# Digital Infrastructure and Local Economic Growth: Early Internet in Sub-Saharan Africa*

Moritz Goldbeck† Valentin Lindlacher‡

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**Abstract**

Digital infrastructure enables widespread access to modern information and communication technologies—most prominently the Internet—promising to stimulate economic growth. We analyze 10 Sub-Saharan African (SSA) countries in the early 2000s and ask if Internet availability even at basic speeds contributes to regional economic development. Exploiting quasi-random variation in Internet availability induced by sub-marine cable arrivals in a difference-in-differences setting, we measure the growth of SSA towns using nighttime light data. Our findings suggest that Internet availability at basic speeds leads to about two percentage points higher economic growth of SSA towns in the years after connection compared to a control group of similar cities not (yet) connected.

*Keywords*: Internet, regional/urban development, cities, nighttime light, Sub-Saharan Africa

*JEL-Codes*: O33, O18, R11

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†University of Munich & ifo Institute, goldbeck@ifo.de.

‡Corresponding author. Poschingerstr. 5, 81679 Munich (Germany). University of Munich & ifo Institute, lindlacher@ifo.de.

# 1 Introduction

In the last decades, the provision of digital infrastructure in many countries enabled widespread access and adoption of modern information and communication technologies (ICT), most prominently the Internet. Evidence shows positive effects of (broadband) Internet availability on individual-level economic performance (Akerman et al., 2015) and country-level economic growth (Czernich et al., 2011) for developed countries. Hopes are high that Internet access can foster regional economic growth in the developing world as well (World Bank, 2016). In Sub-Saharan Africa (SSA) for example—where impulses for economic growth are required to fight poverty and deprivation—Governments, public-private partnerships, and companies alike invest large amounts of money to bring the Internet to everyone. To date, SSA countries invested more than 28 billion US-Dollar into their national Internet backbone network (Hamilton Research, 2020). Facebook recently announced an effort to build a new sub-marine Internet cable to Africa for one billion US-Dollar (Bloomberg, 2020). And China plans to invest more than 60 billion US-Dollar in Africa's digital infrastructure as part of its Belt-and-Road initiative (Invesco, 2019).

Despite these enormous investments, a growth effect of Internet in SSA is less obvious than it seems. On the one hand, lacking legacy infrastructure (i.e., fixed-line telephony networks) to build on makes the provision more complex and costly. At the same time, low population density apart from a few mega-cities, missing hardware, financial constraints and a lower willingness to pay lead to lower adoption rates (World Bank, 2016). On the other hand, the potential of Internet seems particularly high in SSA since alternative ICT like fixed-line telephony is largely absent. It is thus crucial to investigate the effect of Internet availability on regional economic development in a developing-country context. With the notable exception of Hjort and Poulsen (2019), who find sizable positive individual-level effects of a broadband Internet speed upgrade on employment in SSA around 2010, evidence on the economic impact of Internet availability in developing countries is surprisingly rare.

In this paper, we ask if there is a causal effect of Internet availability on local economic growth in SSA even at basic speeds. We focus on the initial introduction of Internet in SSA since the early 2000s through the first wave of Internet-enabled sub-marine cables, which made basic Internet speed available to SSA countries. To investigate if potential individual-level effects matter for the economic development of entire localities, we conduct our analysis at the town level. Further, we provide suggestive evidence on the mechanisms driving the effect.

To identify the causal effect of Internet availability on local economic growth, we exploit quasi-random variation in the timing of Internet availability induced by the arrival of the first sub-marine Internet cables (SMCs) in SSA in the early 2000s. This approach was established by Hjort and Poulsen (2019), who use an Internet speed upgrade in SSA induced by SMCs around 2010. In a difference-in-differences setting, we then compare the growth of towns with Internet access at the time of SMC arrival to a control group of similar towns getting access only later. To ensure our results are in fact driven by Internet availability induced by SMC arrival, we control for the roll-out of other (potentially confounding) infrastructure.

We measure economic growth in each SSA town by nighttime light intensity data captured by satellites, a well-established proxy introduced by Henderson et al. (2011) and validated e.g. by Storeygard (2016). Town-level Internet availability is determined by data on the location of access points (APs) to the national Internet backbone. Because existing data on the location and establishment year of APs in SSA only starts in 2009 (Hamilton Research, 2020), we backdate the establishment year of APs to their actual construction year by hand via an extensive review of network deployment projects for each SSA country.

This is the first study investigating the effect of Internet at basic speeds on economic growth in the developing world. At comparable speeds, Czernich et al. (2011) find positive growth effects of Internet in developed countries. In our study, we estimate Internet effects in a setting with no pre-existing fixed-line telephony network. Therefore, our results show that the Internet induces growth even when penetration is low. With our approach utilizing nighttime light satellite data we are able to capture towns in 10 SSA countries getting an SMC connection in the 2000s. Thus, our results suggest that the Internet fosters regional development at the town-level in a comprehensive set of SSA towns.

We find that connection to the Internet on average leads to a 7% increase in light intensity of SSA towns in the years after connection, which approximately translates into 2 percentage points higher economic growth.[1] Moreover, we differentiate growth in the number of lit pixels, indicating a spatial expansion of towns (extensive margin), and growth in brightness, which is associated with a higher density of economic activity in the towns (intensive margin). We find that towns with Internet access are becoming both brighter and larger. This provides suggestive evidence that cities with Internet access grow at the intensive margin as well as the extensive margin, i.e. geographically. Controlling for population further suggests that the observed growth is partly driven by migration. Our findings therefore point to the increased economic activity being a result of both an increase in per capita economic activity and migration into connected towns.

We contribute to two main strands of the literature. First, we add to the literature assessing the impact of infrastructure on economic outcomes. For developing countries, Hjort and Tian (2021) gives an overview of the effects of internet connectivity. Dividing this literature into supply-side and demand-side mechanisms, we are the only ones investigating local income growth. Most closely related to our work is Hjort and Poulsen (2019). Besides an increase in economic activity, they find a skill-biased and net positive employment effect for an internet speed upgrade in SSA. Our analysis contributes to these findings by showing that the benefits of digital infrastructure are present not only at the individual level but at the more aggregate town level as well. We further show that even the availability of Internet (at basic speeds only) adopted by few individuals and businesses is beneficial for regional development.

[1] Henderson et al. (2011) finds an elasticity of GDP-to-light of 0.284.

For developed countries, the effect of the digital infrastructure and especially (broadband) Internet has been assessed widely. Czernich et al. (2011) identify an effect of broadband infrastructure on annual per capita growth for OECD countries. For the US, Kolko (2012) finds a positive relationship between broadband expansion and local economic growth. He applies the slope of the terrain as an instrument for broadband expansion and detects growth in population, employment, the average wage, and the employment rate. Focusing on labor market effects, Atasoy (2013) discovers that gaining access to broadband services in a county is associated with approximately a 1.8 percentage points increase in the employment rate. This contrasts with Czernich (2014), who finds no effect on the unemployment rate for Germany. On the firm level, Akerman et al. (2015) identify different broadband Internet effects depending on the skill level of workers on labor market outcomes and productivity for Norway. For Germany, Bertschek et al. (2013) detect broadband Internet effects on the firms' innovation activity, but not on their labor productivity. Colombo et al. (2013) find that the productivity performance of small and medium enterprises in Italy is not influenced by basic broadband applications. However, depending on the sector, advanced broadband applications do influence productivity. On broadband adoption, Grimes et al. (2012) discover an increase in firm productivity.

Related to Internet are mobile phones which are especially in SSA the most important digital infrastructure. Jensen (2007) shows that the adoption of mobile phones by fishermen and wholesalers in Kerala led to a reduction in price dispersion. He also finds that the use of mobile phones led to complete elimination of waste and near adherence to the Law of One Price, which increased both consumer and producer welfare. In a related paper, Aker and Mbiti (2010) study how the introduction of mobile phone between 2001 and 2006 affected grain prices in Niger. These papers emphasize the importance of rolling out mobile network infrastructure for improving economic efficiency of markets. More generally, mobile communication offers a major opportunity to advance economic growth in developing countries by: providing information about prices, improving the management of supplies, increasing the productive efficiency of firms, reducing transportation costs, and other means (Aker and Mbiti, 2010).

There is also a large body of related literature on the effect of non-digital infrastructure on economic outcomes in developing countries. This literature is more established for developing countries than the literature on digital infrastructure. The infrastructure of interest is very manifold and covers besides transportation infrastructure, such as (paved) roads, highways, and railways, electrification, and water supply. Most important in our context is Storeygard (2016) as he estimates the effect of transportation costs in SSA cities and towns. He finds that reducing transportation costs increases growth rates in local economic activity. However, the economic literature has found mixed results. Ghani et al. (2016) find similar results for India, while Banerjee et al. (2020) find them unchanged, but find a positive effect on levels, and Faber (2014) even finds a decrease both in China. Aggarwal (2018) studies the development of paved roads in rural India and finds that paved roads lead to lower prices, higher market integration and higher use of agricultural technologies. Finally, Donaldson (2018) investigates the effect of railroads in colonial India. He finds that the railroads decreased trade costs and hence increased interregional and international trade, as well as increased real income levels.

Electrification is another important issue in developing countries. Its provision demands also high infrastructure expenses. Electrification in rural areas was also analyzed by Dinkelman (2011) for South Africa. She shows that electrification increases female employment. Similar effects are found by Grogan and Sadanand (2013) for Nicaragua. For India, Rud (2012) looked at increased manufacturing output by electricity through the channel of electric pump sets. Lipscomb et al. (2013) find large positive effects of electrification on development through broad-based improvement in labor productivity in Brazil. Finally, Duflo and Pande (2007) show the positive effect of irrigation dams on agricultural production and how these can reduce rural poverty in India.

Second, our work contributes to the literature on urban and regional development. Starting with Nunn and Puga (2012) who showed that in Africa less fortunate geography had a positive impact on today's economy and Henderson et al. (2012) who indicated that the hinterland is growing faster than coastal areas and that primate cities are not growing faster than their hinterland, a strand of literature now focuses on the catch-up from secondary to primate cities, with no conclusive results. While Christiaensen and Todo (2014); Christiaensen and Kanbur (2017); Fetzer et al. (2016) show that secondary cities are meaningful to reduced poverty, Bluhm and Krause (2018) show with an adjusted nighttime light data approach that primate cities remain the economic centers.

Economic productivity is typically higher in agglomerations for several reasons, for example, thick local labor markets, knowledge spillovers, low transportation costs, but also due to local provision of amenities (see e.g., Albouy, 2016; Clark et al., 2002; Deller et al., 2008). Thinking of digital infrastructure as a local amenity, our findings indicate that the benefits of Internet availability are spatially highly concentrated, accruing to connected locations (towns) only, with important implications for regional inequality both across cities and between cities and rural areas.

The paper proceeds as follows. In Section 2, we provide a brief overview of the early Internet in Sub-Saharan Africa. Section 4 lays out the empirical strategy and in Section 5 the data and spatial methods are described. Results are presented in Section 6. Section 7 discusses our results in comparison with related research, while Section 8 suggests policy implications.Section 9 concludes.

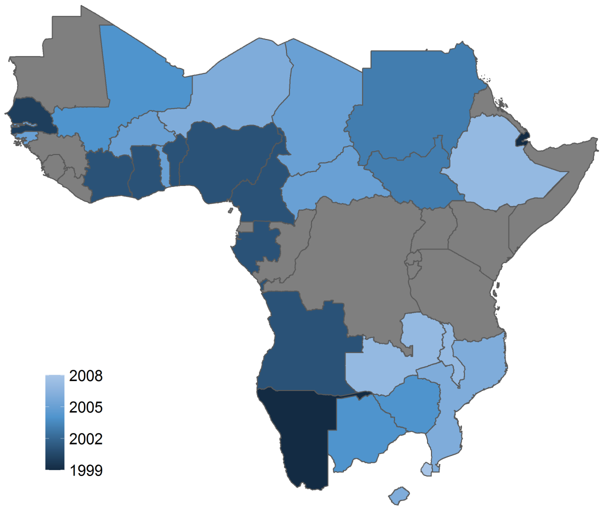
## 2 Background

There are three major components of Internet infrastructure determining availability and bandwidth of Internet in a given location. First, international sub-marine fiber-optic cables connect SSA countries to the global Internet backbone. Second, within-country inter-regional fiber cables form the national backbone. Precondition for Internet availability in a location is an access point (AP) to the national backbone. Finally, individual users in a location are reached via the *last mile infrastructure.

## 2.1 International backbone: sub-marine cables

Since the vast majority of web pages and applications is hosted on servers located in North America or Europe, almost all African Internet traffic is routed inter-continentally (Kende and Rose, 2015; Chavula et al., 2015). Before the first fiber-optic sub-marine cables (SMCs) landed on African shores, the only way to connect to the Internet on the continent was via satellite.[2] While being largely unconstrained by geography and local infrastructure, satellite connection is costly and allows only for very narrow bandwidths. With SMCs—often a joint effort of governments, private investors, and/or multinational organizations—Internet connection was first brought to SSA at a noticeable scale.

**Figure 1:** Sub-marine Cable Connection Years




*Notes:* The figure shows SSA countries with SSA connection years before 2008. Darker blue colors indicate earlier initial SMC connection years. Gray indicates countries not connected by SMC until 2008.

As shown in Figure 1, the first wave of internet-enabled SMCs arrived in SSA countries only in the early 2000s.[3] These *first-generation cables had the capacity to provide Internet at basic speeds. The biggest of them was SAT-3 and started operating in 2001. It featured landing points on the shores of eight SSA countries at the western coast of Africa.[4] These landing points—typically one per country—constitute the starting point for the respective national backbones (cf. Section 2.2). Until the late 2000s, most SSA countries were connected to the Internet via these *first-generation SMCs.[5]

[2]Single-channel and co-axial SMCs for telegraphy and telephony already existed before. The first telegraphy cable (*East coast cable) started operating as early as 1879.

[3]South Africa was connected in 1993, when the first SMC constructed to enable the use of the Internet (SAT-2) preceded an old co-axial telephone cable established in 1968 (SAT-1).

[4]Benin, Cameroon, Côte d'Ivoire, Gabon, Ghana, Nigeria, Senegal, and South Africa.

[5]The *second-generation of SMC landed very similarly between 2009 and 2012.

## 2.2 National backbone: inter-regional cables

After being routed through a SMC, Internet traffic travels through the national backbone. The national backbone infrastructure consists of inter-regional (fiber) cables. Therefore, as soon as a new SMC arrives at a landing point of a SSA country, Internet becomes available country-wide in every location with access to the national backbone. As Internet capacity (i.e. speed) of the national backbone does not depend substantially on distance to the landing point, this upward shift occurs uniformly across the country's connected locations. In the last decades, national backbone networks were continuously improved and expanded in parallel to the installation of SMCs.[6] This network expansion focused heavily on connecting economically and/or politically important locations since they feature the largest market potential (high population density and GDP per capita).[7] This often lead to a network evolution where the national capital (often a coastal city) was connected first. Then, the network spread out to the next largest (or politically important) cities, which are often regional capitals or other large cities. Due to their role as nodes in the national backbone networks, we call these cities *nodal cities.

Inter-regional cables are almost always built along pre-existing infrastructure (roads, but also railroads, the electric grid, and pipelines) to minimize construction costs. Even though the goal was to connect nodal cities, in many cases, towns on the route of inter-regional cables incidentally got Internet access as well. Our empirical strategy (cf. Section 4) focuses on these on-route towns which get Internet connection because of their location next to an inter-regional cable but are not nodal cities themselves.

## 2.3 Local transmission: *last mile infrastructure

Internet traffic transported by inter-regional cables is accessed at *access points (APs). There are several technologies transmitting Internet traffic from these access points (so-called fiber nodes) to the user. These *last mile transmission technologies include fiber cables (FTTH/B), copper cables, and wireless transmission using cellular towers (e.g. mobile or WiMax). Unlike in many developed nations which rely heavily on transmission to the end user via pre-existing telephony cable infrastructure, in SSA countries the Internet is mostly accessed via wireless and/or mobile devices. For this technology, no local cable network connecting each users exact locality (firm, household) is needed. Traffic data is exchanged wirelessly between cellular towers and the user's device. Relative to the costs to construct an inter-regional cable it is thus cheap to establish Internet access along the cable, making it profitable for the network operator to establish APs even in on-route towns, which are typically much smaller than nodal cities.

Figure A.2 shows how bandwidth and usage increases in countries that were served by a first generation SMC (South Africa which has a lot higher figures is not included). Though, figures being relatively low in

[6] Many of these cables were built decades ago as part of the telegraph and telephone infrastructure and were only later used for the transmission of early Internet traffic. They typically have been installed by the national telecom. Each country typically has an own, self-contained backbone network.There are no network operators owning networks in more than one country.

[7] Routes establishing connections to (landlocked) neighboring countries are a focus of network expansion as well.

absolute values, the relative change is remarkable. Furthermore, one can notice that both start increasing when the first SMC was constructed (1999 in Senegal) and that both lines increase rather jointly. Although, broadband usage is low among the population, broadband penetration in firms might be completely different. Unfortunately, we do not have data on the adoption of broadband in SSA firms. However, the *World Bank Enterprise Survey* shows even before the second generation of SMCs landed on SSA shores that 52% of all firms used email for communication and 23% had an own website.

# 3 The case of Benin

This section gives an overview of one example, how the backbone network was rolled out and how it influenced internet usage. This example is Benin, one of the countries that was connected by the SAT-3 SMC. This cable brought an international connection of 45 mbps (Chabossou, 2007).

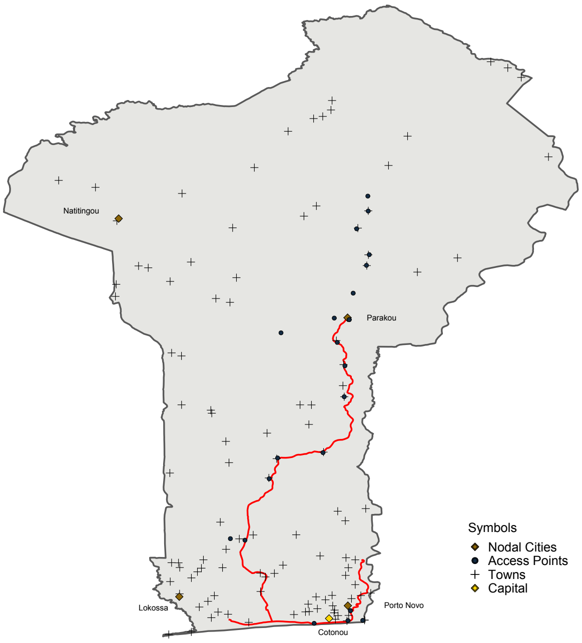
The rollout of the national backbone network was planned by Benin Telecoms SA, the fixed-line monopolist which manages the gateway to the national internet, operates as the national carrier, and administers the national domain (.bj). Benin Telecoms SA is state-owned and offers permanent ADSL connections with up to 2 mbps (Agyeman, 2007).

Following Chabossou (2007), the Sat-3 SMC landed in Cotonou, Benin's biggest city, the location of the seat of government, and 40 km away from Benin's capital, Porto-Novo. Close by, in Abomey-Calavi Benin's hub is located as well. These cities form with Godomey Benin's largest agglomeration with nearly 2.5 million inhabitants (about a third of Benin's population). From there, first, a connection to Parakou with a 425 km optical fibre cable was built in 2001. Parakou is Benin's next largest economic center with more than 150,000 inhabitants in the 2002 census and the capital of the Borgou department. This connection was constructed along Benin's railway line and roads network (Figure 2) and connected further regional towns on its way. On the way further smaller towns, for instance Savalou with 30,000 inhabitants were connected. Next, from Parakou connections to the borders of Niger, in the north-east, and Burkina Faso, in the north-west, were constructed along the road network, transforming Benin to a sub-regional digital hub interconnecting Togo, Nigeria, Burkina Faso, and Niger. The first kilometers of the fiber network and access points were still constructed in 2001. The connection towards Burkina Faso and Togo was constructed through Natitingou, the capital of Atakora department. Again, connecting also further smaller towns, such as Kandi or Djougou, incidentally. Only later on, further rural towns were connected when constructing backbone circles to make the network more reliable.[8] Consequently, Benin Telecoms SA investment in the telecommunications sector peaked in 2001 with more than $80 billion.

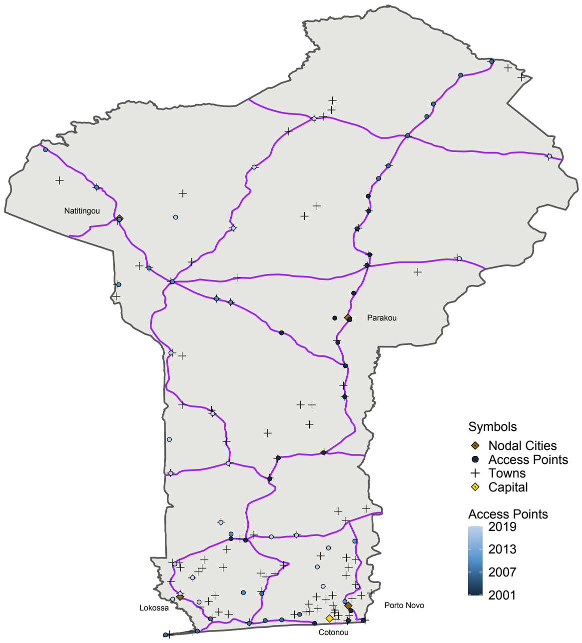
All transmission happens via Benin Telecoms SA. They offer data transmission networks to mostly commer-

[8] Towns like Nikki, Ségbana, or Banikoara, were connected to the national backbone only in 2019, but had internet access at very low speeds via VSAR satellites from 2001 on.

**Figure 2:** Rollout in Benin




**(a)** APs in 2001 and railroads




**(b)** All APs and roads

*Notes:* Figure shows SSA countries with SSA connection years before 2008. Darker blue colors indicate earlier initial SMC connection years. Gray indicates countries not connected by SMC until 2008. The right panel shows the induced increase in capacity by the SMCs.

cial clients (banks, hotels, ministries etc.) in packets.[9] Having grown exponentially, thousands of cybercafes offer wireless access. While international institutions, major corporations, service providers, and some cybercafés have permanent links, home access remains very limited (Chabossou, 2007). Still, in 2007 only 25% of people in Benin's population have used the internet at least one time. Access is mainly at cybercafes (21%) or at the workplace (2.2%) while internet at home remains a luxury. Though, workplace internet usage is low, it indicates that firms are great adopters of broadband internet. Among the groups of higher education, internet usage is also a lot higher. Therefore, we expect local growth through firm's productivity to increase induced by broadband internet.

# 4 Empirical strategy

We are interested in the relationship between Internet availability and local economic growth. However, their correlation is not informative about the causal effect of Internet availability on local economic growth due to endogeneity concerns. In particular, towns with and without Internet access might be very different. Internet access is not randomly assigned and likely driven by commercial interest and/or political and administrative planning. Decision makers might prioritize the connection of a priori larger towns on a higher growth path above smaller stagnating towns.

To address these endogeneity concerns, we leverage two distinct features of Internet infrastructure evolution in SSA countries. First, we use plausibly exogenous time variation in connections to sub-marine cables (SMCs), which determine Internet availability nation-wide, to investigate the effect of Internet availability. Following Hjort and Poulsen (2019), we argue that the exact timing of SMC arrival is essentially random.[10] First, for each individual SMC, it is exogenous to national planners when exactly it is put into operation and starts providing (international) Internet connection. This is because each SMC typically connects many countries and the connection years are highly uncertain due to unforeseen delays in construction and coordination difficulties among consortium members.[11],[12] Second, within SMCs the connection years are mainly determined by the geographical location because SMCs come from Europe, either through the west passing Spain or Portugal or trough the east passing Egypt or the Arabic peninsula, and connect SSA countries according to their location at Africa's coastline. Moreover, landlocked countries get their connection through the backbone network of their neighboring countries and rely therefore on the construction speed there. This construction speed again is exogenous for the respective landlocked country.

[9] Network interconnectivity enables new providers to use the incumbent's infrastructure instead of having to invest greatly to build an own one, which incentivizes competitive adaptation. There are, in addition to the former monopolist, which still owns the infrastructure, three licensed providers. However, there are about 50 providers operating without a licence and there is no adequate framework for regulation.

[10] This exogeneity was also exploited by Cariolle (2021).

[11] Consortium investors ussually are public and private telecom operators and neighboring and foreign investors (Jensen, 2006)

[12] For example, the cable EASSy was delayed by five years due to coordination difficulties among consortium members (Poppe, 2009).

Second, we focus on incidentally connected towns, i.e., towns close to an access point (AP) that are not (endogenously connected) nodal cities. We focus our analysis on these towns because they are very similar to each other in key characteristics such as size and infrastructure. Therefore, we exclude nodal cities: the landing point, the capital, regional capitals, and economic centers (cities with a population of more than 100,000 inhabitants). Importantly, all towns in our analysis get connected eventually, mainly because of their favourable location between nodal cities. Hence, we also exclude towns that are still waiting for an Internet connection today.

This enables us to use a difference-in-differences (DiD) design. We compare on-route towns that already have access to the national backbone when the SMC arrives to a control group of similar on-route towns getting an access point in later years (first difference) before and after the arrival of a SMC (second difference). Since national backbones are self-contained and (coastal) countries have own landing points (cf. Section 2.2) each country has a specific treatment date. Therefore, depending on the nation-wide connection date, towns in different countries are treated at different points in time.

The basic model used to identify the average treatment effect on the treated (ATT) of Internet availability on local economic growth is given by

$$y_{ict} = \beta_0 + \beta_1 \left( smc_{ct} \times access_{ic} \right) + \boldsymbol{X}_{ict}\beta + \alpha_{ic} + \delta_{ct} + \varepsilon_{ict} \tag{1}$$

where $y_{ict}$ is economic growth of town $i$ in country $c$ in calendar year $t$ as proxied by nighttime light luminosity measured by satellites (cf. Section 5). The dummy variable $smc_{ct}$ indicates if country $c$ has access to a SMC in calendar year $t$. The variable $access_{ic}$ is one if town $i$ in country $c$ is located within 10km distance to an access point that was established in the year of SMC arrival or before. Contrary, the indicator is zero if town $i$ in country $c$ is located close to an access point that was established in the years after the SMC arrival.[13] Thus, the interaction term $smc_{ct} \times access_{ic}$ indicates Internet availability in town $i$ in country $c$ in calendar year $t$. The coefficient of interest is $\beta_1$. It captures the effect of Internet availability on local economic activity. $\boldsymbol{X}_{ict}$ contains time-varying control variables, such as mobile internet coverage. We include two types of fixed effects into the model. Time-constant differences across towns are captured by town fixed effects $\alpha_{ic}$. Differences across calendar years common to all towns within a country are absorbed by country-year fixed effects $\delta_{ct}$. Note that this allows for country-specific time trends and variations in satellite sensor quality over years. $\varepsilon_{ict}$ is an error term. Like in many other DiD applications, our panel data are serially correlated in the time dimension. Hence, we use cluster-robust standard errors whereby we cluster at the town level.

The key identifying assumption for this DiD model is that treatment and control towns would have evolved

[13] Towns within 10km distance to an access point that was established in the three years under observation after the arrival of the SMC are excluded from the control group. Otherwise, due to getting treated in the observation period they would confound our analysis.

similarly in the absence of treatment (parallel trends assumption). This assumption cannot be tested. Its plausibility can, however, be examined by testing for pre-treatment differences in time trends between the treatment and control group. Therefore, we look at the dynamic impact of Internet availability on local economic activity using event studies:

$$y_{ict} = \beta_0 + \sum_{j=\underline{T}}^{\overline{T}} \beta_{1j}\left(t_j \times access_{ic}\right) + \boldsymbol{X}_{ict}\beta + \alpha_{ic} + \delta_{ct} + \varepsilon_{ict} \tag{2}$$

where $t_j$ indicates the year relative to treatment year, i.e. the year when the SMC arrives, starting in relative year $j = \underline{T}$ and ending with relative year $j = \overline{T}$. The treatment year is normalized to $j = 0$. We exclude $j = -1$ as the reference point. Thus, the interaction $t_j \times access_{ic}$ indicates if town $i$ in country $c$ is part of the treatment group and restricts the coefficient to one particular relative year $j$. The coefficients $\beta_{1j}$ inform about the dynamic effect of Internet availability. Thereby, each coefficient captures relative-year-specific treatment effects. We expect to see no effect before the treatment. Thus, if we cannot distinguish the estimates of the coefficients on the pre-treatment relative-year dummies (i.e. $\hat{\beta}_{1j} \forall j < 0$) from zero, the treatment and control group follow similar trends before the treatment, supporting the common trends assumption.

# 5 Data and spatial methods

We analyze the effect of Internet availability on local economic growth in SSA.[14] To this end, we tap two main data sources. First, local economic activity is measured by nighttime light (NTL) satellite data. Second, locations connected to the Internet are identified via the geo-location and construction year of access points (APs) to the national fiber-cable backbone network. Moreover, we use data on towns' built-up area, merged with characteristics, such as administrative status and population, and on infrastructure, such as (rail)roads, mobile coverage, and the electricity grid. Finally, we make use of the countries' connection dates to the sub-marine cables (SMCs). This section describes the data sets we use, the processing steps we apply, and shows descriptive statistics relevant for our analysis.

## 5.1 Local economic activity: nighttime lights and built-up areas

We measure economic activity at the town level. To identify town locations and extent, we use the established data from *Africapolis* on built-up areas.[15] This database contains the geographical delineation of 5,811 SSA agglomerations with more than 10,000 inhabitants in 2015. The median size is around 20.000 inhabitants and about 90 percent have less than 100.000 inhabitants.

[14] We define Sub-Saharan Africa as the mainland of the African continent without the Northern African countries, Algeria, Egypt, Libya, Morocco, Tunisia, and Western Sahara. Moreover, we exclude South Africa as it is economically more developed and therefore less comparable to the other SSA countries.

[15] https://africapolis.org

Since geographically and chronologically granular data on economic activity in SSA is lacking—especially for the period we investigate—we deploy nighttime light (NTL) satellite data. This data measures human-caused NTL emissions in a geographically high resolution and on a yearly basis. There have been two major programs that collected NTL data. First, NTL data was collected in the *Defense Meteorological Satellite Program* (DMSP) *Operational Linescan System* (OLS) between 1992 and 2013. Second, the follow-up program *Visible Infrared Imaging Radiometer Suite* (VIIRS) on the *Suomi National Polar-orbiting Partnership* satellite started in April 2012. The instruments of DMPS-OLS satellites measure light intensity on an integer scale from 0 to 63 with pixels covering 30 arc-second grid-cells (an area of .86 km$^2$ at the equator). The data is then combined to yearly composite images. With VIIRS, both the spatial (pixels are smaller) and radiometric resolutions (both dark and bright spots are recorded better) as well as the temporal resolution have been improved.

On the country level, NTL data is well established as a measure of economic activity and widely used by economists (Henderson et al. (2012) and Chen and Nordhaus (2011) among the first ones). Closely related to our work, Storeygard (2016) established this data on the city level. At larger geographic resolutions, Bruederle and Hodler (2018) added the relation to household wealth, education, and health for DHS cluster locations as well as for grid cells of roughly 50×50 km.

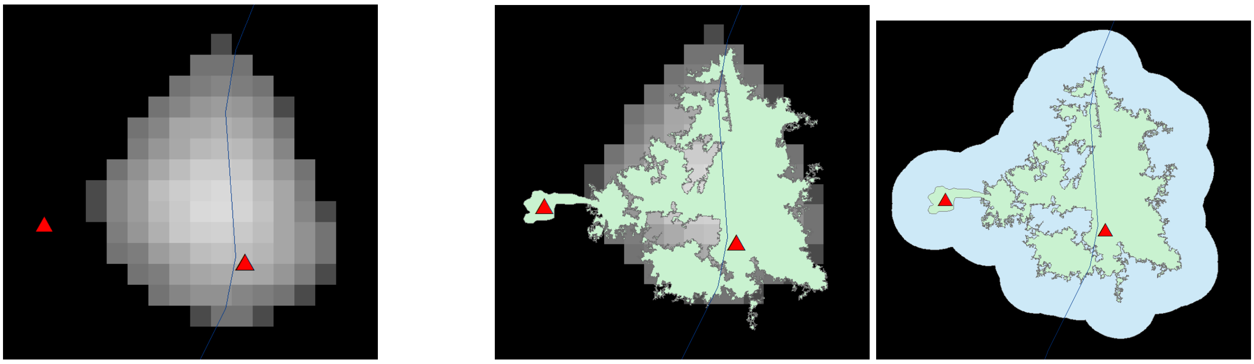
We use the harmonization of the two sources by Li et al. (2020) to get consistent yearly NTL data from 1992 to 2018. Though, we do not need that long time frame for our main results, it allows us to investigate medium-term effects. Moreover, we exploit the advantage of this procedure that noise from aurora, fires, boats, and other temporal lights are excluded. Another advantage of this data is that the DMPS-OLS data has been inter-calibrated globally from 1992 to 2013 as well, making it temporally consistent. To harmonize the two satellite programs, Li et al. (2020) recalculated the newer and better VIIRS data to the (spatial and radiometric) resolution of the original DMPS-OLS data. Therefore, the lower DMPS-OLS resolutions apply.

Unlike in the developed world, very high light intensities (i.e. top-coded pixels) are less a concern in the context of SSA (Bluhm and Krause, 2018). Looking at pixels in our sample that only contains cities and towns, less than 2% of pixels are assigned light intensities of 60 or more (Figure A.3). Figure A.3 shows the distribution of light intensity by year for our estimation sample. In the left panel non-lit pixels are included, while in the right panel the distribution of lit pixels only is shown. For earlier years, the maximum density is typically smaller than for later years. Hence, the towns in our analysis are generally getting brighter over time. Most lit pixels have a light intensity of 10 or lower, reflecting the large share of rural locations with small- and mid-sized towns. Hence, as stated before, top coded pixels are not an issue in our setting.

As light blurs out to adjacent pixels, cities appear bigger in the data than they actually are. By taking the extent of the towns in 2015, we capture some of the blurring as the towns might have been growing after our observation period. However, for some towns, the NTLs still might blur over the extent of the built-up areas. Therefore, we account for blurring by adding a radius of 2km to the built-up area, such that the growth of light emissions in the extensive margin is properly captured.[16]

Figure 3 shows for Parakou, Benin, its NTL emission, built-up area, and infrastructure. A road connecting Parakou with its neighbouring cities (blue line) and the access points (red triangles) constructed in 2001 are shown in all panels. Panel (a) shows moreover the nighttime lights for the year 2001, where a brighter gray reflects higher light intensity. Panel (b) adds Parakou's built-up area from *Africapolis*. It shows that the blurring of the nighttime light data exceeds the built-up areas boundaries. Therefore, we draw a buffer of 2 km around the area (shown in Panel(c)). This allows us to take all light emissions into account.

**Figure 3:** Data example: Parakou, Benin



**(a)** **(b)** **(c)**

*Notes:* Panels (a)-(c) show our data for Parakou, Benin. Panel (a) shows the constructed access points (red triangles) and nighttime lights for the year 2001. The blue line represents a road connecting Parakou with its neighbouring cities. The black-to-white scale indicates light intensity, with brighter colors reflecting higher light intensities. Panel (b) adds its built-up area from *Africapolis* (shown in green). Finally, Panel (c) shows in blue a 2 km buffer around the built-up area.

Within each town, we define several outcome measures. Local economic activity is measured by summing the light intensity of all pixels within a town in each year. This measure was established by Storeygard (2016) and accounts for both geographical extension and light intensity. As alternative measures, we calculate the sum of all lit pixels, ignoring light intensity, in each year within a town and the average light intensity of pixels within each town and year. We interpret the sum of lit pixels as a proxy for spatial extension of a town (extensive margin) and the average light intensity as a proxy for density in terms of population or per capita economic activity (intensive margin).[17]

### 5.2 Internet infrastructure: backbone access points and sub-marine cables

For the treatment year, we use information on SMCs' landing dates on the shores of SSA countries. The data comes primarily from *Submarine Cable Map*.[18] Table B.1 shows the country-specific connection dates

[16]For robustness, we also show the results using different radii on the built-up areas, including a specification without a radius.
[17]As specified in Section 4, we apply the logarithm of each outcome measure.
[18]https://www.submarinecablemap.com

of all SSA countries that were connected before 2009. If the country was connected via a SMC, the SMC landing point is stated as well. We geo-coded this point to merge it to the respective built-up area. The connection year of through neighboring countries was also mainly taken from *Submarine Cable Map*. In the last column, the upgrade year of the next SMC is shown. These SMCs had a lot higher capacities and landed in SSA between 2009 and 2012.The geo-location of the APs for the national fiber-cable backbone comes from *Africa Bandwidth Maps* and are mapped in Figure A.1.[19] The database contains the most comprehensive set of APs for Africa, covers the period starting from 2009 and is updated on a yearly basis. The data is directly sourced from the network operators. As APs existing in 2009 were largely established earlier, we conducted an extensive review of network deployment projects for each country. Thereby, we determined the construction years of the APs from 2009 going back to the late 1990s for all SSA countries. This makes it possible to identify which towns already were connected to the national fiber-cable backbone when the first wave of SMCs arrived. We match APs to towns via their geo-location: First, we calculate the distance between the towns' border and the closest AP. Then, we assign a national fiber-cable backbone connection to towns within a distance of less than 10 km.

To date, there are 2.708 APs in SSA countries. About half of them were constructed since 2013. Especially in bigger cities, more than one AP is usually built to account for the limited capacity of each AP. In 2019, for example, although 189 new APs were constructed, only 27 new cities and towns were connected. In total, around 900 cities and towns have an AP close by.

### 5.3 Estimation sample

We focus on early SMCs bringing internet connections at basic speeds to SSA in the early 2000s. Therefore, we do not consider countries which were connected after 2008 for the first time, when the next generation of SMCs (which allowed for much higher speeds) landed. This leaves 27 SSA countries, which are listed in Table B.1. Among the first countries are Djibouti, where an SMC landed in 1999, Namibia, which was connected by a trans-national fiber cable from South Africa in 1999, and Senegal, which got connection in 2000 with an individual-country SMC. In 2001, seven more countries were connected by a single SMC, the SAT-3 cable. In the following years unteil 2008, 17 more countries got an SMC connection or were connected through their neighboring countries.

However, not all countries that were connected until 2008 had built a national backbone infrastructure before the respective SMC or the connection through a neighboring country arrived. In this case, the treatment group is missing as there are no towns with national backbone connection right after the connection. This reduces the number of countries in our analysis to 23.[20] Moreover, 11 countries built at least one AP before

[19] http://www.africabandwidthmaps.com

[20] Central African Republic has not yet built a national backbone infrastructure. In Lesotho, the APs were built in 2009m three years after being connected through South Africa. In Djibouti, the first APs were built in 2007, which is 8 years after the first SMC connection. Nigeria built its first APs in 2003, which is 2 years after the arrival of the first SMC.

SMC arrival, but only in nodal cities.[21] Finally, we cannot consider Namibia in our analysis because it did not construct APs after getting Internet access. Therefore, we are unable to define a control group. This leaves 12 countries for our analysis.

Due to the staggered arrival of SMCs, this sample represents an unbalanced panel. In our main specification we take a conservative approach and estimate on a balanced panel. Therefore, we truncate the data to attain a balanced panel. For example, the first connected country in our sample is Senegal, which was connected in 2000. This leaves us with 7 pre-treatment years. Hence, on the left with a truncation at 7 years before treatment year, we have no data loss. This limits our pre-treatment comparison to a period of 7 years. Malawi and Mozambique got connection in XXXX and thus only have 2 post-treatment years. Hence, estimating on a balanced sample with 3 post-treatment years leaves us with a sample of 10 countries.[22] For robustness, we will soften these restrictions.

### 5.4 Descriptive statistics

For the estimation sample in the balanced panel, figure 4 shows the geographical distribution and the location of the treatment and control group towns. There are four countries in West Africa and Southern Africa and two countries in East Africa in our sample. For many countries, there is no specific pattern of the towns' location. Of the 10 countries, five are coastal and five are landlocked.[23]

We focus our analysis on mid-sized towns. From 510 agglomerations, for which NTL data is detected in each year, in the ten countries in the estimation sample, 143 were connected to the Internet via an AP before the country was connected via SMC or a neighboring country. Therefore, they are part of our treatment group. 70 of these agglomerations are nodal cities. Another 147 towns got an AP in the subsequent years and are therefore in the control group. The remaining 220 agglomerations are still not connected. Further XXX were connected in the three years after SMC arrival and are therefore not considered as they would confound our control group.

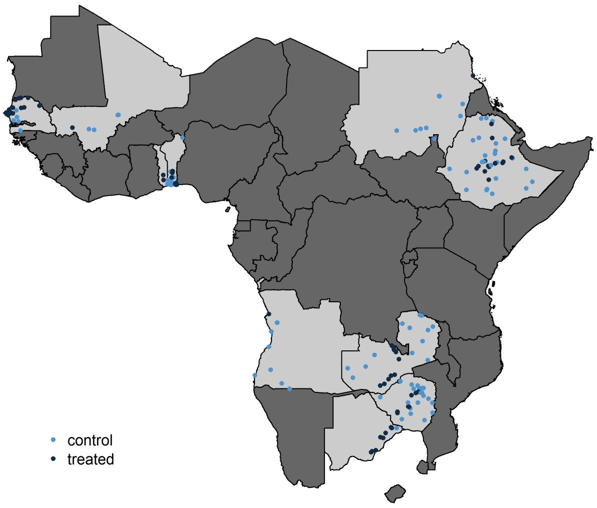
Figure 5 compares the average size of cities and towns by the year they get an AP (relative to the SMC connection year). In the early years, many nodal cities are connected. Hence, the connected cities are bigger on average in the early years. In subsequent years, cities and towns are a lot smaller on average and vary for all subsequent years around a population of 20,000 inhabitants. However, when only examining treated and control towns—i.e. excluding nodal cities—there is no clear pattern with respect to population size over time anymore: treated towns have a population of 20,000 inhabitants on average and control towns also vary around this value (in some years up to more than 35,000 inhabitants and in other years down to 10,000 inhabitants). This suggests that treated towns are not selected into treatment because of their population

[21] Guinea-Bissau, Lesotho, and Swaziland built all APs until today only in nodal cities.

[22] These countries are Angola, Benin, Botswana, Ethiopia, Mali, Sudan, Senegal, Togo, Zambia, and Zimbabwe

[23] Sudan is a special case as 10 cities are in the control group but only one city is in the treatment group. We account for that by...grouping countries? robustness leave-out?)

**Figure 4:** Countries and towns location in the estimation sample



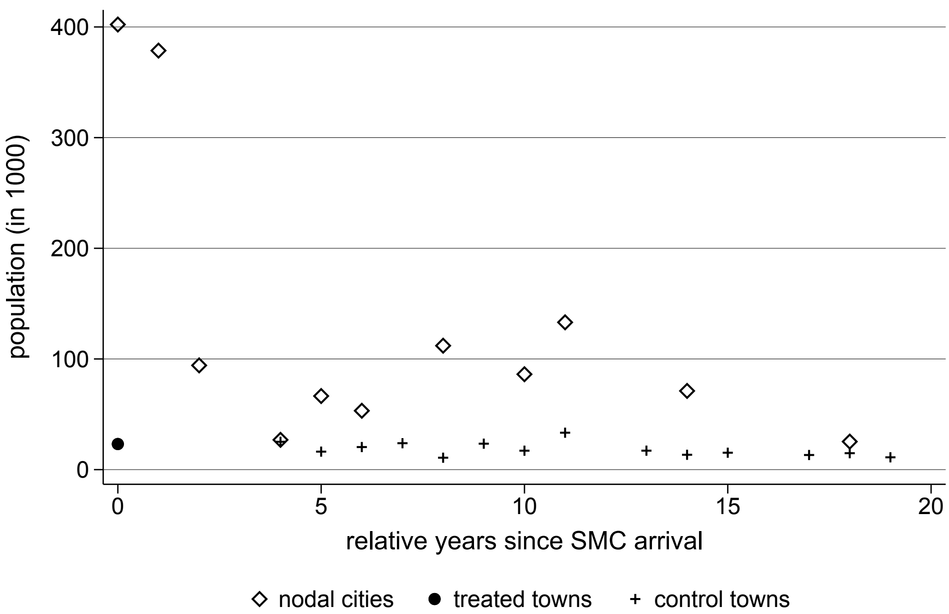

*Notes:* This figure depicts the countries in our analysis (brighter gray) and for each country the towns in the treatment and control group.

size. Importantly, nodal cities are still connected in further years after the arrival of the first SMC. Their size decreases after the first two years as capital cities are usually connected first and a lot bigger than other nodal cities. Nonetheless, their size is still greater on average than the size of the control towns.

Table B.2, gives a broad overview of the towns. The statistics of the outcome measure of the light intensity show a value of 463.04 on average one year before the treatment (161.50 at the 25th percentile, 285.00 at the median, and 530.50 at the 75th percentile). The size of the towns, measured with the NTL data, values are as followed: 43.35 on average one year before the treatment (24 at the 25th percentile, 35 at the median, and 53 at the 75th percentile). On average, including no-lit pixels with a value of zero, towns have values of 7.50 on average one year before the treatment (3.22 at the 25th percentile, 5.25 at the median, and 10.07 at the 75th percentile). Given that the instruments pickup light usually at a threshold of 4, the average values are rather modest. The rather high number of lit pixels corresponds to the condition that towns have to show up in each year in the NTL data. Coming to the other variables, mid-sized towns have a population of around 20,500 inhabitants on average in 2000 (8,500 at the 25th percentile, 16,000 at the median, and 30,00 at the 75th percentile). Mobile coverage is available in about 62 percent of the towns one year before treatment, given that usually the percentage covered is either zero or one. By construction, the distance to the closest AP is with 9.43 km smaller than 10 km. On average, this distance is a lot smaller with 1.26 km. More than half of the towns have an AP even within the built-up area and most cities have it within 2 km (1.21 km at the 75th percentile).

The distances to further infrastructure, such as the road network, railroad network, or electricity grid, are

**Figure 5:** Population size of connected cities and towns by year (relative to connection year)




*Notes:* The figure depicts the average population size of connected cities and towns by year relative to the connection year. The black dot in the lower left corner represents the treated towns, while the control towns are represented by the plus symbol and the nodal cities by a diamond.

usually small with median distances of 0 km (3.8 km for the railroad network). Further distances are given for the next port, for coastal countries, as well as to the capital city, to the next regional capital, and geographical measures, such as the coastline or the next river. The variables come either from *Natural Earth (NE)*, *OpenStreetMap (OSM)*, and *Africa Infrastructure Country Diagnostic (AICD)*. Therefore, the data is time-invariant and not dated before the treatment but was collected in 2007 (AICD), 2010 (NE), or more recently (OSM).

Before presenting the estimation results, we show the development of cities and town over time. We use the main outcome measure, log light intensity, averaged over the types of city but do not include any fixed effects or controls. First, we show it for the whole sample, including capital cities, landing points, regional capital cities, (nodal) cities with more than 100,000 inhabitants, treated towns, towns in the control group, and towns without an AP (Figure A.4) and then focus on the treatment and control group only (Figure 6). In Figure A.4, it can be seen that the capital cities and landing points, which coincide for many coastal countries, are by far the biggest cities and that towns which do not get an access point by the end of our data are the smallest on average. However, they are not a lot smaller than the cities in the treatment and the control group. Additionally, the other excluded (nodal) cities are rather similar to each other in comparison to the towns in our analysis. It can be noted that the regional capitals on average do not exceed the bigger cities category. It is hard to see growth patterns in this aggregated figure. Therefore, we show a figure of just the treatment and control group next. Figure 6 shows that in the early pre-treatment years both groups grew with similar rates. In more recent years before the treatment, this growth stagnated. This stagnation holds on for the control group, while the treated cities grew again in the second and third year after the treatment. Finally, at the end of the observation period, the before rather small gap between these towns grew by about .1 from about .4 to about .5 on a logarithmic scale.

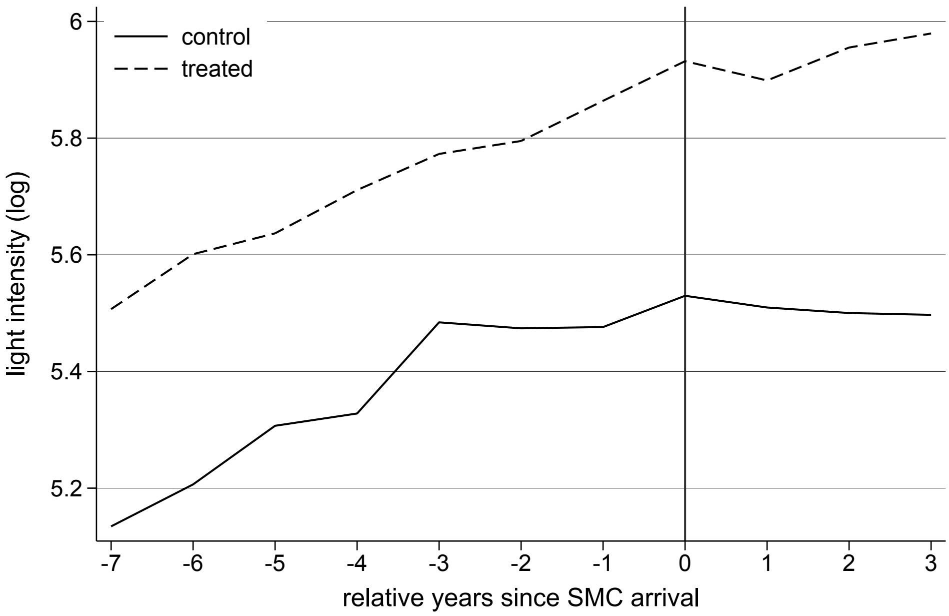
# 6 Results

## 6.1 Main effects

We estimate the effect of Internet availability on local economic growth. We are particularly interested in the effect of early Internet availability brought by the *first-generation SMCs. We estimate a linear model on a balanced panel by difference-in-differences.

In our main specification, we measure economic activity by the logarithm of the sum of light intensities. Table 1 shows the main results. In the first column, the raw specification, nodal cities and the landing point are still included. We then step-wise eliminate nodal cities until we reach our preferred specification where the remaining towns are comparable. In the second column, we remove the city of the landing point and the national capital. In the third column, we also remove regional capitals. In the fourth column, we remove cities of more than 100.000 inhabitants. Finally, we add as a control variable the share of the towns' area with GSM mobile network coverage (column 5).

**Figure 6:** Time trends of treatment and control group




*Notes:* The figure depicts the average growth of treated and control towns before and after the treatment year. The measurement is the logarithm of light intensity.

We find an economically and statistically positive effect of internet at basic speeds on local economic growth. In our preferred specification (column 5), towns which were connected to the Internet in the year of SMC arrival are 7% brighter than towns without Internet availability. For an approximation of the implied economic effect, we perform a back-of-the-envelope calculation using the GDP-luminosity elasticity of $\varepsilon_{GPD,light} = 0.284$ from Henderson et al. (2012). The calculation translates the increase in light intensity of 7% into about 2 percentage points higher GDP growth.

For our preferred specification (column 5), Figure 7 presents event study coefficients. Before the SMC connection, the point estimates are close to zero and insignificant. In the years after SMC arrival, the point estimates are between .05 and .1 and have slightly the tendency to increase to nearly .15 in year three after the connection, when the effect gets significant at the 5%-level. We cannot estimate effect for a longer time period as second-generation SMCs arrive in the years after initial SMC arrival to upgrade Internet capacity and speeds. From this dynamic perspective, there is no evidence for a potential fading-out of the effect.

**Table 1:** The Effect of Internet on Economic Growth of Cities

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| post x treated | 0.0462 | 0.0532* | 0.0591* | 0.0633* | 0.0703** |
| | (0.0286) | (0.0302) | (0.0328) | (0.0344) | (0.0349) |
| GSM coverage | | | | | 0.0486 |
| | | | | | (0.0342) |
| Observations | 3,190 | 3,069 | 2,563 | 2,420 | 2,420 |
| R-squared | 0.971 | 0.961 | 0.958 | 0.943 | 0.943 |
| #countries | 10 | 10 | 10 | 10 | 10 |
| #cities | 290 | 279 | 233 | 220 | 220 |
| share treated | .493 | .473 | .468 | .445 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | | | ✓ | ✓ | ✓ |
| w/o population ¿100k | | | | ✓ | ✓ |

*Notes:* Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

## 6.2 Mechanism

### 6.2.1 Population, Intensive, and Extensive Margin

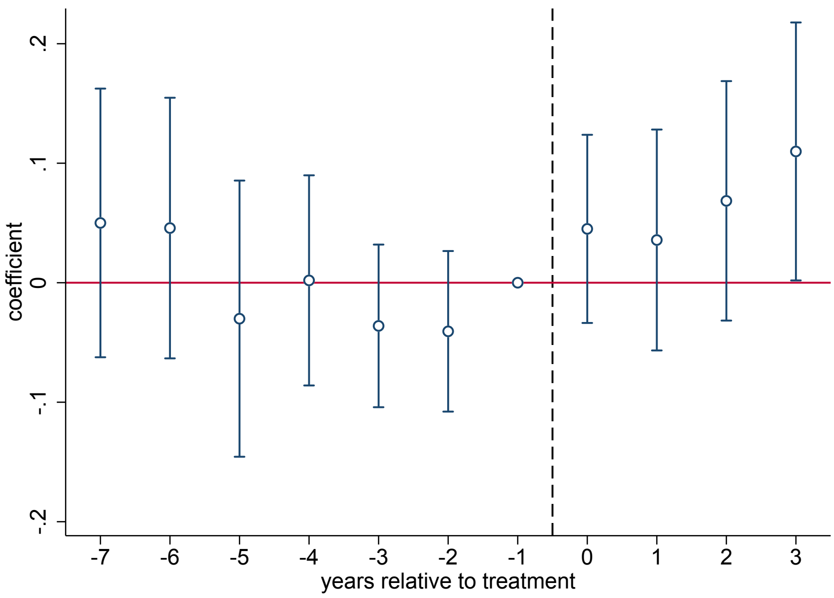
Next, we investigate the intensive and extensive margin. Therefore, we take the mean luminosity (Table 2, column 3 & 4) and the sum of lit pixels (Table 2, column 5 & 6) as alternative outcome measures to the sum of luminosity (Table 2, column 1 & 2). All outcomes are logged. In odd columns, we estimate specifications as in column 5 of Table 1. In even columns, we add population as a control. We observe that towns having Internet available are getting brighter (columns 3 and 4) and also that they increase in their size (columns 5 and 6). Adding population as a control, the main effect remains robust. The coefficient of the population control is specifically significant for the extensive margin (column 6).[24] We can state the effect is not driven by migration as we see the strongest effect in the intensive margin. Furthermore, the population is insignificant there. Hence, we are assured that we mainly estimate an effect of productivity increase.

### 6.2.2 Industry

In Table 3, we can show how the industry changes when internet arrives. We use survey data from IPMUS to calculate the share of jobs in certain industries (agriculture, manufacturing, and service). Countries where not visited all in the same year. Therefore, we estimate a long difference with one survey year before the arrival of the SMCs and one survey afterwards. Unfortunately, not all countries were visited two valid points

[24]Taking an additional radius around the built-up area of the towns, we assume that lit pixels are inside the towns' border. Therefore, blurring of nighttime lights on the satellite image are not an issue anymore and *size measures the actual growth of the towns. Hence, the growth can mainly be reduced to an increase in light intensity.

**Figure 7:** Event Study Coefficients




*Notes:* Coefficients for event study specification of model (5) from Table 1. Robust standard errors clustered by town for 95% confidence interval reported as bars.

in time. Also, there is not data for all regions. Therefore, the sample shrinks. On the other hand, we can add countries that were connected late (in 2006 and 2007) where the second generation cables landed shortly afterwards. The treatment is defined as above. Results indicate that internet removes jobs from agriculture to manufacturing and service jobs. In Columns 1–3, we estimate on four countries and 62 towns. The share of jobs in agriculture declines by more than 4 percentage points when internet arrives. In contrast, job shares in manufacturing and in service increase. In Columns 4–6, we estimate on the only country from our main specification (Zambia) that has data of sufficient quality. Here, the decrease in agriculture jobs is with more than 7 percentage points even bigger.

### 6.2.3 Firm creation

It would be great to see whether the changes in shares of the distinct industries are rooted in an increase of jobs in these industries. Unfortunately, the data is limited in that regard. However, we were able to investigate firm creation with *crunchbase*. Here, new start-ups and their offices are collected. The data has a strong focus on capitals, we cannot investigate whether in small towns new firms are founded. However, we can show that our identification allows us to investigate the number of firms in each city with country FE instead of country-year FE. However, this estimate is only based on only 26 cities in 14 countries. The estimation shows that the number of offices increases by around 20 percent in comparison to cities in the control group.

**Table 2:** Population, Intensive, and Extensive Margin

| VARIABLES | (1) combined ln_sum_light | (2) combined ln_sum_light | (3) intensive ln_mean_light | (4) intensive ln_mean_light | (5) extensive ln_size | (6) extensive ln_size |
|---|---|---|---|---|---|---|
| post x treated | 0.0703** | 0.0661** | 0.0513** | 0.0503** | 0.0516* | 0.0473* |
| | (0.0349) | (0.0318) | (0.0231) | (0.0229) | (0.0282) | (0.0244) |
| GSM coverage | 0.0486 | 0.0461 | 0.0477** | 0.0471* | 0.0281 | 0.0255 |
| | (0.0342) | (0.0336) | (0.0240) | (0.0241) | (0.0263) | (0.0255) |
| population (ln, gpw) | | 0.359* | | 0.0793 | | 0.375** |
| | | (0.190) | | (0.113) | | (0.148) |
| Observations | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 |
| R-squared | 0.943 | 0.944 | 0.947 | 0.947 | 0.924 | 0.925 |
| #countries | 10 | 10 | 10 | 10 | 10 | 10 |
| #cities | 220 | 220 | 220 | 220 | 220 | 220 |
| share treated | .445 | .445 | .445 | .445 | .445 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o population ¿100k | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

*Notes:* Light intensity in the combined models is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. The measure for the intensive margin is logarithmic mean light intensity and for the extensive margin logarithmic sum of pixels. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Population is measured as inhabitants per square kilometer within town area from GPW. All specifications are estimated on a sample restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

## 6.3 Robustness

### 6.3.1 Longer post-period

Originally, we limit the sample when the second generation of SMCs arrive. So, we can estimate the effect of broadband internet at basic speeds. The event study estimates, Figure 7, show that the effect on local economic growth increased on a yearly basis. Therefore, we show for robustness how this effect evolves in two more subsequent years. One should note, however, that the effects in the last periods might be driven by fast internet induced by the new SMCs. On the other hand, not all countries already have fast internet available by the end of the new sample. Indeed, the average effect increases to .12. The event study estimates are shown in Appendix Figure A.5 and indicate the the growth rate increases further to more than 20%.

### 6.3.2 Different FE

As explained above, we apply fixed effects on country-years to account for country-specific growth paths in their economies. For robustness, we estimate the model also with classical two-way fixed effects: towns and calendar years. The estimate remains robust but looses precision.

**Table 3:** Employment shares by industry

| VARIABLES | (1) agriculture | (2) manufacturing | (3) service | (4) agriculture | (5) manufacturing | (6) service |
|---|---|---|---|---|---|---|
| post x treated | -0.0423** | 0.0234* | 0.0189* | -0.0727*** | 0.0299*** | 0.0429*** |
| | (0.0191) | (0.0120) | (0.0104) | (0.0213) | (0.00879) | (0.0138) |
| Observations | 124 | 124 | 124 | 56 | 56 | 56 |
| R-squared | 0.972 | 0.846 | 0.981 | 0.970 | 0.913 | 0.979 |
| #countries | 4 | 4 | 4 | 1 | 1 | 1 |
| #cities | 62 | 62 | 62 | 28 | 28 | 28 |
| share treated | .323 | .323 | .323 | .429 | .429 | .429 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o population ¿100k | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| late adopters | included | included | included | excluded | excluded | excluded |

*Notes:* Light intensity in the combined models is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. The measure for the intensive margin is logarithmic mean light intensity and for the extensive margin logarithmic sum of pixels. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Population is measured as inhabitants per square kilometer within town area from GPW. All specifications are estimated on a sample restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

#### 6.3.3 Higher Level Clustering of SE

Next, we apply a higher level of standard error. In our preferred specification, we cluster the standard errors at the town level as the treatment, the access point construction, is occurring there. However, the effects of the AP might generate spillover effects in the town's surrounding area. Therefore, I cluster the standard errors on the Admin-1 (state) level as robustness to account for potential spillover effects. The estimate remains.

#### 6.3.4 Spatial correlation

Following Conley (1999) we calculate the standard error to account for spatial correlation. Results remain. Moreover, Moran's I indicates that the data is not spatially correlated.

#### 6.3.5 Linear time trends

Next, we add linear time trends on the town level. This is the most demanding specification. As the estimate remains, we can show that after the SMC arrival, the connected towns grow in a nonlinear manner.

#### 6.3.6 No buffer

Lastly, we remove the 2 km buffer and estimate on the original *Africapolis* built-up area. As the estimate remains, we can show that city growth does not necessarily happen at the city border.

### 6.3.7 Ethnic favoritism

A further concern could be that in the rollout ethnic groups were favored. Though, the exogenous shock comes from the arrival year of the sub-marine cables and the parallel trends in the event study do not underpin this concern. A threat could be that certain ethnic groups are also favored in any other dimension. Your strategy to overcome this threat is two-fold. First, we perform our analysis constructing country-ethnic group entities. As the sample size does not shrink a lot, it shows that for most ethnic groups for which APs were constructed in the treatment period, APs were also constructed afterwards. Estimates remain in their economic size and statistical significance declines only slightly. Second, we can show visually that many countries construct APs for more than one ethnic group in the treatment period (Figure A.11. This indicates that not a specific ethnic group is favored by giving them APs. For the countries in our analysis, all countries but Angola provided at least two different ethnic groups with access to the Internet.[25] Ethiopia and Togo did this for even six different ethnic groups.

**Table 4:** Robustness

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| post x treated | 0.0703** | 0.121*** | 0.0580* | 0.0661** | 0.102** | 0.0665** | 0.0720* |
| | (0.0349) | (0.0392) | (0.0338) | (0.0330) | (0.0449) | (0.0290) | (0.0374) |
| GSM coverage | 0.0486 | 0.0611 | 0.0908*** | 0.0461 | 0.0193 | 0.0197 | 0.0482 |
| | (0.0342) | (0.0380) | (0.0320) | (0.0330) | (0.0332) | (0.0256) | (0.0408) |
| Observations | 2,420 | 2,860 | 2,420 | 2,420 | 2,420 | 2,156 | 1,804 |
| R-squared | 0.943 | 0.937 | 0.927 | 0.944 | 0.962 | 0.978 | 0.939 |
| #countries | 10 | 10 | 10 | 10 | 10 | 10 | |
| #cities | 220 | 220 | 220 | 220 | 220 | 196 | 164 |
| share treated | .445 | .445 | .445 | .445 | .445 | .464 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | | ✓ | ✓ | ✓ | |
| w/o capital+landingpoint | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o population ¿100k | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| longer post-period | | ✓ | | | | | |
| #ethnic group-countries | | | | | | | 13 |
| Ethnic Group-Country x Year FE | | | | | | | ✓ |
| no buffer | | | | | | ✓ | |
| linear time trends | | | | | town-level | | |
| Cluster | | | | state-level | | | |
| Year FE | | | ✓ | | | | |

*Notes:* Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

### 6.3.8 Other infrastructure

In Table B.3, we include additional controls. As was shown in Figure XX, access points were constructed along other infrastructure. Hence, we control for this other infrastructure to rule out that towns closer to this

[25] Angola built very few APs in total. Therefore the low number of provided ethnic groups is not surprising.

other infrastructure grow faster when the SMC arrives, irrespective of whether they are in the treatment or the control group. We follow two approaches. Unlike the mobile network coverage (GSM), we do not have time-varying data on other infrastructures. We therefore intersect these controls with the post dummy for the time after the arrival of the SMC and construct placebo treatments. First, we control for the linear distance of the towns to the next greater (paved) road (Column 2), to the next railroad (Column 4), and to the next electricity grid (Column 6). Next, we repeat this exercise with a connection dummy for each infrastructure, indicating whether the distance is below 10 km (as we defined treated towns with APs) (Columns 3, 5, and 7). Finally, we include both approaches jointly (Columns 8 and 9). In each case, the estimate remains. In the case of roads, we loose slightly precision. Nevertheless, controlling for all infrastructures jointly, the estimate is again statistically significant at the 5%-level. The estimates of the placebos are all statistically insignificant and very small in their economic significance.

#### 6.3.9 Definition of nodal cities

The main results show that the estimate does not change when restricted to towns with less than 100.000 inhabitants. However, this threshold is chosen arbitrarily. Therefore, we vary the population threshold as a further robustness check. Figure A.6 shows that the estimate remains independently of the chosen population threshold.

#### 6.3.10 Definition of control group

One concern might be that very late connected towns might not be comparable to the treated towns. However, Table B.5 shows that when restricting the year when control towns were connected does not have a strong impact on the estimate. In contrast to the a priori concern, economic and statistical significance increases when only including towns that were connected shortly after the arrival of the SMC. This indicates that the control towns might be a heterogeneous group. Nonetheless, the restriction decreases the sample size. The last column repeats the main effect estimate.

#### 6.3.11 External validity

We repeat the excise with the classical two-way fixed effect model of Column 3 in Table 4 on a less restrictive sample. Again, we apply fixed effects for years instead of country-years. Therefore, we can allow countries in our sample containing either only control or treated towns. Table B.4 repeats the step-wise selection of non-nodal cities from the main table. The estimated result is very comparable to the more restrictive sample. Nevertheless, it indicates that the effect of broadband internet is very comparable across SSA countries (irrespective of how they rollout the national backbone infrastructure). Also, the event study graph (Figure A.7) is fine.

One concern is this setting is that the classical two-way fixed effect estimator does not account for the staggered timing of the treatment. Recent literature developed estimators for this setting (Roth and Sant'Anna, 2021; Callaway and Sant'Anna, 2020; **?**). Figures A.9, A.10, and A.8 show event study estimates for the respective estimators. Again, it is shown that the results hold when accounting for heterogeneous outcomes in staggered treatment timing by the propensity score weighting method and potential comparing of treated and not-yet-treated observations.

### 6.3.12 Other outcome measure

Our results also hold when estimating the absolute light intensity instead of the logarithm (Table B.6). Especially, nodal cities, in the first columns of Table B.6, growth a lot stronger in absolute terms.

# 7 Discussion

Previous estimates of economic growth induced by broadband serve for comparison with our results. We find that cities with internet available growth 2 percentage points faster in their GDP than not connected cities. Though Czernich et al. (2011) also investigate GDP growth in OECD countries induced by broadband internet and timing and internet speed is very comparable, some factors make it difficult to compare the two results. Czernich et al. (2011) find that the broadband increased GDP per capita by 2.7—3.9%, implying a .9–1.5 annual per capita growth when internet penetration is increased by 10 percentage points (with penetration ranging between 13.5% in Greece and 37.2% in Denmark in 2008). They define broadband if a user can surf with at least 256 kbps. In comparison, Hjort and Poulsen (2019) state that SSA users had on average 430 kbps before the second generation of SMCs arrived. Most OECD countries introduced broadband internet between 1999 and 2000 with some late adopters like Greece (2003) and Ireland (2002). This is only very few years earlier than the landing of the SAT3-cable in 2001. Two major differences are that we cannot investigate broadband penetration and compare cities within countries and not broadband penetration across countries. Though, broadband penetration is very low in SSA, it is likely that the very first adopters, mainly firms, have the biggest impact on economic growth. Though, in SSA broadband internet fails high penetration, it still counts as a general purpose technology as firms can access information such as global prices a lot easier with access to the Internet.

For SSA, Hjort and Poulsen (2019) estimates a 3.3 percent increase in economic activity of the later arrival of fast internet. First of all, their work differs by the internet speed available. But most importantly, while we use variation between towns, they use variation within local cells. Hence, though in both cases local economic activity is measured, the comparison is different. Finally, the selection of cities and towns is different as we focus on mid-size towns. All together, it is hard to compare whether the estimates tell something about different speeds or whether they are affected by other issues. Finally, it cannot be rejected that the effects of the extensive margin—of pure connectivity—are still in play when the next generation of SMCs landed. Nevertheless, both studies show that SMCs that brought internet to SSA a different speeds had both a positive effect on the local economic growth there.

Finally, we want to compare our results to Storeygard (2016) who also estimates city growth. Though, not estimating the effects of a digital infrastructure, he is most closely related to our work with regard to the outcome measure. Therefore, we can state that a town experiencing an oil price shock of $70 and being 200 km away from the primate city can compensate this loss when having internet available in comparison to a not connected but otherwise identical city.

Both studies include only coastal countries.

# 8 Policy implication

The rollout of new infrastructure is always expensive. Therefore, policy makers might think of saving money and only rolling out this infrastructure where the effects of this infrastructure payoff the costs of the rollout. Our study comes in at this point. We showed that even smaller towns that were connected incidentally are growing faster than comparable towns without access points to make internet available. Therefore, first, it is important to account for these smaller towns when evaluating the benefits of an infrastructure. Second, one can derive from our results that the internet has growth potential not only for economic and political centers but also for smaller towns. The effects of internet are not bound to a high uptake. Hence, we recommend to rollout this infrastructure further even when only a low uptake is expected. We believe that even a small uptake by some firms generates external effects for the whole town. Moreover, of course, the internet might have further effects on educational or political outcomes. Hence, there might be other reasons to connect the whole country which are not targeted in this study.

# 9 Conclusion

Digital infrastructure is a key precondition for locations to harvest digital dividends from Internet connectivity. We investigate if the availability of even basic Internet speeds fosters economic development in developing countries. In particular, we study the arrival of the first sub-marine Internet cables (SMCs) in 10 Sub-Saharan African (SSA) countries in the 2000s. To learn about the causal effect of basic Internet on local economic growth, we compare economic activity—measured by nighttime light satellite data—of towns connected to the national Internet backbone at the time of SMC arrival to a control group of similar towns not (yet) connected to the national digital infrastructure.

We find that the connection of towns to the world wide web, on average, leads to an increase in light intensity of about 7%, relative to similar towns not (yet) connected. This translates into 2 percentage points higher growth in terms of GDP. Moreover, we differentiate growth in more pixels, where towns increase in their area (extensive margin), and in a higher average of the light intensity, which is associated with a higher density of economic activity (intensive margin). We find that towns with Internet availability due to access to digital infrastructure typically grow on both margins, i.e. become brighter and geographically bigger. Further, our results suggest that this growth is partly driven by growing populations in connected towns.

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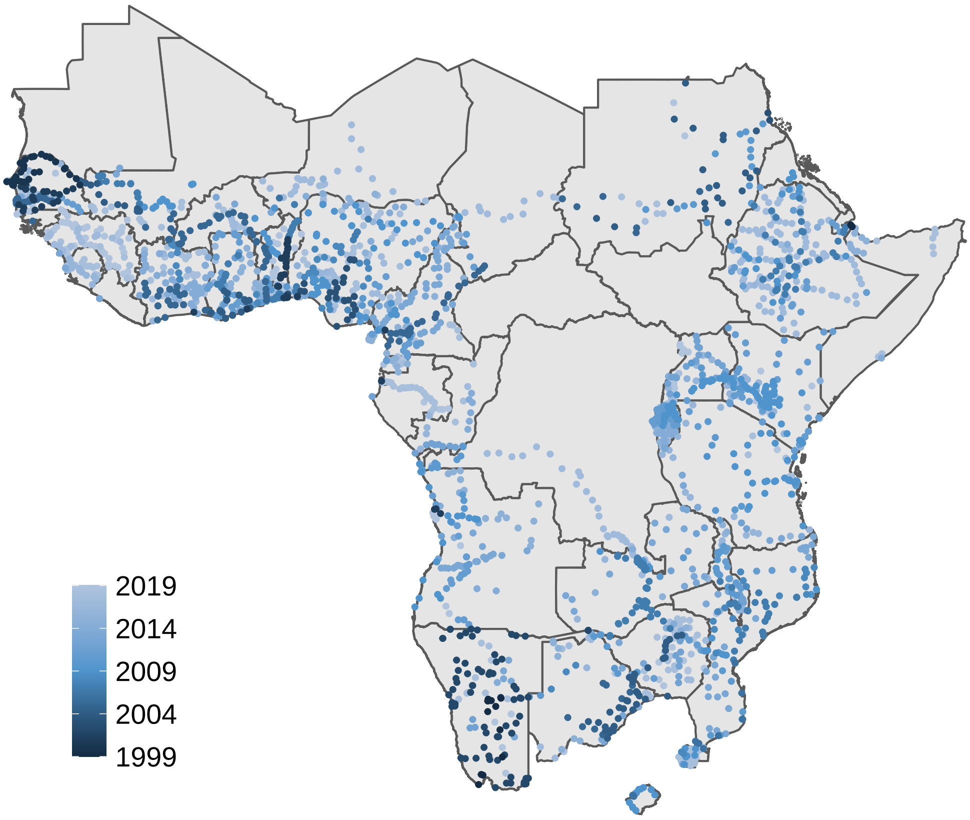
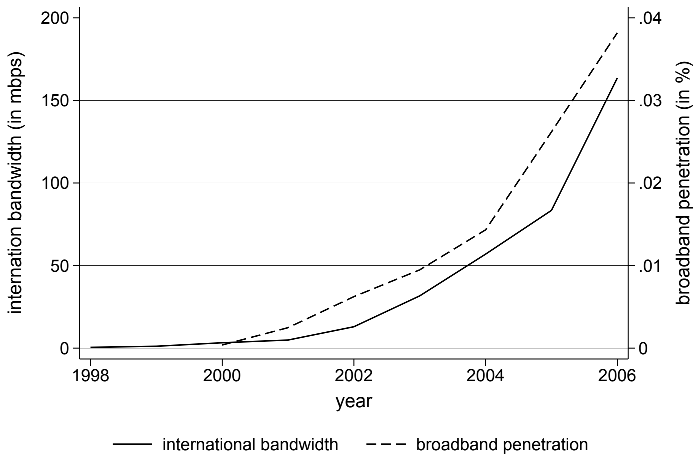
# A Appendix: Figures

**Figure A.1:** Access points and their construction years



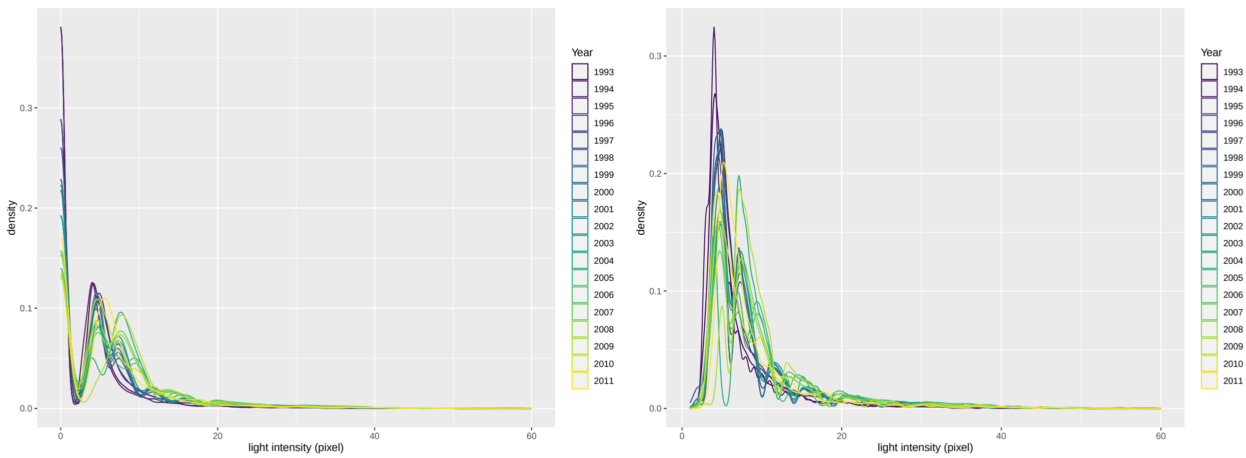

*Notes:* The figure depicts the location and construction date of all SSA access points. Brighter blue dots correspond to later constructed APs.

**Figure A.2:** International Bandwidth and Broadband Penetration




*Notes:* Data was sourced from ITU.

**Figure A.3:** Distribution of pixels' light intensity by year

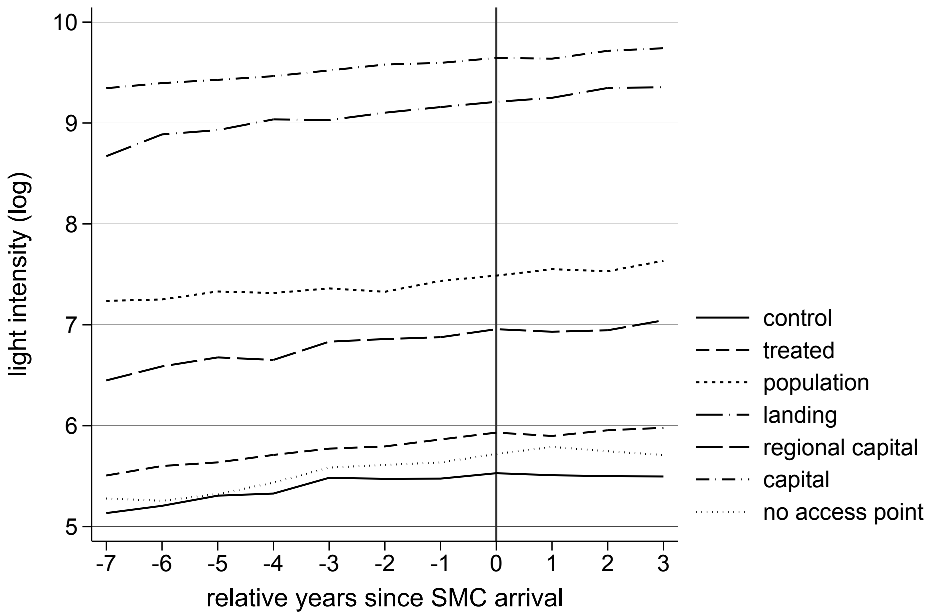



**(a)** including non-lit pixels

**(b)** excluding non-lit pixels

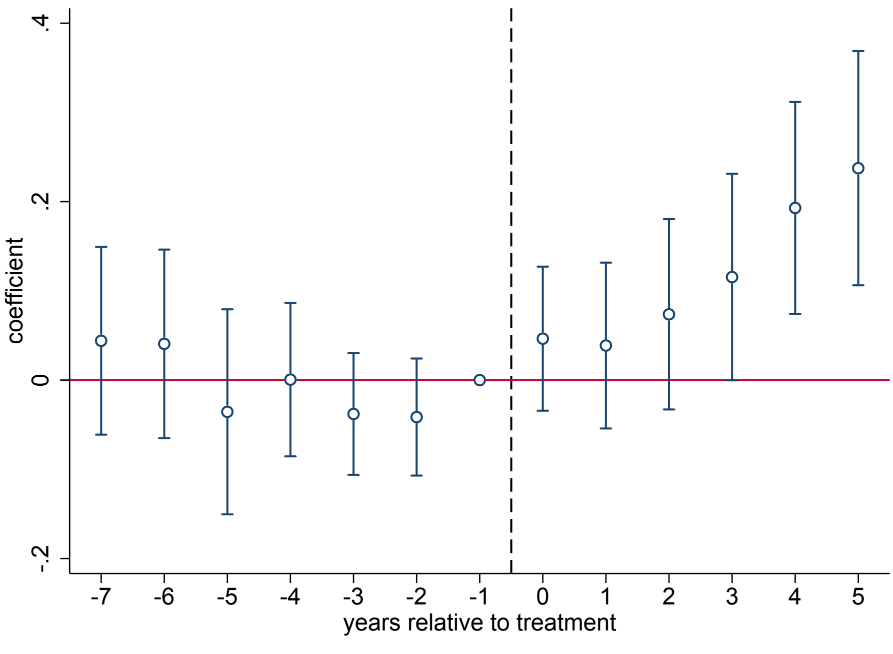
*Notes:* Each figure depicts kernel density plots pixels' light intensities by year.

**Figure A.4:** Time trends by city type



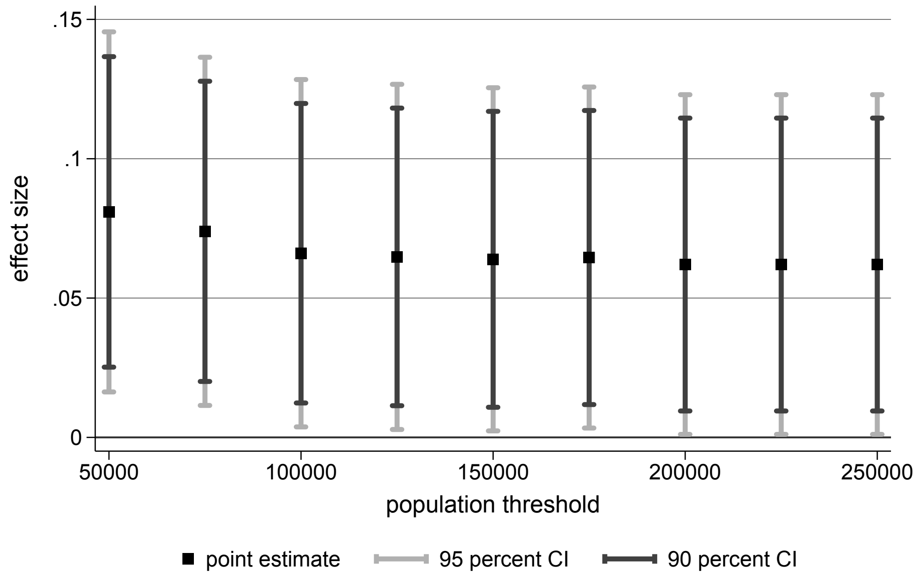

*Notes:* The figure depicts the average growth of all types of cities before and after the treatment year. The measurement is the logarithm of light intensity.

**Figure A.5:** Event-study coefficients with longer post-treatment period



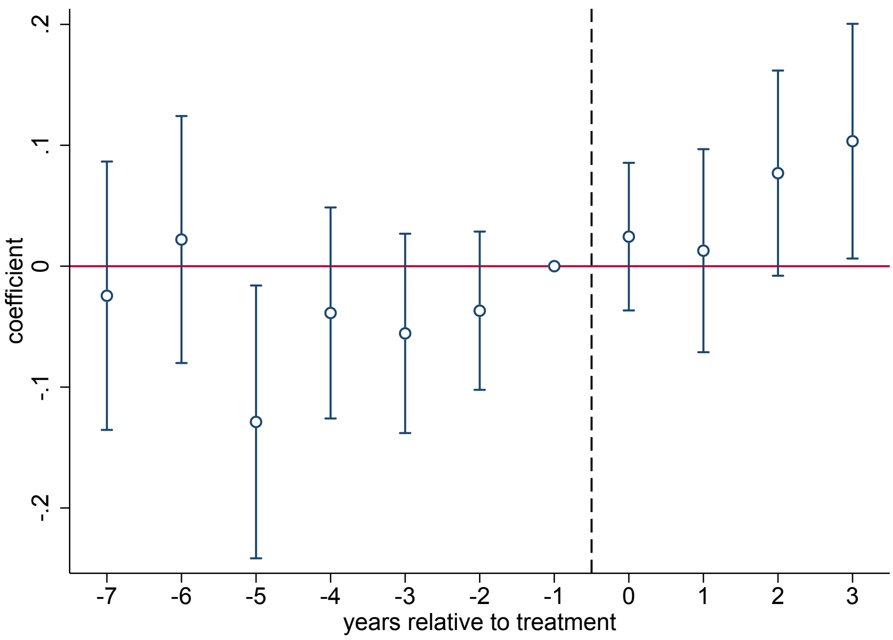

*Notes:* Coefficients for event study specification of Column 2 from Table 4. Robust standard errors clustered by town for 95% confidence interval reported as bars.

**Figure A.6:** Robustness nodal cities



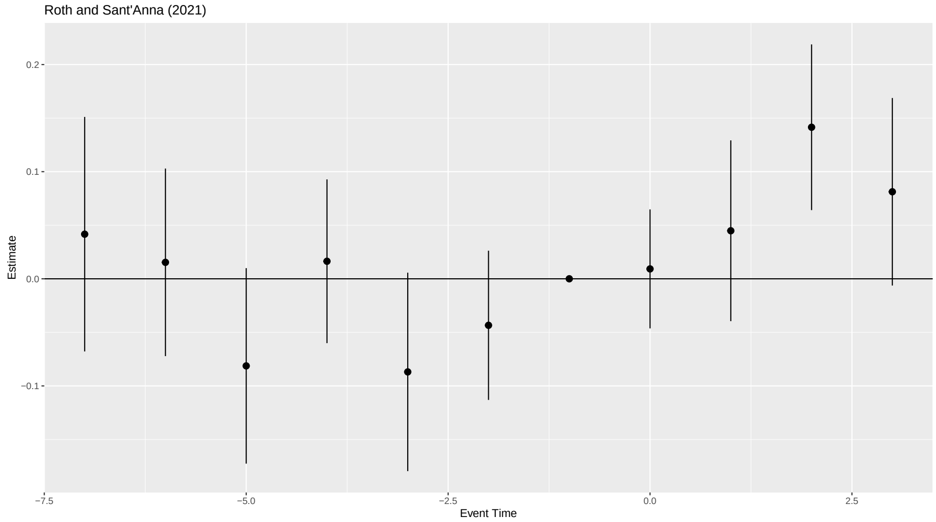

*Notes:* Variation of population thresholds are shown. Coefficients for the specification of Column 5 from Table 1. Robust standard errors clustered by town.

**Figure A.7:** Robustness event study (external validity)



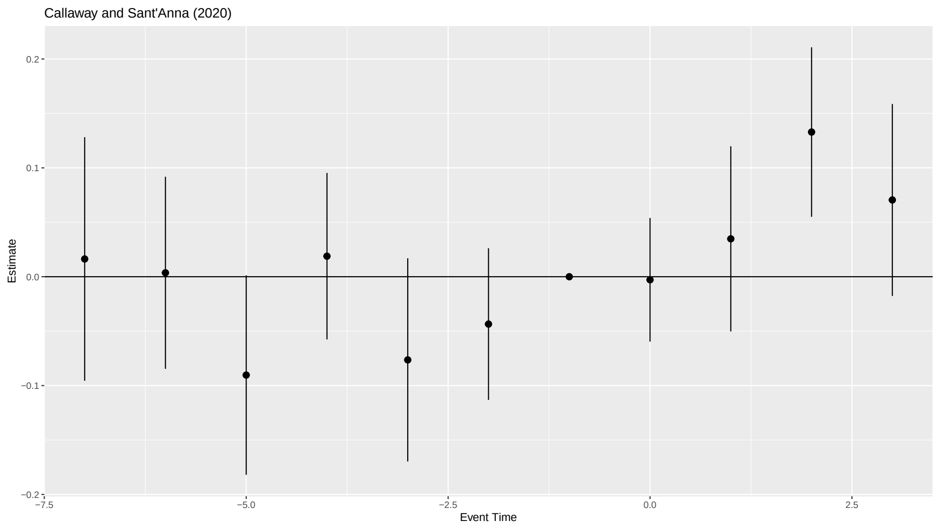

*Notes:* XX

**Figure A.8:** Robustness event study (external validity)



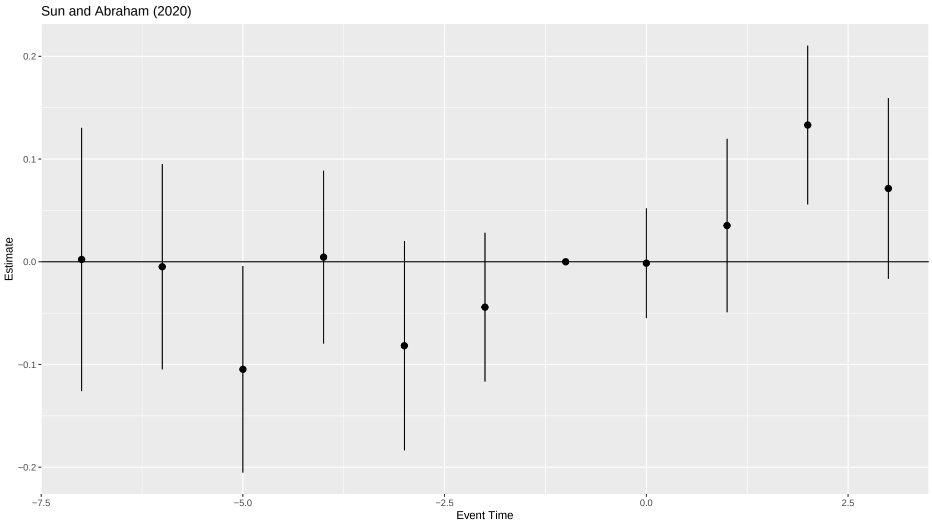

*Notes:* Staggered adoption, applying Roth and Sant'Anna (2021)

**Figure A.9:** Robustness event study (external validity)



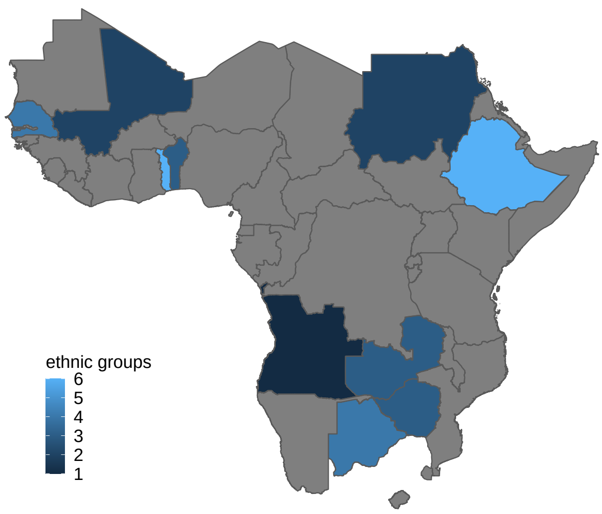

*Notes:* Staggered adoption, applying Callaway and Sant'Anna (2020)

**Figure A.10:** Robustness event study (external validity)




*Notes:* Staggered adoption, applying Sun and Abraham (2020)

**Figure A.11:** Ethnic groups




*Notes:* The figure shows for each SSA country in our analysis how many different ethnic groups were provided with at least one AP before the arrival of a SMC. Brighter blue colors indicate more different ethnic groups. Gray indicates countries not included in our analysis.

# B Appendix: Tables

**Table B.1:** Connection years

| Country | Connection year | Connected by | SMC landing point | Upgrade year |
|---|---|---|---|---|
| Namibia | 1999 | Neighboring country | | 2012 |
| Djibouti | 1999 | Sub-marine cable | Djibouti City | 2009 |
| Senegal | 2000 | Sub-marine cable | Dakar | 2010 |
| Angola | 2001 | Sub-marine cable | Sangano | 2012 |
| Benin | 2001 | Sub-marine cable | Cotonou | 2012 |
| Ghana | 2001 | Sub-marine cable | Accra | 2010 |
| Cameroon | 2001 | Sub-marine cable | Douala | 2012 |
| Gabon | 2001 | Sub-marine cable | Libreville | 2012 |
| Nigeria | 2001 | Sub-marine cable | Lagos | 2010 |
| Ivory Coast | 2001 | Sub-marine cable | Abidjan | 2010 |
| Sudan | 2003 | Sub-marine cable | Port Sudan | 2010 |
| Mali | 2004 | Neighboring country | | 2010 |
| Botswana | 2004 | Neighboring country | | 2009 |
| Zimbabwe | 2004 | Neighboring country | | 2011 |
| Burkina Faso | 2005 | Neighboring country | | 2010 |
| Togo | 2005 | Sub-marine cable | Lomé | 2012 |
| Gambia | 2005 | Sub-marine cable | Banjul | 2012 |
| Chad | 2005 | Neighboring country | | 2012 |
| Central African Republic (CAR) | 2005 | Neighboring country | | 2012 |
| Guinea-Bissau | 2005 | Sub-marine cable | Suro | 2012 |
| Mozambique | 2006 | Sub-marine cable | Maputo | 2009 |
| Lesotho | 2006 | Neighboring country | | 2010 |
| Niger | 2006 | Neighboring country | | 2012 |
| Malawi | 2007 | Neighboring country | | 2010 |
| Ethiopia | 2007 | Neighboring country | | 2012 |
| Zambia | 2007 | Neighboring country | | 2011 |
| Swaziland | 2008 | Neighboring country | | 2009 |

*Notes:*The table reports the connection years of all SSA countries being connected before 2009. Source: *Submarine Cable Maps* and *Africa Bandwidth Maps*.

**Table B.2:** Summary Statistics

| VARIABLES | (1) mean | (2) sd | (3) min | (4) p25 | (5) p50 | (6) p75 | (7) max | (8) N |
|---|---|---|---|---|---|---|---|---|
| population | 20,581.39 | 17,933.61 | 0.00 | 8,501.50 | 16,019.00 | 30,114.00 | 82,602.00 | 220.00 |
| distance to any regional capital | 85.45 | 80.54 | 1.67 | 26.98 | 66.57 | 129.70 | 407.28 | 220.00 |
| distance to the capital | 231.65 | 203.73 | 1.67 | 75.81 | 170.73 | 355.42 | 987.20 | 220.00 |
| distance to the coastline | 426.58 | 307.37 | 0.00 | 154.25 | 427.69 | 632.76 | 1,175.48 | 220.00 |
| distance to next river | 56.84 | 56.65 | 0.00 | 15.16 | 43.99 | 86.89 | 411.27 | 220.00 |
| distance to next port | 195.34 | 272.67 | 8.23 | 28.40 | 74.31 | 177.52 | 1,207.12 | 75.00 |
| distance to the road network | 2.58 | 12.07 | 0.00 | 0.00 | 0.00 | 0.00 | 112.57 | 220.00 |
| distance to the railroad network | 57.26 | 96.44 | 0.00 | 0.00 | 3.80 | 82.08 | 440.13 | 220.00 |
| distance to the electricity grid | 13.44 | 40.58 | 0.00 | 0.00 | 0.00 | 3.80 | 350.51 | 220.00 |
| number of lit pixels | 43.35 | 33.26 | 1.00 | 24.00 | 35.00 | 53.00 | 288.00 | 220.00 |
| summed light intensity | 463.04 | 529.12 | 21.00 | 161.50 | 285.00 | 530.50 | 4,026.00 | 220.00 |
| average light intensity | 7.50 | 5.97 | 0.26 | 3.22 | 5.25 | 10.07 | 29.38 | 220.00 |
| GSM coverage | 0.62 | 0.47 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 | 220.00 |
| distance to next AP in 2019 | 1.26 | 2.52 | 0.00 | 0.00 | 0.00 | 1.21 | 9.43 | 220.00 |

*Notes:* The table reports summary statistics of the estimation sample.

**Table B.3:** Robustness: Competing infrastructure

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| post x treated | 0.0703** | 0.0631* | 0.0647* | 0.0766** | 0.0942** | 0.0753** | 0.0733** | 0.0729** | 0.0903** |
| | (0.0349) | (0.0345) | (0.0349) | (0.0371) | (0.0376) | (0.0357) | (0.0356) | (0.0368) | (0.0375) |
| GSM coverage | 0.0486 | 0.0449 | 0.0477 | 0.0482 | 0.0463 | 0.0481 | 0.0480 | 0.0440 | 0.0450 |
| | (0.0342) | (0.0341) | (0.0341) | (0.0342) | (0.0340) | (0.0342) | (0.0343) | (0.0342) | (0.0340) |
| Road network (in 100km) | | -0.197 | | | | | | -0.198 | |
| | | (0.215) | | | | | | (0.211) | |
| Road network (dummy) | | | 0.0928 | | | | | | 0.104 |
| | | | (0.0768) | | | | | | (0.0757) |
| Railroad network (in 100km) | | | | 0.0112 | | | | 0.0102 | |
| | | | | (0.0213) | | | | (0.0222) | |
| Railroad network (dummy) | | | | | -0.0624 | | | | -0.0657 |
| | | | | | (0.0385) | | | | (0.0406) |
| Electricity grid (in 100km) | | | | | | 0.0415 | | 0.0335 | |
| | | | | | | (0.0495) | | (0.0526) | |
| Electricity grid (dummy) | | | | | | | -0.0227 | | -0.00718 |
| | | | | | | | (0.0391) | | (0.0405) |
| Observations | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 | 2,420 |
| R-squared | 0.943 | 0.943 | 0.943 | 0.943 | 0.943 | 0.943 | 0.943 | 0.943 | 0.943 |
| #countries | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| #cities | 220 | 220 | 220 | 220 | 220 | 220 | 220 | 220 | 220 |
| share treated | .445 | .445 | .445 | .445 | .445 | .445 | .445 | .445 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o population ¿100k | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

*Notes:* Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

**Table B.4:** Robustness: External validity

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| post x treated | 0.0620** | 0.0712** | 0.0833** | 0.0888** | 0.0938*** |
| | (0.0263) | (0.0282) | (0.0325) | (0.0345) | (0.0343) |
| GSM coverage | | | | | 0.0415* |
| | | | | | (0.0237) |
| Observations | 5,401 | 5,170 | 4,048 | 3,872 | 3,872 |
| R-squared | 0.963 | 0.947 | 0.936 | 0.916 | 0.916 |
| #countries | 19 | 18 | 18 | 17 | 17 |
| #cities | 491 | 470 | 368 | 352 | 352 |
| share treated | .334 | .309 | .307 | .287 | .287 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Year FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | | | ✓ | ✓ | ✓ |
| w/o population ¿100k | | | | ✓ | ✓ |

*Notes:* Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

**Table B.5:** Robustness: Connected control towns

| VARIABLES | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| post x treated | 0.277*** | 0.267*** | 0.115* | 0.121** | 0.111** | 0.110** | 0.107** | 0.0980** | 0.0700* | 0.0625* | 0.0703** |
| | (0.0999) | (0.1000) | (0.0604) | (0.0538) | (0.0480) | (0.0471) | (0.0457) | (0.0458) | (0.0401) | (0.0378) | (0.0349) |
| GSM coverage | 0.0758 | 0.0790 | 0.0947* | 0.102** | 0.0696 | 0.0688 | 0.0687 | 0.0682 | 0.0592 | 0.0520 | 0.0486 |
| | (0.0642) | (0.0598) | (0.0528) | (0.0480) | (0.0428) | (0.0427) | (0.0422) | (0.0421) | (0.0398) | (0.0382) | (0.0342) |
| Observations | 1,265 | 1,364 | 1,573 | 1,650 | 1,793 | 1,804 | 1,837 | 1,848 | 2,123 | 2,233 | 2,420 |
| R-squared | 0.954 | 0.951 | 0.950 | 0.950 | 0.949 | 0.949 | 0.949 | 0.949 | 0.944 | 0.944 | 0.943 |
| #countries | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| #cities | 115 | 124 | 143 | 150 | 163 | 164 | 167 | 168 | 193 | 203 | 220 |
| share treated | .852 | .79 | .685 | .653 | .601 | .598 | .587 | .583 | .508 | .483 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o population ¿100k | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| backbone border | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |

*Notes:* Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

**Table B.6:** Robustness: Light intensity (absolute)

| VARIABLES | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| post x treated | 318.6*** | 79.87*** | 56.50*** | 42.99** | 44.74*** |
| | (111.4) | (23.00) | (19.72) | (17.26) | (17.19) |
| GSM coverage | | | | | 12.25 |
| | | | | | (14.63) |
| Observations | 3,190 | 3,069 | 2,563 | 2,420 | 2,420 |
| R-squared | 0.987 | 0.979 | 0.986 | 0.963 | 0.963 |
| #countries | 10 | 10 | 10 | 10 | 10 |
| #cities | 290 | 279 | 233 | 220 | 220 |
| share treated | .493 | .473 | .468 | .445 | .445 |
| City FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| Country x Year FE | ✓ | ✓ | ✓ | ✓ | ✓ |
| w/o capital+landingpoint | | ✓ | ✓ | ✓ | ✓ |
| w/o regional capitals | | | ✓ | ✓ | ✓ |
| w/o population ¿100k | | | | ✓ | ✓ |

*Notes:* Light intensity is measured as the sum of light intensities of DMPS-OLS pixels within town area. GSM mobile phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100k inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.