,t} = 0) \\ & + \gamma^{RE}(RoadIV_{i,t} = 1 \ \& \ ElectricityIV_{i,t} = 1) \\ & + \beta^{I} Internet_{i,t} + Controls_{i} + FE + \varepsilon_{i,t} \qquad (4.2) \end{aligned}$$

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

with $Road_{i,t}\#Electricity_{i,t}$ being one of the interactions terms between the dummies $Road_{i,t}$ and $Electricity_{i,t}$.

The second stage equation is given by:

$$\begin{aligned} Sector_{i,t} &= \alpha + \beta^{R,2SLS}(\widehat{RoadIV_{i,t} = 1 \ \&\ ElectricityIV_{i,t} = 0}) \\ &\quad + \gamma^{RE,2SLS}(\widehat{RoadIV_{i,t} = 1 \ \&\ ElectricityIV_{i,t} = 1}) \\ &\quad + \beta^{I,2SLS} Internet_{i,t} + Controls_{i,t} + FE + \varepsilon_{i,t} \end{aligned} \tag{4.3}$$

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

Table 3 reports the results for the 2SLS method for Ethiopia and Kenya. First-stage results are reported in Table A10 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.

Table 3: Two-stage least squares regression results for Ethiopia and Kenya

	Agriculture	Manufacturing	Services	Agriculture	Manufacturing	Services
Roads only	-0.106*	0.0642**	0.0414	-0.0933*	0.0634**	0.0299
	(-2.46)	(3.31)	(1.27)	(-2.14)	(3.17)	(0.90)
Roads × Elect.	-0.265*	0.184**	0.0807	-0.195+	0.181**	0.0140
	(-2.50)	(3.63)	(0.95)	(-1.67)	(3.28)	(0.15)
Internet				-0.0595**	0.00725	0.0522**
				(-2.60)	(0.58)	(2.62)
Subnational FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.530	0.360	0.430	0.533	0.362	0.426
N. of observations	1887	1887	1887	1887	1887	1887

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

Access to paved roads without access to electricity led to a 10.6 percentage-point decrease in the share of agriculture employment and a 6.4 percentage-point increase in the share of manufacturing employment. The impacts are much larger when combining infrastructures, districts with access to paved roads and electricity saw a 26.5 percentage-point shift of workers from agriculture mostly to manufacturing. The results change when including access to Internet at the district level. Access to internet reduced the share of agriculture employment by 6 percentage-point, mostly to increase the share of services employment. Access to internet has a non-significant impact on manufacturing. Table A11 in the appendix reports the results of the

IV specification for Ethiopia only. The results are similar but access to internet had a two times larger impact on reducing the share of employment in agriculture and increasing the share of employment in services.

5 Welfare Impacts of Infrastructure

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.

5.1 The Model

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

5.1.1 Setup

The whole geography consists of many locations, $n \in N$, of varying land size (H_n) and endogenous population (L_n). Consumers value consumption of agriculture goods, C^T, manufacturing goods, C^M, services, C^S, and land, 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 ν_n:

$$U_n = \nu_n C_n^{\alpha} h_n^{1-\alpha} \tag{5.1}$$

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

$$C_n = [\psi^T (C_n^T)^{\rho} + \psi^M (C_n^M)^{\rho} + \psi^S (C_n^S)^{\rho}] \tag{5.2}$$

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 $j \in [0,1]$:

$$C_n^T = [\sum_{i \in N} \int_0^1 (c_{ni}^T(j))^{\nu} dj]^{1/\nu} \tag{5.3}$$

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:

$$P_n^T = \left[\sum_{i \in N} \int_0^1 (p_{ni}^T(j))^{1-\sigma} dj\right]^{\frac{1}{1-\sigma}} \tag{5.4}$$

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.

$$Y_n^i = z^i \left(\frac{L_n^i}{\mu^i}\right)^{\mu^i} \left(\frac{h_n^i}{1-\mu^i}\right)^{1-\mu^i} \qquad i = T, M \tag{5.5}$$

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

$$F_n^i(z^i) = e^{(-A_n^i z^i)^{-\theta}} \qquad i = T, M \tag{5.6}$$

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:

$$p^i_{nm} = \frac{\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm}}{z^i_m} \tag{5.7}$$

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:

$$p^i_{nm} = min\{p^i_m, m \in N\} \tag{5.8}$$

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:

$$\pi^i_{nm} = \frac{A^i_m(\omega_m^{\mu^i} r_m^{1-\mu^i} d_{nm})^{-\theta}}{\sum_{k\in N} A^i_k(\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta}} \tag{5.9}$$

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:

$$\xi^K_n = \frac{(\psi^K)^\kappa (P^K_n)^{1-\kappa}}{(\psi^M)^\kappa (P^M_n)^{1-\kappa} + (\psi^T)^\kappa (P^T_n)^{1-\kappa} + (\psi^S)^\kappa (P^S_n)^{1-\kappa}}, \qquad K \in \{T, M, S\} \tag{5.10}$$

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

$$P^i_n = \gamma\Big[\sum_{k\in N} A^i_k(\omega_k^{\mu^i} r_k^{1-\mu^i} d_{nk})^{-\theta}\Big]^{-1/\theta} = \gamma(\Phi^T_n)^{-1/\theta} \tag{5.11}$$

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:

$$V_{n,c} = \bar{V}_c = \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha} v_{n,c}\omega_{n,c}}{[P_{n,c}]^{\alpha/(1-\kappa)} r_{n,c}^{1-\alpha}}, \forall n \in \text{ country } c \tag{5.12}$$

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

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.

5.2 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 A12 in the appendix reports the parameters from the literature to calibrate the model which are like the ones in Moneke (2020) applied 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 $\{A^T_n, A^M_n, A^S_n\}_{n \in N}$ for which the distribution of population, employment, and land is an equilibrium given the current trade costs.

5.3 Counterfactuals

We calibrate the model to assess the welfare and spatial impacts of new infrastructure investments. 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.

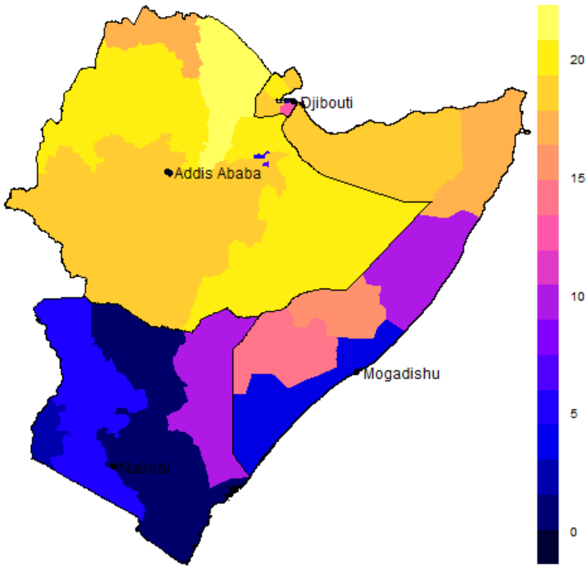
To build the electrification counterfactual, we assume that access to electricity increases productivity in manufacturing and services sectors (see Moneke (2020)). To build the transport counterfactuals, we use the available road networks for each country, making assumptions about speed along the networks based on the type and condition of roads that are registered. For Kenya, we used reported speed from our sources for the latest year. For other countries, we relied on additional features, such as the type of surface and the condition of the roads. 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 Horn of Africa into 32 regions, including 11 first-order administrative divisions in Ethiopia, 5 in Djibouti, 8 groupings of first-order administrative divisions in Somalia, and 8 groupings in Kenya. Figure A11 shows the share of agricultural employment and the population for each subnational region.

5.3.1 Productivity shocks from electrification in the Horn of Africa

The counterfactual consists in providing access to electricity for all in all regions based on the current coverage measured by night time lights as described in previous sections. 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. Figure 2 shows the percent of productivity increase per location. The shock is the highest in most regions of Ethiopia and in the Northern part of Somalia.

Figure 2: Counterfactual productivity increase in manufacturing and services from electrification in the Horn of Africa, in percent



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

5.3.2 New transport infrastructure in the Horn of Africa

We investigate the impact of several regional transport corridors listed in Table 4 and mapped in Figure 3.

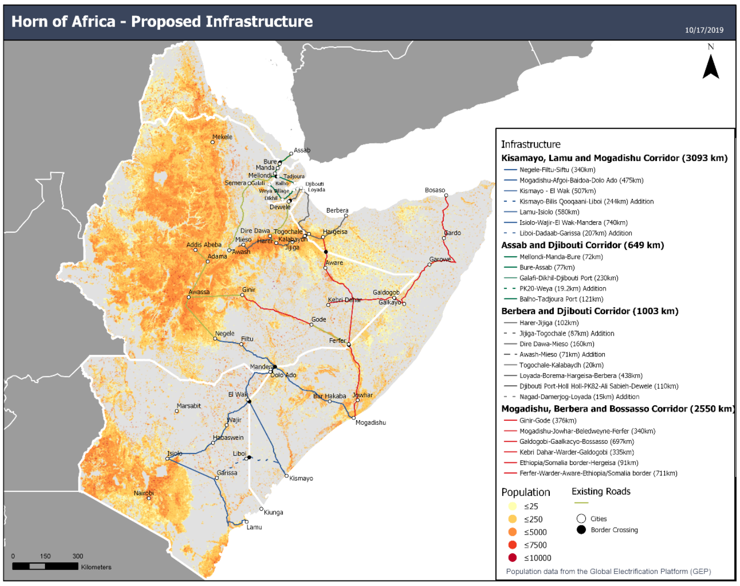
Corridor 1: Kismayo, Lamu and Mogadishu Corridor. Corridor 1 links population centers in Ethiopia, Kenya, and Somalia with the Somali ports of Mogadishu and Kismayo and the Kenyan port of Lamu. The corridor serves several purposes. It provides an important bilateral artery between the Kenyan and Ethiopian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

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

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

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

Figure 3: Proposed road corridors in the Horn of Africa



Source: World Bank document.

Table 4: Summary of counterfactual scenarios for transport investments

Scenario	Country	Road infrastructure	Policies
Baseline			
1	Djibouti, Ethiopia, Kenya, Somalia	Speed and road conditions from latest surveys	High Border Delays
With transport infrastructure investments			
2.1	Kenya, Somalia, Ethiopia	Corridor 1: Kismayo, Lamu and Mogadishu Corridor with 3093km of rehabilitation or new roads	High Border Delays
2.2	Djibouti, Ethiopia	Corridor 2: Assab and Djibouti Corridor with 649km of rehabilitation or new roads	High Border Delays
2.3	Somalia, Djibouti	Corridor 3: Berbera and Djibouti Corridor with 1003km of rehabilitation or new roads	High Border Delays
2.4	Djibouti, Ethiopia, Somalia	Corridor 4: Mogadishu, Berbera and Bossasso Corridor with 2550km of rehabilitation or new roads	High Border Delays
With border infrastructure investments			
3	Djibouti, Ethiopia, Kenya, Somalia	Corridors 1–4	50% reduction in border times at border posts along corridors 1–4

We create counterfactuals using the transport networks from each country described in Section 3. Figure A10 in the appendix shows the new corridors and investments in border posts. We assume a speed of 70 kilometers an hour for the new corridors and reduce the time by half at the border in some of the scenarios. Finally we create counterfactuals combining both road and electricity investments to study the interaction effects from combining infrastructure investments (Table 5).

Table 5: Summary of counterfactual scenarios for combined investments

Scenario	Country	Road infrastructure	Electrification
Baseline			
1	Djibouti, Ethiopia, Kenya, Somalia	Speed and road conditions from latest surveys	Limited access to electricity
With road infrastructure investments only			
2	Djibouti, Ethiopia, Kenya, Somalia	Higher speed along Corridors 1–4	Limited access to electricity
With electrification only			
3	Djibouti, Ethiopia, Kenya, Somalia	Speed and road conditions from latest surveys	Electrification for all
With both investments			
4	Djibouti, Ethiopia, Kenya, Somalia	Higher speed along Corridors 1–4	Electrification for all

5.3.3 Employment Impacts

While new roads reduce the share of employment in the agricultural sector for all countries, the impact varies across countries when reduction in border delays are also considered. Table 6 shows the changes in the shares of employment in nonagricultural sectors, which include manufacturing and services. The proposed investments in transport corridors would lead to a 1.5 percentage-point increase in the share of employment in nonagricultural sectors overall. Kenya would experience the largest increase, followed by Ethiopia, Djibouti, and Somalia. Trade facilitation measures that reduce border times by half would add little to the change in the share of employment in nonagricultural sectors in the Horn of Africa as a whole, but it would lead to large increases in the share of employment in nonagricultural sectors in Kenya and Djibouti and a decrease in Ethiopia. Lower transport and trade costs lead to more workers in the agricultural sector in Ethiopia, for which the country has a comparative advantage compared to its neighbors.

The impact of electrification on structural change is rather small. The electrification would lead to a 0.3 percentage-point increase in the share of employment in nonagricultural sectors overall, with the largest increase in Kenya and a decrease in Ethiopia.

The impacts from combined investments on structural change significantly differ from the sum of isolated investments and depend on the comparative advantage of each location in the Horn of Africa and the general equilibrium effects included in the model. An increase in productivity in manufacturing and service sectors can lead to an increase in employment in these sectors if the increased market access leads to an increase in demand for manufacturing and services; otherwise there can be a reduction in employment in these sectors. The largest reduction in the agricultural employment share happens when roads and trade facilitation are combined for Kenya, and when roads end electrification are combined for Djibouti and Somalia.

Table 6: Counterfactual increase in share of nonagricultural employment in Horn of Africa, by country

Scenarios	Total	Ethiopia	Djibouti	Somalia	Kenya
in percentage					
Electrification only	0.6	-2	1	2.4	3.3
Roads only	3	2.6	1.3	0.4	4.2
Roads and Trade Facilitation	3.5	-1	4.3	0.8	10.7
Roads and Electrification	0.4	-3	5.7	6.7	4.1
Roads, Trade Facilitation and Electrification	2	-2.5	3.5	-0.3	9
in percentage points					
Electrification only	0.3	-0.7	0.8	1.3	2.1
Roads only	1.5	1.1	1	0.2	2.6
Roads and Trade Facilitation	1.7	-0.5	3.3	0.5	6.7
Roads and Electrification	0.2	-1.4	4.4	3.7	2.6
Roads, Trade Facilitation and Electrification	1	-1.1	2.7	-0.2	5.7

5.3.4 Welfare Impacts

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 compute the welfare impact in each counterfactual and compare it to the baseline welfare:

$$\Delta Welfare_{n,c} = \Delta[Population_{n,c} \times V_{n,c}] \tag{5.13}$$

with $V_{n,c}$ the welfare or real income in location n of country c defined in equation 5.12.

Table 7 shows the change in real income for isolated and combined investments. The overall increase in welfare is just 1 percent for corridor investments; it is four times larger when border delays along the corridors are reduced. Somalia enjoys the largest gains, followed by Djibouti, Kenya, and Ethiopia. While combining roads investments and trade facilitation leads to higher gains for all countries, combining roads and electrification has mixed impacts on welfare. Investments in the identified corridors and electrification are complementary for Somalia and Djibouti, but substitutes for the others.

Table 7: Counterfactual increases in real income in Horn of Africa, by country (in percent)

Scenarios	Total	Ethiopia	Djibouti	Somalia	Kenya
Electrification only	3.5	4.8	1.7	3.5	0.9
Roads only	1	1.3	0	1.4	0.7
Roads and Trade Facilitation	4.3	3.9	5.3	6.3	4.9
Roads and Electrification	2.1	2.6	7.6	6.2	0.3
Roads, Trade Facilitation and Electrification	7.8	9	8.6	10.1	5.1

5.3.5 Spatial Impacts

Local complementary impacts of infrastructure Table 8 describes how the simulated changes in non-agricultural employment correlates with local characteristics and the impact of infrastructure investments on accessibility and productivity. Controlling for initial characteristics of each region, the impact of improved market access is associated with a higher increase in non-agricultural jobs when complemented with investments in electrification. We look at the different impacts of road accessibility for the regions whose access to electrification is currently below 50% of the population in the baseline and the rest.[18] Columns (1) and (2) show that there is no difference on the impact of road accessibility when comparing the two types of regions before the electrification counterfactual. Improvement in market access through roads only is here not significantly associated with change in sectoral employment. Columns (3) and (4) show that the impact on non-agricultural jobs is only significant for the regions that had less than 50% access to electricity before the simulated bundle of investments in infrastructure. In line with the reduced-form results, bundled investments are associated with larger impacts on sectoral change. In appendix, Table A13 provides a similar analysis ons welfare showing that complementarity effects are less significant for local welfare change than for structural change.

Table 8: OLS results for change in non-agricultural employment for different scenarios

	Scenarios			
	Roads	Roads + borders	Roads + Elect.	All three
	(1)	(2)	(3)	(4)
Population	−1.928	0.239	5.027**	4.710***
	(1.379)	(2.130)	(2.470)	(1.570)
Wage	−4.999	−13.886***	−2.714	−8.174**
	(3.358)	(4.706)	(5.716)	(3.300)
Employment in Agriculture	0.001	−0.080**	0.111**	0.034
	(0.026)	(0.037)	(0.046)	(0.027)
Market Access (roads)*I(Electrification=1)	0.004		0.754***	
	(0.060)		(0.116)	
Market Access (roads)*I(Electrification=0)	−0.100		0.133	
	(0.067)		(0.116)	
Market access (roads + borders) *I(Electrification=1)		0.072**		0.175***
		(0.029)		(0.023)
Market access (roads + borders) *I(Electrification=0)		0.071**		−0.013
		(0.031)		(0.022)
Productivity shock			−0.739***	−0.753***
			(0.099)	(0.059)
Constant	4.314*	9.630***	2.809	9.567***
	(2.327)	(3.244)	(3.953)	(2.268)
Observations	205	205	205	205
R^2	0.035	0.077	0.277	0.483
Adjusted R^2	0.011	0.054	0.255	0.467
Note:				*p<0.1; **p<0.05; ***p<0.01

Overall Impacts The impacts of infrastructure investments and their combinations differ across regions. Lower transport and trade costs increase market access, providing more opportunities for producers in districts that benefit from transport investments. Better connectivity

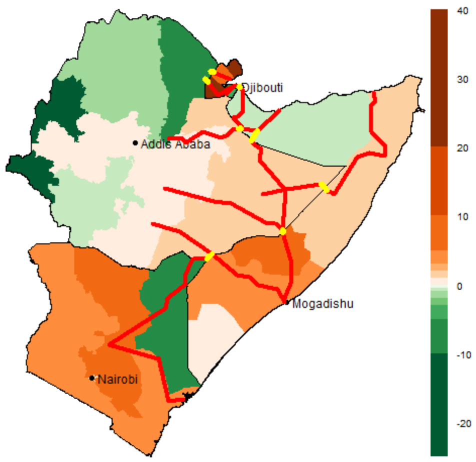
[18]The 50% threshold corresponds to the threshold used in the reduce-form estimation part.

leads to higher specialization and increases competition from imports from other regions in the country for the traded good sectors (manufacturing and agricultural activities). Electrification increases productivity in manufacturing and services sectors. Workers move across locations and sectors in response to changes in wages and prices.

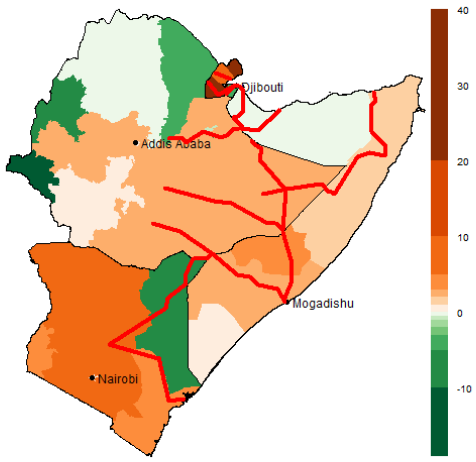
For some regions, better regional connectivity or higher productivity in manufacturing and services sectors translates into higher specialization in agricultural production. In Figure 4, the green areas are regions where the share of agricultural employment will increase because of the transport corridor investments and better trade facilitation; the orange and red areas are regions where the share of nonagricultural employment will increase. The regions that experience an increase in the share of agricultural employment are either isolated regions or border regions, mostly in the northwest of Ethiopia and the northeast of Kenya. The spatial patterns remain the same when the time to cross the borders is reduced by half, but the largest changes become larger. Investments in infrastructure amplify the comparative advantage of each region and the regional specialization.

Figure 4: Changes in share of nonagricultural employment in isolated counterfactual scenarios relative to baseline (in percentage points)

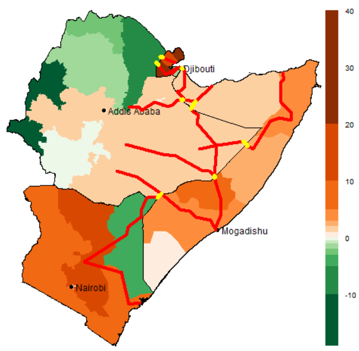
(a) Electricity only



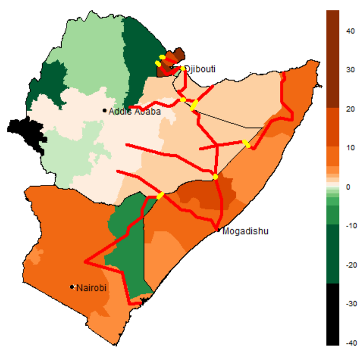
(b) Roads only



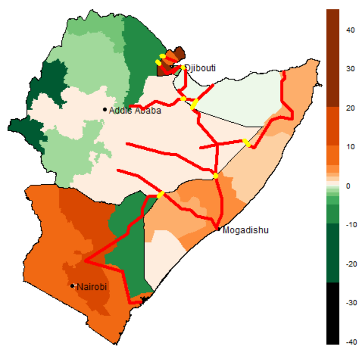
(c) Roads and borders



(d) Roads and electricity



(e) Roads, electricity, and borders



Source: Authors' calculations.

Specialization in manufacturing—the traded nonagricultural good—changes most in regions that benefit from corridor improvement. However, not all regions that benefit from better connectivity experience an increase in specialization in manufacturing. The shares of manufacturing employment will increase the most in Djibouti and Kenya; they increase only slightly in the central and eastern parts of Ethiopia and in the regions around Mogadishu in Somalia (Figure A12). When transport investments are complemented with trade facilitation measures that reduce border times by half, the share of employment in manufacturing decreases across Ethiopia. In Somalia, and particularly in Kenya, the changes in employment shares become even larger, with most regions in Kenya further specializing in manufacturing.

Overall, welfare, measured as the real income of the region, increases at the aggregate level for all countries but not for all subnational regions when isolated improvements in either transport corridor or electricity are undertaken (Figure 5). If border times also decrease, almost all regions in the Horn of Africa enjoy higher welfare, with some regions in Kenya and Somalia benefiting the most in percentage terms.

Figure 5: Welfare impacts in counterfactual scenarios relative to baseline, percentage

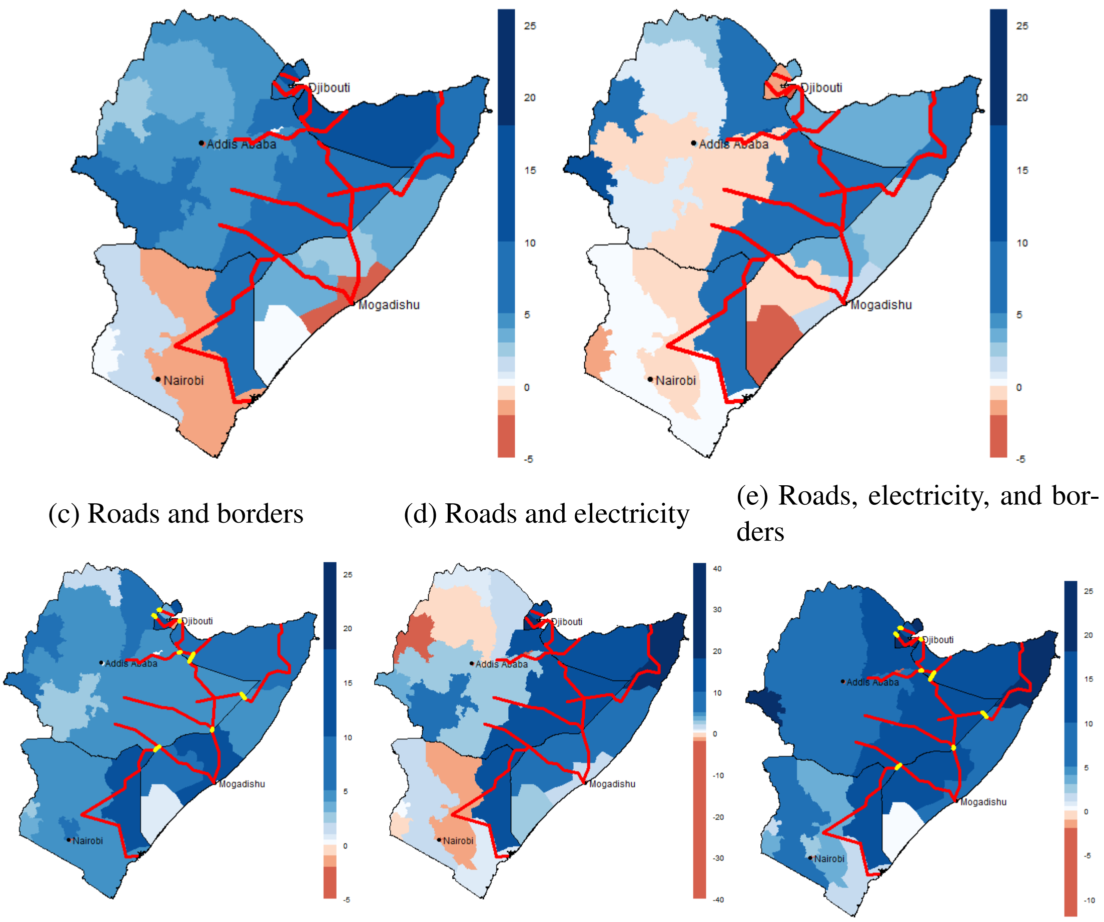
(a) Electricity only

(b) Roads only

(c) Roads and borders

(d) Roads and electricity

(e) Roads, electricity, and borders



Source: Authors' calculations.

6 Conclusion

This paper investigates how infrastructure - transport, electricity and Internet - affects economic development through sectoral employment and structural change. It first estimates the impacts of past transport, electricity, and Internet investments and their interactions in Ethiopia and Kenya on sectoral employment. The empirical analysis shows that access to paved roads alone led to a reduction in agricultural employment and an increase in employment in manufacturing and services sectors. Complementing road improvements with investments in electrification led to a much larger shift from agriculture to manufacturing and services.

The paper's spatial general equilibrium model estimates the potential impacts of proposed regional transport corridor projects in the Horn of Africa. While the empirical part shows the importance of considering bundled investments rather than in isolation, results from the model, which includes network and general equilibrium effects, show how big push infrastructure investments cause different patterns of structural transformation and welfare gains than the sum of isolated infrastructure investments. 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 in the Horn, the analysis also looks at the impact of complementary trade facilitation measures. At the local level, the marginal gains from improving market access increase when increasing the electricity coverage of the population. Investments in corridors become more valuable when combined with electricity investments. The analysis also shows the importance of complementary interventions in facilitating regional integration and enhancing the benefits of transport corridors. The welfare gains from infrastructure investments in roads and electricity would be multiplied by almost four when reducing border delays, but the spatial impacts depend on the comparative advantage of each location in the region.

This paper 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 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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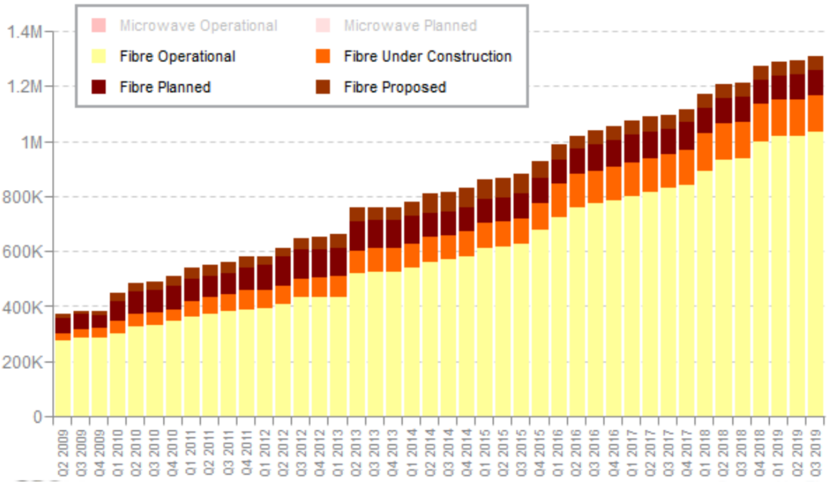
A Appendix

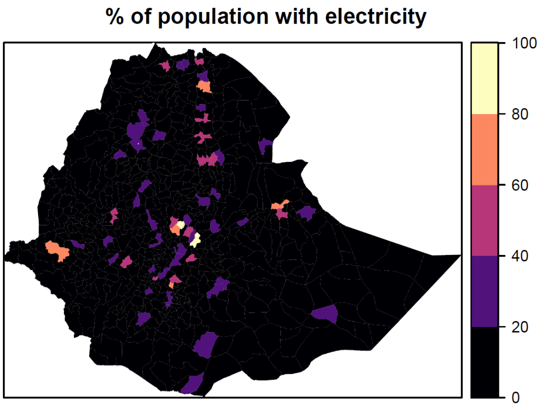
Figure A1: Route-Kilometers of Terrestrial Transmission Network, Africa 2009 - 2019



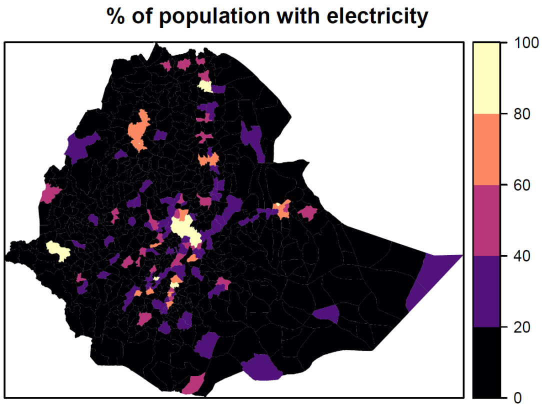
Source: http://www.africabandwidthmaps.com/

Figure A2: Percentage of population with access to electricity based on nightlights, 1998 and 2016

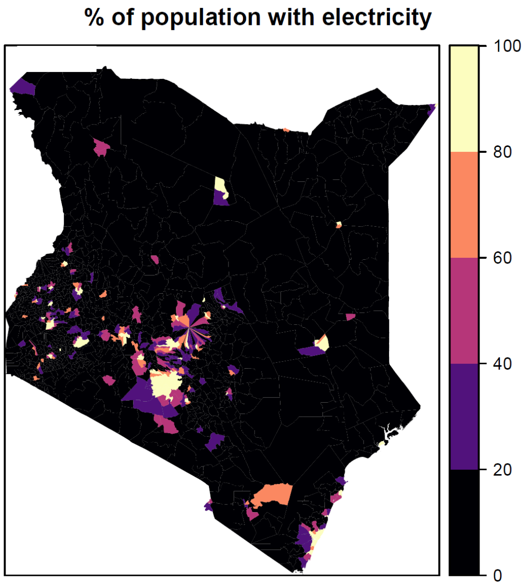
(a) Ethiopia, 1998



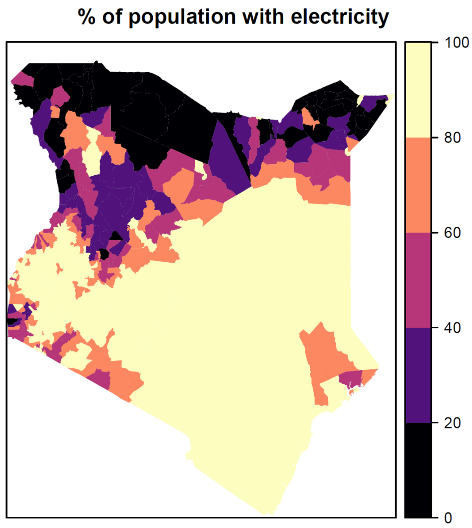
(b) Ethiopia, 2016



(c) Kenya, 1998



(d) Kenya, 2016



Source: Authors' calculations

Figure A3: Paved road network in Ethiopia, 1996 and 2016

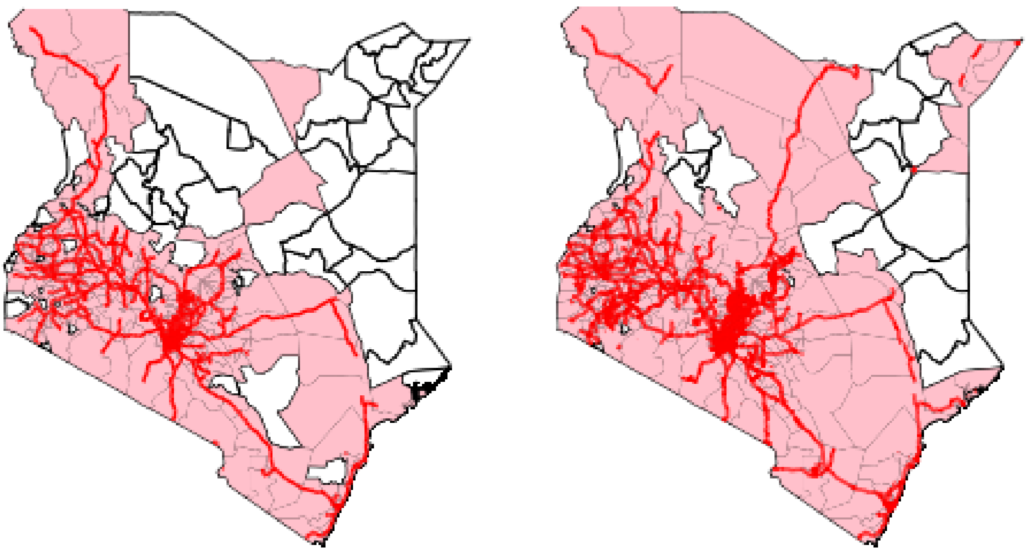
(a) 1996

(b) 2016

Source: Data from the Ethiopian Roads Authority (ERA) used in Croke and Duhaut (2020).

Figure A4: Paved road network in Kenya, 2003 and 2018

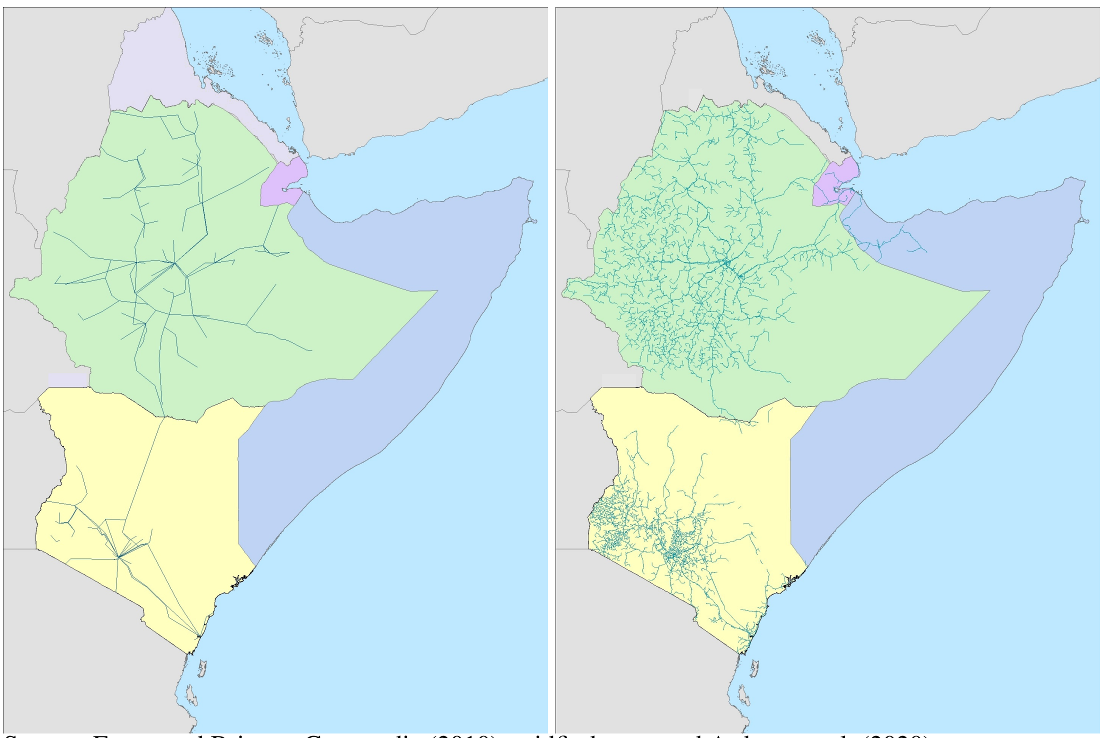
(a) 2003 (b) 2018



Source: Kenya Road Board.

Figure A5: Electricity grid in Ethiopia and Kenya

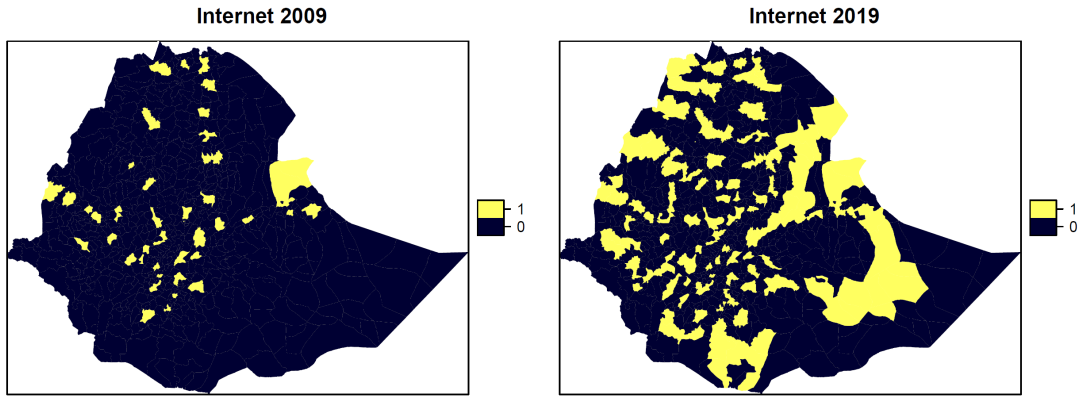
(a) 2007 (b) 2018



Source: Foster and Briceno-Garmendia (2010), gridfinder.org and Arderne et al. (2020)

Figure A6: Access to internet backbone in Ethiopia, 2009 and 2019

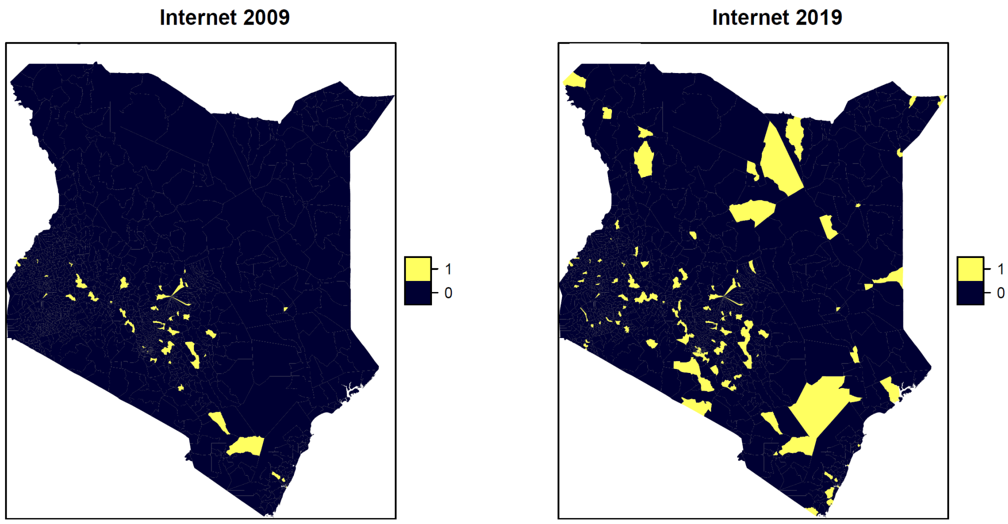
(a) 2009 (b) 2019



Source: Africa Bandwidth Maps

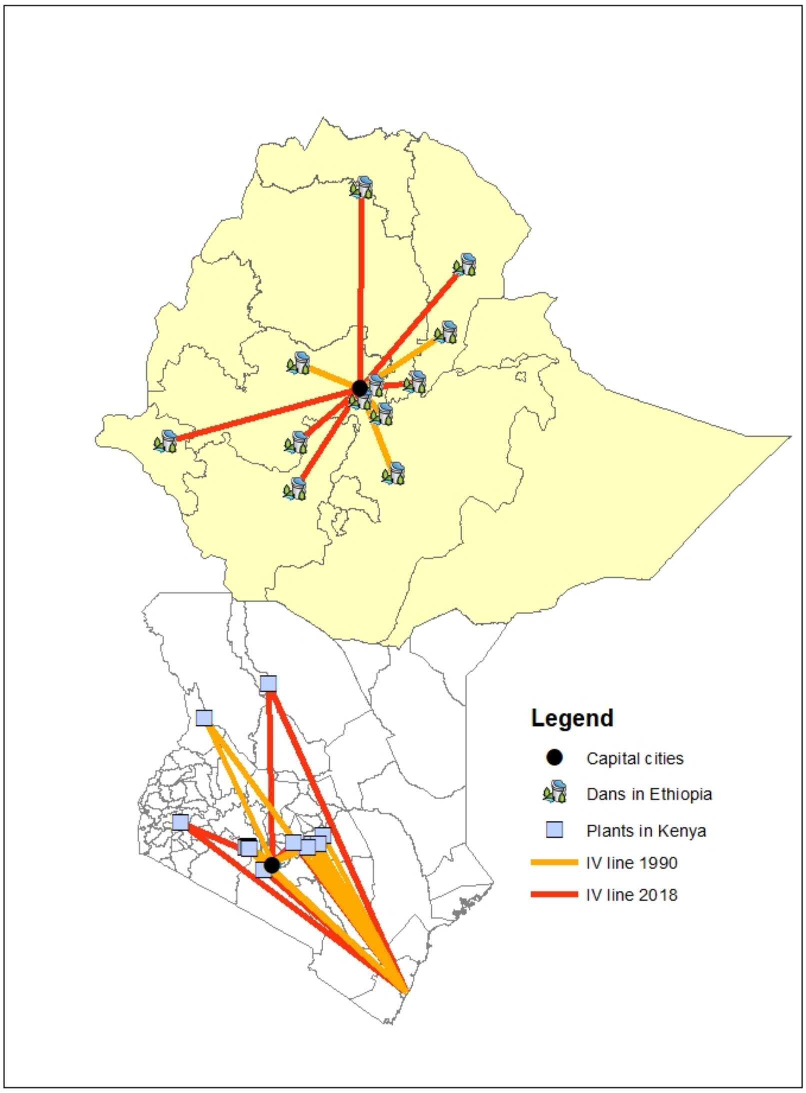
Figure A7: Access to internet backbone in Kenya, 2009 and 2019

(a) 2009 (b) 2019



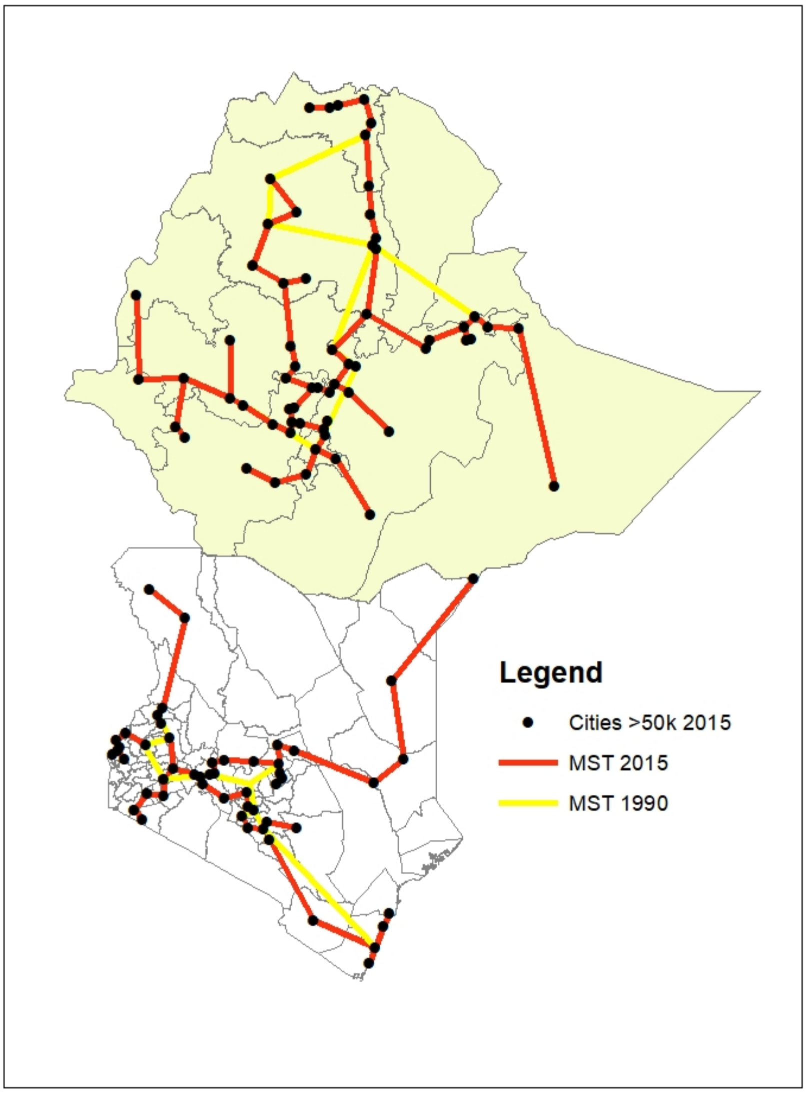
Source: Africa Bandwidth Maps

Figure A8: Electrification instrument: Straight lines between cities and energy sources for Ethiopia and Kenya (1990 and 2015)



Source: Authors' calculation.

Figure A9: Road instrument: Minimum Spanning Tree method for Ethiopia and Kenya (1990 and 2015)



Source: Authors' calculation.

Table A1: Isolated versus bundled investments using the 50% electricity threshold

(a) Roads and electricity

	Electricity		
Paved road	0	1	Total
0	1823	22	1845
1	1237	340	1577
Total	3060	362	3422

(b) Roads and internet

	Internet		
Paved road	0	1	Total
0	1832	13	1845
1	1360	217	1577
Total	3192	230	3422

(c) Electricity and internet

	Electricity		
Internet	0	1	Total
0	2921	271	3192
1	139	91	230
Total	3060	362	3422

Table A2: Isolated versus bundled investments using the 80% electricity threshold

(a) Roads and electricity

	Electricity		
Paved road	0	1	Total
0	1842	3	1845
1	1380	197	1577
Total	3222	200	3422

(b) Electricity and internet

	Electricity		
Internet	0	1	Total
0	2028	164	3192
1	194	36	230
Total	3222	200	3422

Table A3: GADM administrative levels

Level	Ethiopia	Kenya	Somalia	Djibouti
Adm1	11	47	18	5
Adm2	79	301	74	11
Adm3	690	1446		

Table A4: OLS results for Ethiopia

	Agriculture	Manufacturing	Services
Paved road	-0.0320	0.0217*	0.0103
	(-1.50)	(2.53)	(0.63)
Internet	0.0383	-0.0177	-0.0206
	(0.62)	(-1.25)	(-0.35)
Road + Internet	-0.0668	0.0218	0.0450
	(-0.93)	(0.91)	(0.71)
Road + Electricity	-0.313**	0.0893**	0.223**
	(-6.67)	(3.65)	(6.77)
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared	0.332	0.117	0.347
N. of observations	1162	1162	1162

t statistics in parentheses

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

Table A5: OLS results for Kenya

	Agriculture	Manufacturing	Services
Paved road	-0.0523+	0.0299	0.0224
	(-1.76)	(1.60)	(0.82)
Internet	-0.167	0.224*	-0.0571
	(-1.00)	(2.17)	(-0.84)
Road + Internet	0.151	-0.239*	0.0879
	(0.90)	(-2.31)	(1.27)
Road + Electricity	-0.196**	0.0693**	0.127**
	(-8.31)	(4.86)	(5.99)
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared	0.353	0.222	0.331
N. of observations	725	725	725

t statistics in parentheses

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

Table A6: Heterogenous effects on employment in agriculture in Ethiopia, by initial share of agricultural employment

	Agriculture q0.25	Agriculture q0.5	Agriculture q0.75
main			
Paved road	-0.0668^{+}	-0.0135	-0.0138
	(-1.68)	(-0.59)	(-1.18)
Internet	0.0504	0.0808	-0.0737*
	(0.41)	(0.88)	(-2.34)
Road + Internet	-0.0165	-0.0377	0.0354
	(-0.13)	(-0.36)	(0.55)
Road + Electricity	-0.341**	-0.489**	-0.347**
	(-8.70)	(-16.12)	(-4.63)
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
N. of observations	1162	1162	1162

t statistics in parentheses

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

Table A7: Heterogenous effects on employment in manufacturing in Ethiopia, by distance to a main city

	Manufacturing q2	Manufacturing q3	Manufacturing q4
Paved road	0.00887	0.0217	0.0437*
	(0.59)	(1.07)	(2.34)
Internet	-0.0737**	0.00372	0.0982**
	(-3.35)	(0.09)	(3.35)
Road + Internet	0.112*	0.0151	0
	(2.40)	(0.26)	(.)
Road + Electricity	-0.0299	0	-0.130**
	(-0.83)	(.)	(-4.84)
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared	0.127	0.076	0.136
N. of observations	287	276	295

t statistics in parentheses

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

Table A8: Heterogenous effects on service employment in Ethiopia, by distance to a main city

	Services q2	Services q3	Services q4
Paved road	-0.0301	-0.0220	0.115**
	(-1.10)	(-0.92)	(3.05)
Internet	-0.183**	-0.0229	0.0861+
	(-4.66)	(-0.40)	(1.80)
Road + Internet	0.220**	0.0152	0
	(3.11)	(0.19)	(.)
Road + Electricity	0.0368	0	0.267**
	(0.70)	(.)	(4.93)
Year FE	Yes	Yes	Yes
Controls	Yes	Yes	Yes
R-squared	0.288	0.159	0.314
N. of observations	287	276	295

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

Table A9: Energy sources in electricity production (in %)

	1990		2015	
	Ethiopia	Kenya	Ethiopia	Kenya
Hydro	89%	81%	93%	39%
Renewable, excluding hydro	NA	14%	7%	48%
Oil, gas and coal	10%	4%	0%	12%

Table A10: First Stage: Roads IV and Electricity IV for Ethiopia and Kenya

	Dependent variable:	
	Paved Roads Only	Paved Roads × Electricity
Road Only IV	0.0460*	0.0602**
	(-1.57)	(3.52)
Road Only IV × Elec IV	0.0179	0.0732**
	(-1.88)	(2.81)
Subnational FE	Yes	Yes
Controls	Yes	Yes
Windmeijer cond. F.	135.82	28.93
F-test statistic	194.14	212.11
N. of observations	1887	1887

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

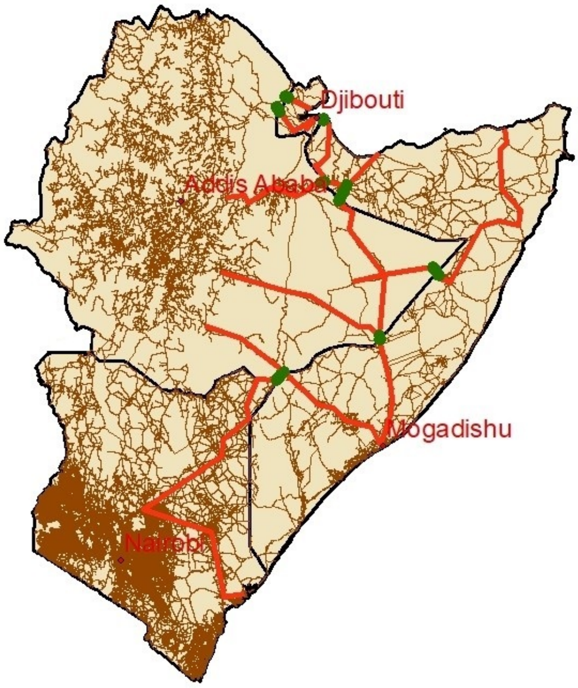
Table A11: Two-stage least squares regression results for Ethiopia

	Agriculture	Manufacturing	Services	Agriculture	Manufacturing	Services
Roads only	-0.103*	0.0618**	0.0410	-0.0852^{+}	0.0623**	0.0230
	(-2.36)	(3.18)	(1.25)	(-1.91)	(3.09)	(0.68)
Roads × Elect.	-0.291**	0.151**	0.140^{+}	-0.200^{+}	0.154**	0.0462
	(-3.05)	(3.72)	(1.84)	(-1.82)	(3.32)	(0.52)
Internet				-0.108**	-0.00305	0.111**
				(-2.61)	(-0.17)	(3.28)
Subnational FE	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.384	0.151	0.373	0.389	0.150	0.371
N. of observations	1162	1162	1162	1162	1162	1162

t statistics in parentheses

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

Figure A10: Transport network, new corridors and new border points in the Horn



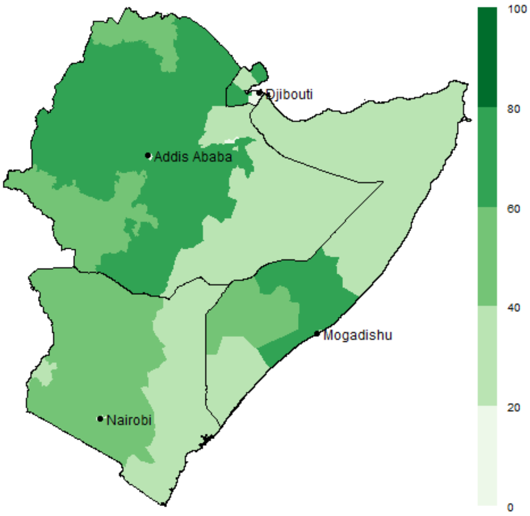
Note: The red corridors represent the roads that are considered in the counterfactuals. A reduction in border delays is added along the red corridors at the green crossing points only. High border delays remain for all other border points.

Table A12: Parameters for Structural Estimation

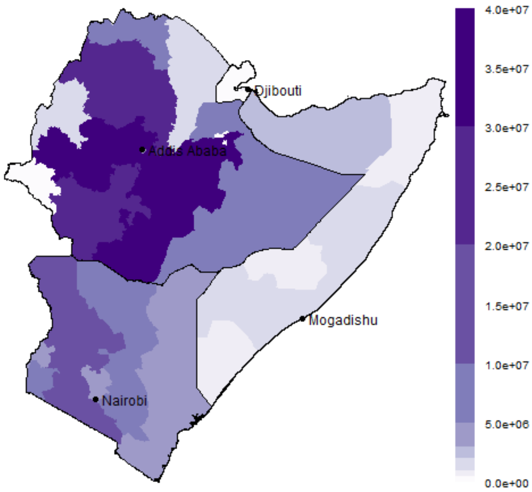
Parameter	Value	Source	Description
σ	4	Bernard et al. (2003)	Elasticity of substitution between varieties
$1-\alpha$	0.25	Data for Ethiopia (HCES)	Expenditure share on land/housing
κ	0.5	Ngai and Pissarides (2007)	Elasticity of substitution across sectors
μ^M	0.82	Moneke (2020) for Ethiopia	Labor share 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 A11: Descriptive statistics for the 32 regions in the Horn of Africa

(a) Share of employment in agricultural sector



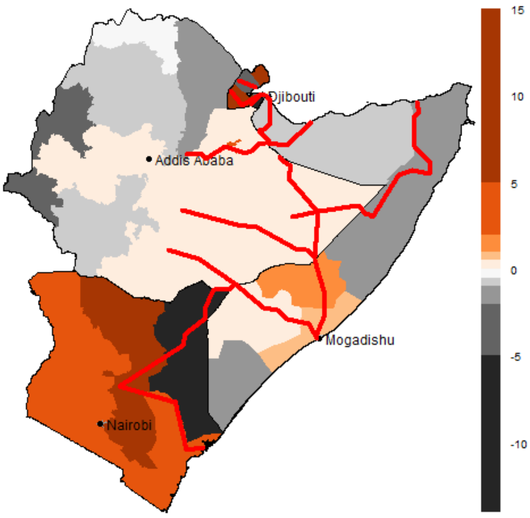
(b) Total population per subregion



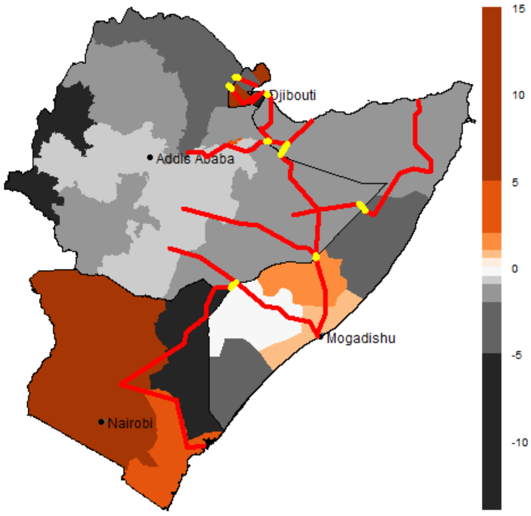
Source: Authors' calculations.

Figure A12: Change in share of manufacturing employment in counterfactual scenarios relative to baseline (in percentage)

(a) Transport corridor investments



(b) Transport corridor investments and trade facilitation



Source: Authors' calculations.

Table A13: OLS results for change in welfare for different scenarios

	Dependent variable:			
	Roads	Roads + borders	Roads + Elect.	All three
	(1)	(2)	(3)	(4)
Population	−2.408**	−3.046***	−3.453***	−5.347***
	(1.014)	(0.583)	(1.324)	(1.066)
Wage	6.319**	−9.223***	−37.720***	−13.061***
	(2.470)	(1.288)	(3.064)	(2.241)
Employment in Agriculture	0.042**	0.091***	−0.230***	−0.032*
	(0.019)	(0.010)	(0.025)	(0.018)
Market Access (roads)*I(Electrification=1)	0.251***		0.802***	
	(0.044)		(0.062)	
Market Access (roads)*I(Electrification=0)	0.001		0.508***	
	(0.049)		(0.062)	
Market access (roads + borders) *I(Electrification=1)		0.106***		0.123***
		(0.008)		(0.016)
Market access (roads + borders) *I(Electrification=0)		0.077***		0.075***
		(0.008)		(0.015)
Productivity Electrification			0.475***	0.553***
			(0.053)	(0.040)
Constant	−2.372	2.855***	20.013***	8.033***
	(1.712)	(0.888)	(2.119)	(1.540)
Observations	205	205	205	205
R^2	0.273	0.773	0.760	0.761
Adjusted R^2	0.255	0.767	0.752	0.754
Note:				*p<0.1; **p<0.05; ***p<0.01