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

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Abstract

Does internet availability, even at basic speeds, foster local economic growth in developing countries? We analyze 220 towns in 10 Sub-Saharan African (SSA) countries in the early 2000s and measure local economic growth of towns using nighttime light satellite data. In a difference-in-differences setting, we exploit quasi-random variation in internet availability induced by sub-marine cable arrivals. 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 towns connected only later. This result seems to be driven mainly by per capita productivity growth and only to a small extent by migration into connected towns. Moreover, internet availability is accompanied by a shift from agriculture to manufacturing in regional employment shares.

Keywords: Internet, regional development, towns, nighttime light, Sub-Saharan Africa

JEL-Codes: O33, O18, R11

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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 (Hamilton Research, 2020). Facebook recently announced an effort to build a new internet-enabled sub-marine cable (SMC) 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).

Lacking legacy infrastructure (i.e., fixed-line telephony networks) to build on makes the provision more complex and costly. Despite these enormous investments, a growth effect of Internet in SSA is less obvious than it seems. 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 and especially besides capitals and economic centers.

In this paper, we ask if there is a causal effect of internet availability on overall local economic growth (economic activity) in SSA even at basic speeds. We focus on the initial introduction of Internet in SSA through the first wave of internet-enabled SMCs starting in the early 2000s. To investigate if potential individual-level effects matter for the economic development of entire localities, we conduct our analysis at the town level. We observe changes in the spatial expansion of towns (extensive margin) and in their density of economic activity (intensive margin) and interpret these components as pointing more towards population or productivity growth, respectively. Furthermore, we corroborate this suggestive evidence on mechanisms by directly looking at changes in population and in the industry composition.

With the notable exception of Hjort and Poulsen (2019), who find sizable positive individual-level effects of a internet speed upgrade on employment in SSA between 2009 and 2012, causal evidence on the economic impact of internet availability in developing countries is surprisingly rare.[1] This is the first study investigating the causal effect of internet availability at basic speeds on overall local economic growth in developing countries, which is measured by nighttime light (NTL) satellite data. This measure allows to capture the

[1] See Hjort and Tian (2021) for a comprehensive overview of the current state of literature on the effects of internet connectivity in developing countries.

evolution of towns in 10 SSA countries which get international internet connection before the internet speed upgrade and which rolled out a national backbone. Furthermore, we study early Internet effects in a rural developing country setting with no pre-existing fixed-line telephony network, low penetration rates, and labor-intensive local economies.

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 SMCs in SSA in the early 2000s. This approach was established by Hjort and Poulsen (2019), who exploit an internet speed upgrade induced by SMCs with higher capacities between 2009 and 2012. In a difference-in-differences setting, we make use of the rollout of the national backbone, which makes Internet available through access points (APs), to define treatment and control group towns: First, we focus on incidentally connected towns which are located between nodal cities (political and economic centers). These towns are relatively small and are primarily connected due to their fortunate location. Second, we assign treatment status to towns that were already connected to the national backbone through an AP when the Internet became available nationwide, while our control group consists of similar towns which get an internet connection through an AP only some years later. In a two-way fixed effects (TWFE) model with town and country-year fixed effects, we then compare the growth of towns with Internet access at the time when broadband internet at basic speeds becomes available nationwide for the first time to a control group of similar towns getting access only later.

We tap two main data sources. First, for local economic activity in SSA towns, we use NTL intensity captured by satellites, a well-established proxy introduced by Henderson et al. (2011) on the country level and validated by Storeygard (2016) on the city level for SSA. To get the local town-level measure, we assign NTLs to individual agglomerations by linking lit pixels to built-up areas of SSA cities and towns from *Africapolis*. Second, town-level internet availability is determined using data on the location of APs to the national backbone (Hamilton Research, 2020). Because data on the location of APs in Africa only starts in 2009, we backdate the establishment year of APs to their actual construction year via an extensive review of national backbone deployment projects for each SSA country.[2]

We find that connection to the Internet through an AP leads on average to a 7 percent increase in NTL intensity of SSA towns in the years after nationwide connection compared to a control group of similar towns not connected through an AP at that time. Applying the established light-to-GDP elasticity from Henderson et al. (2012) this translates into about 2 percentage points higher economic growth. Our key identifying assumption is that treatment and control group towns would have evolved similarly in the absence of treatment. Although this assumption cannot be tested for to hold, we perform a dynamic event-study specification of our model to show that there are no differences in pre-treatment trends of economic activity between treatment and control group towns. The event-study results are robust to accounting for heterogeneous effects

[2]In some cases we were not able to determine the exact establishment year. However, we could identify all APs that were established until the year in which Internet became available nationwide for the first time and backdate they establishment year to that year.

in the staggered timing of the treatment using recently proposed estimators by Roth and Sant'Anna (2021), Callaway and Sant'Anna (2020), and Sun and Abraham (2020).

We then differentiate between growth in the average brightness of lit pixels, which is associated with a higher density of economic activity in the towns (intensive margin), and growth in the number of lit pixels, indicating a spatial expansion of towns (extensive 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 yields a small positive coefficient and reduces the main effect only slightly, suggesting that the observed growth is only partly driven by migration. Moreover, we find a shift in regional industry shares. In connected regions, manufacturing employment shares increase by around 2.5 percentage points in comparison to regions getting connected later. These shares are mainly substituted by agricultural employment, though this coefficient is not statistically significant. This suggests that the increase in economic activity is at least partly a result of a changing industry structure induced by internet availability.

To ensure that our results are in fact driven by internet availability, we control for the rollout of mobile-phone coverage (GSM) and perform placebo tests with other potentially confounding infrastructure, such as roads, railroads, and the electricity grid.[3] Moreover, we test the robustness of our results to alternative assumptions about the variance-covariance matrix. Finally, we extend the sample by relaxing some assumptions to assure the external validity of our results.

The paper proceeds as follows. The related literature is discussed in Section 2. In Section 3, we provide a brief overview of the early Internet in SSA and give an example of its rollout in Benin in Section 4. Section 5 lays out the empirical strategy and in Section 6 the data and spatial methods are described. Results are presented in Section 7. Section 8 discusses our results in comparison with related research. Section 9 concludes.

2 Literature review

We contribute to two main strands of the literature. First, we add to the broad literature assessing the impact of infrastructure on economic outcomes. For developing countries, Hjort and Tian (2021) give an overview of the effects of internet connectivity, dividing this literature into supply-side and demand-side mechanisms and overall impact of connectivity. Our study is, to the best of our knowledge, the only one investigating the overall impact of internet availability on local economic growth. Most closely related to our work is Hjort and Poulsen (2019), who study the employment effects of broadband Internet on an individual level. They

[3] At the time we are investigating, all countries only had basic mobile-phone coverage enabling calls and SMS but not surfing the Internet. Specifically, 3G coverage was not existing. For the potentially confounding infrastructure, we do not have time-varying data and can moreover not be sure that roads and railroads were existing prior to the rollout of the national backbone. However, as we know that the rollout followed this infrastructure we take the existing data for the placebo exercise. Finally, the electricity grid data we have is from 2007.

find a skill-biased and net positive employment effect for an Internet speed upgrade in SSA around 2010. 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 and for an overall measure of economic activity as well. We further show that internet availability even at basic speeds and in a setting with low adoption rates benefits regional economic development.

For developed countries, the effect of 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 effects of broadband Internet 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 and widely used digital device. Jensen (2007) shows that the adoption of mobile phones by fishermen and wholesalers in Kerala, India, 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 phones 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, for example 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. Assessed infrastructure includes transportation infrastructure (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 of 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 growth unchanged but a positive effect on levels, and Faber (2014) even finds a decrease in 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.

3 Background

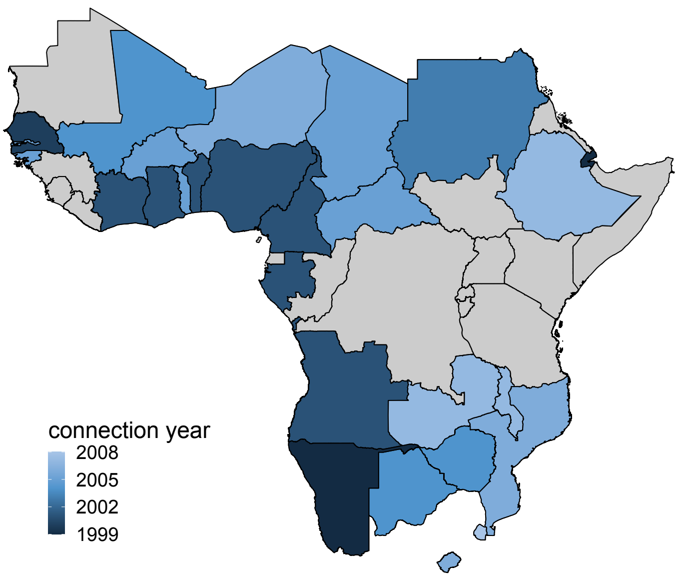
There are three major components of Internet infrastructure determining availability and bandwidth of Internet in a given location. First, international fiber-optic sub-marine cables (SMCs) connect SSA countries to the global Internet backbone.[4] Second, within-country inter-regional fiber-optic cables 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.

[4]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.

3.1 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 SMCs landed on SSA shores, the only way to connect to the Internet on the continent was via satellite.[5] 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— an internet connection was first brought to SSA at a noticeable scale.

Figure 1: Sub-marine cable connection years



Notes: The figure shows SSA with all countries getting an internet connection before 2008. The color gradient depicts the connection year (darker blue colors indicate earlier initial SMC connection years). Gray indicates countries not connected to the Internet until 2008.

As shown in Figure 1, the first wave of internet-enabled SMCs arrived in SSA countries only in the early 2000s. These 'first-generation' cables had the capacity to provide Internet at basic speeds.[6] The biggest of them was SAT-3 and started operating in 2001. It featured landing points on the shores of eight SSA countries on the western coast of Africa.[7] These landing points—typically one per country—constitute

[5]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.

[6]Hjort and Poulsen (2019) state that SSA users had on average 430 kbps before the second generation of SMCs arrived.

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

the starting point for the respective national backbones (cf. Section 3.2). Until the late 2000s, most SSA countries were connected to the Internet via these 'first-generation' SMCs.[8]

Landlocked countries are only indirectly connected through SMCs. They rely on their neighboring countries which connect them through a national backbone. The rollout of these inter-regional (fiber-optic) cables is explained next.

3.2 National backbone: inter-regional cables

After being routed through an SMC, internet traffic travels through the national backbone. The national backbone infrastructure consists of inter-regional (fiber-optic) cables. Therefore, as soon as a new SMC arrives at a landing point of a SSA country, Internet becomes available countrywide 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 backbones were continuously improved and expanded in parallel with the installation of SMCs.[9] This backbone expansion focused heavily on connecting economically and/or politically important locations ("nodal cities") since they feature the largest market potential (high population density and GDP per capita).[10] This often lead to a backbone evolution where the national capital (often a coastal city and located closely to the landing point) was connected first. Then, the backbone 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 constructed 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 got internet access as well due to their fortunate location between two nodal cities. Our empirical strategy (cf. Section 5) focuses on these incidentally connected towns which get an internet connection because of their on-route location next to an inter-regional cable but are not nodal cities themselves.

3.3 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 APs (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 countries which rely heavily on

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

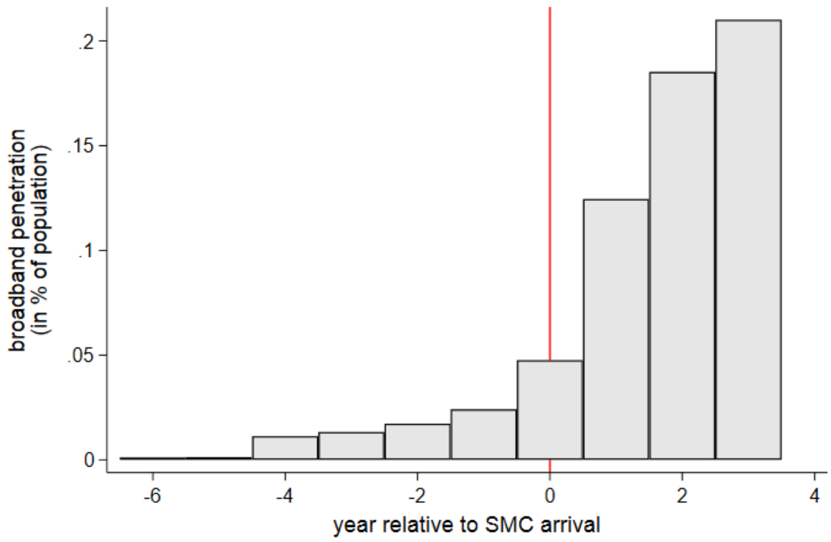
[9]Many of these cables were constructed decades ago as part of the telegraph and telephone infrastructure and were only later used for the transmission of early Internet traffic. They typically have been installed by the national telecom. Each country typically has an own, self-contained backbone.There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

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

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 2 shows how the usage increases in countries that were served by a first generation SMC. Though,the change in absolute numbers is rather low (.2 percentage points), one can notice that the increase starts when the Internet becomes available. Although broadband usage is low among the population, broadband penetration in firms might be completely different. Unfortunately, we do not have data on broadband adoption of SSA firms. However, the *World Bank Enterprise Survey* shows even before the second generation of SMCs landed on SSA shores that 52 percent of all firms used email for communication and 23 percent had an own website.

Figure 2: Arrival of SMCs and broadband adoption



Notes: International capacity is calculated from SMC capacities and assigned to each country by using population-weighted shares. Measures are calculated relative to the establishing year of the internect connection in each country and then aggregated via taking the weighted mean. Weights are population size in 2010.

4 The case of Benin

This section gives an overview of one example, how the national backbone 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 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).

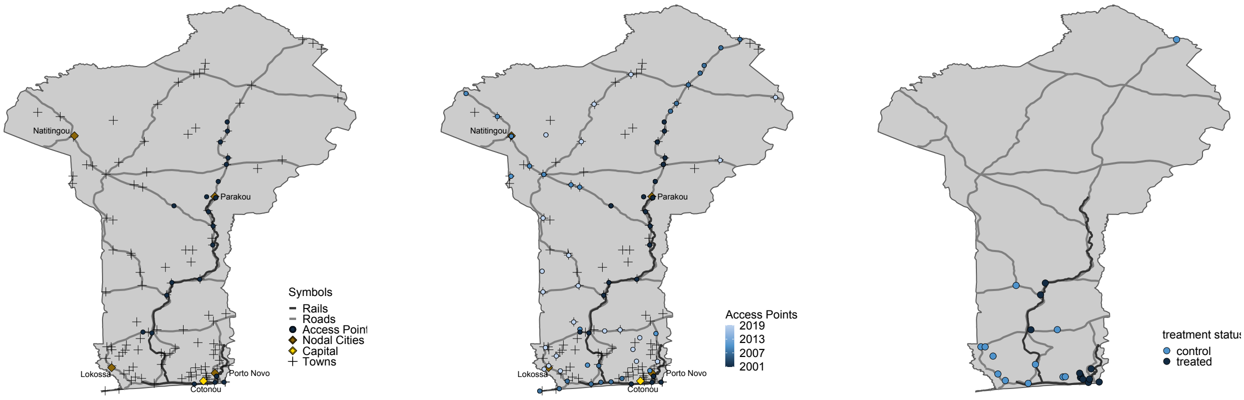
Following Chabossou (2007), the SAT-3 SMC landed in Cotonou, Benin's biggest city, the location of the seat of government, and 40 km away from Benin's capital, Porto-Novo. Close by, in Abomey-Calavi Benin's hub is located as well. These cities form with Godomey Benin's largest agglomeration with nearly 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 constructed 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 3) 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-optic backbone and access points (APs) 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.[11] 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 commercial clients (banks, hotels, ministries etc.) in packets.[12] 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 percent of people in Benin's population have used the internet at least one time. Access is mainly at cybercafes (21 percent) or at the workplace (2.2 percent) while internet at home remains a luxury. Though,

[11] 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.

[12] 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.

Figure 3: Rollout in Benin



(a) APs in 2001 **(b)** All APs **(c)** Treatment/control group

Notes: The figure outlines the rollout of APs in Benin. Besides APs, the maps include the capital city, nodal cities, and all towns. Railroads and roads are included as well. In the left panel, the early rollout with APs being constructed until the arrival of the SMC in 2001 is shown. The middle panel depicts further APs and their respective construction years. The right panel shows the towns of your analysis divided into treatment and control group.

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.

5 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 a distinct feature 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 nationwide for coastal countries, to investigate the effect of internet availability. Following Hjort and Poulsen (2019), we argue that the exact timing of SMC arrival is essentially random.[13] For each individual SMC, it is exogenous to national planners when exactly it is put into operation and starts providing an international internet connection. This is, first, because each SMC typically connects many countries. Therefore, coordination difficulties among consortium members

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

might delay the construction.[14]. Second, the connection years are highly uncertain due to unforeseen delays in construction. For example, the cable EASSy was delayed by five years due to coordination difficulties among consortium members (Poppe, 2009). Moreover, a country's geographical location within SSA can influence the connection year. First, Eastern and Western SSA countries get independently their respective SMCs. Second, landlocked countries get their connection through the national backbone of their neighboring countries and rely therefore on the construction speed of another country's national backbone. This construction speed again is exogenous for the respective landlocked country.

We estimate the effect of early Internet at basic speeds and exploit the arrival of the first generation of SMCs. When the next generation with higher capacities arrives, starting in 2009, countries immediately get a speed upgrade. Therefore, we estimate on a sample containing only years for which countries did not receive a speed upgrade yet. Due to the staggered timing of the upgrade SMC, this sample is unbalanced. To estimate on a balanced sample, we restrict the estimation to three post-treatment years.

This enables us to use a difference-in-differences (DiD) design. We compare towns that already have access to the national backbone when Internet becomes available nationwide to a control group of similar towns getting an access point (AP) in later years (first difference) before and after the country's internet connection (second difference). The definition of towns in the treatment and control group is depicted in Figure A.2. 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 AP today. Moreover, towns being connected in the three years under observation after the internet became available nationwide are excluded from the control group as well as they would contaminate the control group. They do not get the full treatment and would thereby confound our analysis. We exclude nodal cities, i.e. cities close to an AP that are endogenously connected (cf. Section 3.2): the landing point, the capital, regional capitals, and economic centers (cities with a population of more than 100,000 inhabitants). Hence, we focus our analysis on incidentally connected towns that are very similar to each other in key characteristics such as size and infrastructure. Since national backbones are self-contained and (coastal) countries have own landing points 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. For robustness, we vary the threshold of 100,000 inhabitants as the definition of an economic center, we include towns to the treatment group by the year they get an AP, and vary the last possible year of connection for the control group, such that treated towns are not compared with very late connected towns.

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

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

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

where y_{ict} is economic growth of town i in country c in calendar year t as proxied by nighttime light (NTL) measured by satellites (cf. Section 6). In most specifications, we apply the logarithm to estimate changes in the growth rate instead of changes in levels. The dummy variable $connection_{ct}$ indicates if country c has access to the Internet nationwide in calendar year t. The variable $access_{ic}$ is one if town i in country c is located within 10 km distance to an AP that was established in the year of the Internet became available nationwide or before. Contrary, the indicator is zero if town i in country c is located close to an AP that was established in the years afterwards. Thus, the interaction term $connection_{ct} \times access_{ic}$ indicates internet availability in town i in country c in calendar year t. The coefficient of interest is β_1. It captures the effect of internet availability on local economic growth. $\boldsymbol{X}_{ict}$ contains time-varying control variables, such as mobile-phone coverage (GSM). We include two types of fixed effects into the model. Time-constant differences across towns are captured by town fixed effects α_{ic}. Differences across calendar years common to all towns within a country are absorbed by country-year fixed effects δ_{ct}. Note that this allows for country-specific time trends and variations in satellite sensor quality over years. ε_{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 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 analyze the dynamic impact of internet availability on local economic activity using an event-study design:

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

where t_j indicates the year relative to treatment year, i.e. the year when the Internet became available nationwide, 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 β_{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.

As a number of recent contributions have pointed out, two-way fixed effect (TWFE) event-study (or DiD) approaches, similar to the specification in Equation (2), may still yield biased estimates when treatment effects vary over time (see e.g., Athey and Imbens, 2021; de Chaisemartin and D'Haultfœuille, 2020; Borusyak et al., 2021; Goodman-bacon, 2019; Sun and Abraham, 2020). The main reason is that the TWFE estimator uses already-treated towns as control group for newly-treated towns, causing a violation of the parallel trend assumption in the presence of treatment effect dynamics. This cannot happen when applying more rigorous fixed effects. If country-year fixed effects are applied, there is only one treatment (the year the international internet connection was established). However, we can relax the fixed effects. To account for the following threat to identification, we also perform alternative approaches proposed by Callaway and Sant'Anna (2020), Roth and Sant'Anna (2021), and Sun and Abraham (2020). For instance, Callaway and Sant'Anna (2020) suggest a two-step estimation strategy by first estimating 'group-time average treatment effects', where groups are defined by when towns are first treated, before aggregating the treatment effects by relative time using a propensity-score weighting method.

6 Data and spatial methods

We analyze the effect of internet availability on local economic growth in SSA. 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. 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) or via neighboring countries. This section describes the data sets we use, the processing steps we apply, and shows descriptive statistics relevant for our analysis.

6.1 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.

Since geographically and chronologically granular data on economic activity in SSA is lacking—especially for the period we investigate—we deploy 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 radiomet-

[15] https://africapolis.org

ric 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.

Our analysis is focused on rather small towns. These towns might not be precisely measured by the satellites' instruments. In fact, for very small towns we observe that they are not bright enough to reach the instruments' sensitivity threshold in each year. We therefore remove towns which do not have positive light intensity in all years. Thus, we reduce measurement error and additionally the sample loses the very small towns. If towns are visible in all years, we can additionally be sure that they have stable electricity available. So, we can rule out a potential source which might confound our results.

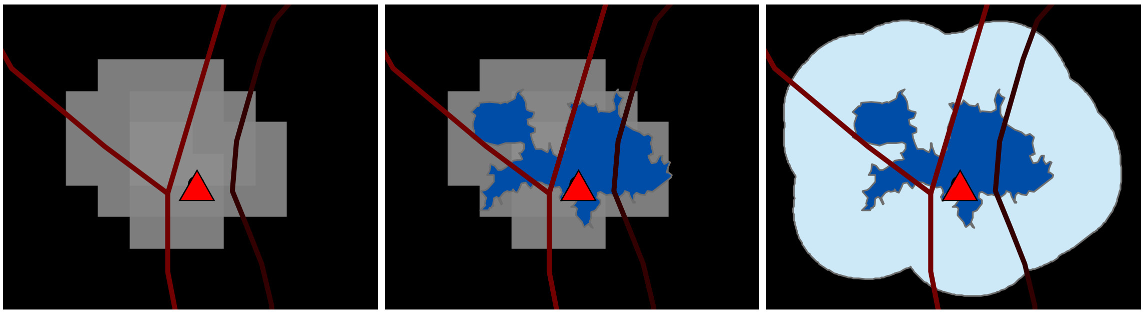
As light blurs out to adjacent pixels, cities appear bigger in the data than they actually are. By taking the extent of the towns in 2015, we capture some of the blurring as the towns might have been growing after our observation period. However, for some towns, the NTLs still might blur over the extent of the built-up areas. Therefore, we account for blurring by adding a radius of 2 km to the built-up area, such that the growth of light emissions in the extensive margin is properly captured.[16] 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). In our sample, less than 2 percent of pixels are assigned light intensities of 60 or more.

Figure 4 shows for Dassa-Zoumè, Benin, its NTL emission, built-up area, and infrastructure. A road and a railroad connecting Dassa-Zoumè with its neighbouring cities (red and darker red 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 2004 (three years after the nation-wide internet connection and at the end of the analysis period), where a brighter gray reflects higher light intensity. Panel (b) adds Dassa-Zoumè's built-up area from *Africapolis*. It shows that the blurring of the NTLs exceeds the built-up boundaries. Therefore, we

[16] For robustness, we also show the results using different radii on the built-up areas, including a specification without a radius.

draw a buffer of 2 km around the area (shown in Panel(c)). This allows us to take all light emissions into account.

Figure 4: Data example: Dassa-Zoumè, Benin (2004)



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

Notes: Panels (a)-(c) show our data for Dassa-Zoumè, Benin, in 2004. Dassa-Zoumè is in the treatment group as one of the incidentally connected towns. Panel (a) shows the access point existing in 2001 (red triangles) and NTLs for the year 2004 (three years after the connection year of Benin). The access point lies within the towns boundaries. The red line represents a major road connecting Dassa-Zoumè with its neighbouring cities and the darker red line the railway connection. 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 darker blue). Finally, Panel (c) shows in blue a 2 km buffer around that built-up area.

Within each town, we define several outcome measures.[17] Local economic activity is measured by summing the light intensity of all pixels within a town (and the 2 km buffer) in each year. This measure was established by Storeygard (2016) and accounts for both increased light intensity and geographical extension. As alternative measures, we calculate the average light intensity of pixels and the sum of all lit pixels, ignoring light intensity. We interpret the average light intensity as a proxy for density in terms of population or per capita economic activity (intensive margin) and the sum of lit pixels as a proxy for spatial extension of a town (extensive margin). For an example treatment town and for an example control group town, Figure A.3 shows how their respective NTLs have changed from the year of the internet connection to three years later.

6.2 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 for coastal countries from *Submarine Cable Map*.[18] We geo-coded the landing point to merge it to the respective built-up area. If the connection was established through a neighboring country, we assign the establishment year of a country border AP to the national fiber-cable backbone as the treatment year. The geo-locations of the APs and their respective establishment years come from *Africa Bandwidth Maps*.[19] Figure A.1 shows a map

[17] As specified in Section 5, we apply the logarithm of each outcome measure.
[18] https://www.submarinecablemap.com
[19] http://www.africabandwidthmaps.com

of all APs and their rollout. Table B.1 shows the country-specific connection years for all SSA countries that were connected before 2009. In the last column, the year of the speed upgrade through the next SMC is shown. These SMCs had a lot higher capacities and landed in SSA between 2009 and 2012.

Africa Bandwidth Maps contains the most comprehensive set of APs for Africa. It 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 backbone 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. Note that it was not always possible to determine the exact year of construction. However, in these cases, it was still possible to determine which APs were established in the year the the nationwide Internet connection was established, which is still sufficient for our analysis. This makes it possible to identify which towns already had access to the national fiber-cable backbone when the Internet became available for the first time. 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.[20]

6.3 Further data sources

We use the share of the area a town has mobile-phone coverage as control variable for the rollout of an alternative digital infrastructure.[21] The data is sourced from *Collins Bartholomew*.[22] Though, since the early 2000s the new mobile-phone standard became 3G, none of the countries in our analysis has rolled out 3G. Therefore, mobile-phone coverage in our data refers to GSM (2G) which allows for basic applications (calls and SMS) but not for mobile internet.

From *OpenStreetMap (OSM)*, we take the definition of nodal cities. Capital cities and region capitals are marked there. For the definition of economic centers we take the population in the year 2000 from *Africapolis*. As time constant measures of infrastructure, we take shapefiles for roads and railroads from *Natural Earth (NE)*. *Africa Infrastructure Country Diagnostic (AICD)* provides a shapefile for the electric grid in the year 2007.

We examine changes in industry shares as a mechanism for the internet growth effect. We aggregate census microdata from *IPUMS-International* to a regional level of second order.[23] For the industry shares, the data contains whether the employment is in agriculture, manufacturing, or services. The data comes usually every ten years. Therefore, we estimate a long difference with one pre-treatment and one post-treatment period.

[20] 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 established 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.

[21] The share is usually either 0 or 1.

[22] https://www.collinsbartholomew.com/

[23] The admin-2 level is below the state level.

6.4 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 countries, which are listed in Table B.1. Among the first countries that were connected 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, where an SMC landed in 2000. In 2001, seven more countries were connected by a single SMC, the SAT-3 cable. In the following years until 2008, 17 more countries got an SMC connection or were connected through a neighboring country.

However, not all countries that were connected until 2008 had constructed 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 access right after the connection. This reduces the number of countries in our analysis to 23.[24] Moreover, eleven countries established only in nodal cities APs before Internet became available nationwide.[25] Therefore, there are no towns in the treatment group and we cannot estimate on these countries. Finally, we cannot consider Namibia in our analysis because it did not construct further APs after getting the Internet connection. 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. Malawi and Mozambique only have two post-treatment years. They were connected in 2007 and 2006, respectively, and got upgraded by an SMC with more capacity in 2010 and 2009, respectively. Thus, only three years lie between the first connection to the Internet and the internet capacity upgrade for both countries. Hence, estimating on a balanced sample with 3 post-treatment years leaves us with a sample of 10 countries.[26] A longer post-treatment period would shrink the sample further. Therefore, we estimate the main specification with 3 post-treatment years. For robustness, we will relax these restrictions.[27]

6.5 Descriptive statistics

For the estimation sample in the balanced panel, Figure A.4 shows the geographical distribution and the location of the treatment and control group towns without the nodal cities. There are four countries in

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

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

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

[27]The first connected country in our sample is Senegal, which was connected in 2000. Therefore, we are less restricted in the pre-treatment period and do not lose any country there.

West Africa and Southern Africa, respectively, and two countries in East Africa in our sample. Of the ten countries, five are coastal and five are landlocked.[28]

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. Of these agglomerations, 70 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 102 towns were connected in the three years after the nationwide internet connection and are therefore not considered as they would confound our control group.

Figure A.5 compares the average size of cities and towns by the year they get an AP, relative to the treatment year. In the early years, until the Internet becomes available nationwide, many nodal cities are connected besides the towns in the treatment group. While connected nodal cities are bigger on average in the early years and decline in their size in subsequent years, towns in the treatment group only have a population of around 20,000 inhabitants on average. Control towns, which are connected in the subsequent years after the observation period of three years, vary for all subsequent years around a population of 20,000 inhabitants as well. Especially, when only examining treated and control towns, i.e. excluding nodal cities, there is no clear (decreasing) pattern with respect to population size over time anymore as there is clearly for nodal cities. This suggests that treated towns are not selected into treatment because of their population size. Importantly, nodal cities are still connected in further years after the arrival of the first internet connection, showing that the rollout continues to other parts of the country. Their size decreases after the first two years as capital cities are usually connected early and are usually a lot bigger than other nodal cities. Nonetheless, the size of later connected nodal cities is still bigger 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). For 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

[28]Sudan is a special case as ten towns are in the control group but only one town is in the treatment group. We account for that by grouping fixed effects for East, Southern, and West African countries for robustness.

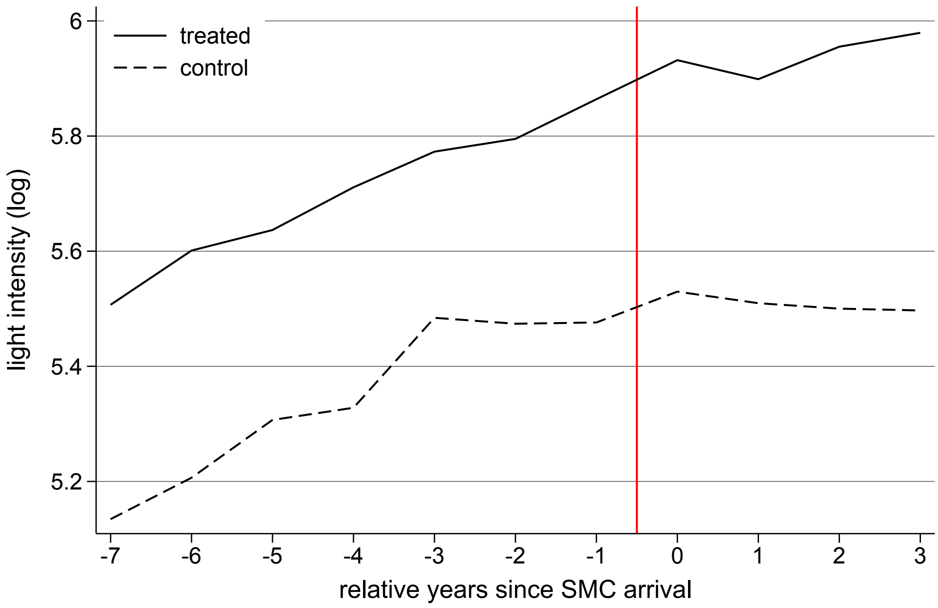
the closest AP is with 9.43 km smaller than 10 km. On average, this distance is a lot smaller with 1.26 km. More than half of the towns have an AP even within the built-up area and most cities have it within 2 km (1.21 km at the 75th percentile).

The distances to further infrastructure, such as the road network, railroad network, or electricity grid, are 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 different groups but do not include any fixed effects or controls. We focus on the treatment and control group only. Figure 5 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. One reason for the stagnation might be a general decrease in economic growth induced by the increasing oil price from the mid-2000s to 2008, which was then followed by the international financial crisis. Another reason could be measurement error in the date of the AP construction year. This measurement error would be biased towards earlier years and might explain the increase in t-3 and t-2. Finally, while the gap between treatment and control group towns is almost equal in t-7 and t-1, at the end of the observation period, the gap between these towns grew by about .1 from about .4 to about .5 on the logarithmic scale. Figure A.7 shows a similar trend for the GDP per capita growth before and after the internet connection was established. However, the growth seems to take off later (only two years before the internet connection was established).

Figure A.6 shows the GDP per capita growth rates of the ten countries before and after the Internet became available nationwide. In general, there is a positive trend for most of the countries. Only Zambia shows a lower growth after an internet connection was established. However, this growth might not be distributed equally over all agglomerations. Figure A.9 shows how different nodal cities are from the towns in the analysis. Moreover, one can see that the group of *other towns*, which do not get APs, is very similar to the treatment and control group. With respect to the growth rates of nodal cities and towns (Figure A.8) one can see that for all groups but the economic centers, annual growth rates declined after the internet connection. Moreover, one can take again from Figure A.8 that before the internet connection all town types had a similar annual growth rate. However, when Internet became available, treated towns showed an a lot larger growth rate than control group towns.

Figure 5: Time trends of treatment and control group



Notes: The figure depicts the average growth of the towns in the treatment and control group over a period of 11 years (7 before and 3 after the treatment year). The measurement is the logarithm of light intensity.

7 Results

7.1 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. Besides town fixed effects, country-year fixed effects are used and standard errors are clustered at the town level. We measure economic activity by the logarithm of the sum of light intensities as the main outcome. We discuss other outcomes like mean light intensity (intensive margin) and sum of lit pixels (extensive margin) in Subsection 7.3.

Table 1 shows the main results. In Column (1), the most basic specification, nodal cities and the landing point are still included. We then stepwise eliminate nodal cities until we reach our preferred specification where the remaining towns are comparable. In Column (2), we remove the city of the landing point and the national capital. In Column (3), we also remove regional capitals. In Column (4), we further 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)) to account for other (tele-)communication technologies.

In line with our expectations, we find an economically and statistically positive effect of Internet at basic speeds on local economic growth. From Columns (1) to (5), the nodal cities are dropped column by column.

Therefore, the number of cities we estimate on, decreases from 290 to 220 towns. Hence, 70 nodal cities are dropped. As only nodal cities are removed, which mostly have an AP, the share of treated towns on the overall population decreases from 49.3 to 44.5 percent. We find a slightly increasing effect size, that is 5 percent for the whole sample and increases to 7 percent for our preferred specification without nodal cities. For bigger cities, the estimate is less precisely estimated as other factors might influence economic development. For these cities, and especially for capital cities, no counterfactual exists in the control group. Especially, nodal cities are bigger on average, both in comparison to other treatment and control group towns. Hence, they differ in levels and therefore possibly have lower growth rates.

In our preferred specification (Column (5)), towns which were connected to the Internet in the year of an SMC arrival become 7 percent brighter than towns without internet availability. This finding supports our initial claim that towns which get incidentally connected to the Internet growth faster in comparison to otherwise comparable towns. The mobile coverage control is statistically insignificant and smaller in size. It makes the estimation more precise as it controls for differences in another telecommunication technology. As it slightly increases the point estimates of the main effect, we are not worried that the main effect is in fact transported through mobile coverage. But we will discuss this issue later in Section D.

We translate the found effect in terms of light intensity to an approximation of the implied economic effect, by a back-of-the-envelope calculation using the GDP-luminosity elasticity from Henderson et al. (2012). Henderson et al. (2012) show that growth in light intensity serves as a good approximation of economic development at the country level. The elasticity remains robust for a global sample as well as a sample of low and middle income countries. Storeygard (2016) further shows that the elasticity at the country level is if anything slightly higher for SSA countries and for coastal primates. Moreover, he shows that the elasticity holds at the sub-national level as well. We follow his argumentation that the elasticity in SSA could be lower as countries have lower light intensities on average or that the elasticity could be higher as SSA finds fewer top-coded cities. Both issues are specifically the case in our sample. We therefore use the elasticity of $\varepsilon_{GPD,light} = 0.284$, for which the calculation translates the increase in light intensity of 7 percent into about 2 percentage points higher GDP growth.

7.2 Event study

For our preferred specification (Column (5)), Figure 6 presents event-study coefficients on the same periods we have a balanced panel. We cannot estimate this effect for a longer time period as second-generation SMCs arrive in the years after the 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. Before SMC connection, the point estimates are close to zero and statistically insignificant. This supports the assumption that treatment and control group towns are not of different growth parts preceding the SMC arrival, conditional on fixed effects. In the year of the SMC arrival, the point estimate turns positive but remains statistically insignificant until year three. In the years after SMC arrival, the point estimates are between .05 and .1 and have a

Table 1: The effect of Internet on economic growth of towns

	(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
#towns	290	279	233	220	220
share treated	.493	.473	.468	.445	.445
town FE	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
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 and a 2 km buffer. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

slight tendency to increase to nearly .15 in year three after the connection, when the effect gets statistically significant at the 5% level. The increase of the effect over time is inline with the expectation that internet adoption takes time to increase after the connection and that the effect could be induced by spillovers and not only by the adopting firms directly.

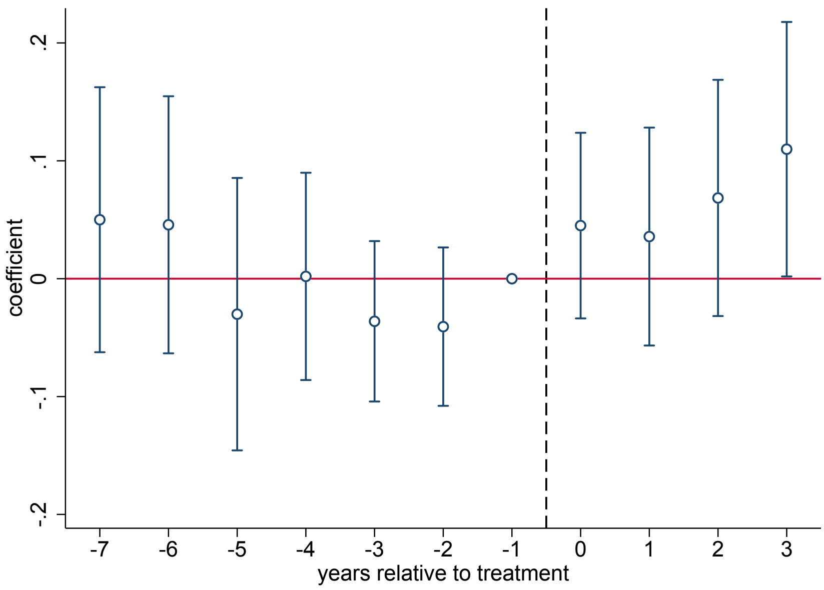
7.3 Mechanism

Next, we analyse what drives the effects. Therefore, we first investigate the effects of the intensive and extensive margin of regional growth and the relation to population growth. Second, we show how internet availability affects the industry composition and that these changes might be a channel through which internet availability affects regional economic growth.

7.3.1 Population, Intensive, and Extensive Margin

Next, we investigate the intensive and extensive margin of regional development. Therefore, we take the mean luminosity (Table 2, Columns (3) and (4)) and the sum of lit pixels (Table 2, Columns (5) and (6)) as outcome measures. The main outcome, the sum of luminosity, is shown again (Table 2, Columns (1) and (2)). All outcomes are logged. In odd columns, we estimate the specifications as in Column (5) of Table 1. Hence, the sample is identical as well in all columns. In even columns, we add the population as a control. By doing so, we control for which part of the effect is driven by economic growth and which by growth in population.

Figure 6: Event-study coefficients



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

The observed increase of towns having internet available in light intensity can thus be explained by both an increase in brightness (Columns (3) and (4)) and in size (Columns (5) and (6)). While towns' light intensity increases by 7 percent, their brightness increases by 5 percent and their size increases by 5 percent as well. However, while the effect on the intensive margin is statistically significant at the 5% level, the effect on the extensive margin is only statistically significant at the 10% level and shows slightly higher standard errors at a slightly lower point estimate. Adding population as a control, the main effect remains robust and statistically significant. Population has an elasticity of .4 on light intensity. The coefficient of the population control is positive and statistically significant at the 10% level (Column (2)). Therefore, the effect of internet availability is mainly inducing an economic development and not showing a population growth. While the main effect is similar for the intensive and the extensive margin, the effect of population is different. For the intensive margin, the effect of population is smaller and statistically insignificant (Column (4)). On the other hand, the population effect is positive and statistically significant for the extensive margin (Column (6)). Again, the main effect remains robust when adding population as a control. This suggests that towns increase in their size due to an increase in population. But that they also increase in their light intensity, which reflects an increase in productivity.

Table 2: Population, intensive, and extensive margin

	combined		intensive		extensive	
	(1)	(2)	(3)	(4)	(5)	(6)
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
#towns	220	220	220	220	220	220
share treated	.445	.445	.445	.445	.445	.445
town FE	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓
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 and a 2 km buffer as in Table 1. The measure for the intensive margin is logarithmic mean light intensity and for the extensive margin logarithmic sum of pixels (coded as 1 if a pixel is lit). 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 *Gridded Population of the World* (gpw). All specifications are estimated on a sample restricted by excluding landing-point cities and capitals, regional capitals, and cities with more than 100,000 inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7.3.2 Industry

Next, we can show how the regional industry composition changes when the Internet becomes available. We use survey data from IPMUS International, a collection of census microdata, to calculate the share of jobs in certain industries (agriculture, manufacturing, and services). As we rely on survey data, we focus our analysis on changes in the industry shares. In the Appendix, we will also discuss changes in levels, though they might depend more strongly on the survey selected individuals. The data contains surveys for 20 SSA countries from which 12 countries were connected by an SMC in 2008 or earlier. For most countries, there are two levels of subnational regions available to which we can merge the built-up areas. However, the survey does not cover all regions. For each country, only a very limited number of years is available as for most countries data is available with a frequency of 10 years. Therefore, we estimate a long difference with one survey year before the arrival of the SMCs and one afterwards. However, not all countries have survey data from a pre-treatment year. On the other hand, allowing for surveys close to the connection year, we can estimate also on countries that were connected late (in 2006 and 2007), for which the upgrade induced by second generation SMCs came shortly after the first connection. The treatment is defined as above. Hence, we remove nodal cities and define a region as treated if a a town in that region has an AP close by by the year an SMC lands. Figure A.10 shows the changes descriptively.

The results in Table 3 indicate that internet availability shifts jobs from agriculture to manufacturing and services. In Columns (1) to (3), we estimate on five countries and 91 towns. The share of jobs in agriculture declines by around 5 percentage points. In contrast, job shares in manufacturing and in services increase each by around 2 percentage points. In Columns (4) (6), we estimate on the countries from our main analysis. Here, the decrease in agriculture jobs is with around 6 percentage points even bigger. Consequently, the substitution to manufacturing and services is with 3 percentage points greater as well. This is inline with Hjort and Poulsen (2019), who finds an increase in employment in Ethiopian manufacturing firms and an increase in net firm entry in services.

Table 3: Employment growth rates and shares by industry

VARIABLES	(1) total	(2) agriculture	(3) manufacturing	(4) services	(5) agriculture	(6) manufacturing	(7) services
post x treated	0.00927	-0.0896	0.278**	-0.0209	-0.0276	0.0257**	0.00191
	(0.0917)	(0.144)	(0.131)	(0.127)	(0.0341)	(0.0108)	(0.0278)
Observations	114	114	114	114	114	114	114
R-squared	0.948	0.936	0.953	0.931	0.938	0.930	0.932
#countries	3	3	3	3	3	3	3
#regions	57	57	57	57	57	57	57
share treated	.281	.281	.281	.281	.281	.281	.281
region FE	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓

Notes: Regional industry composition comes from *IPMUS International* survey. All specifications are estimated on a sample restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100,000 inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7.4 Placebos and permutation tests

7.4.1 Placebo tests with nondigital infrastructure

In Table 4, we include additional controls. As was shown in Figure 3, APs usually are constructed along other infrastructure. In the case of Benin, this infrastructure is railroads and major roads. But also more generally, to save costs fibre cables are rolled out along existing infrastructure (cf. Section 3.2). We control for this other infrastructure to rule out that towns closer to this nondigital infrastructure grow faster when the SMC arrives, irrespective of whether they are in the treatment or the control group. 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. We follow two approaches to define placebo treatments. First, we control for the linear distance of the town to the next greater (paved) road (Column (2)), to the next railroad (Column (4)), and to the next electricity grid (Column (6)). Second, 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)). Column (1) shows our preferred specification without further infrastructure controls as baseline.

In each case, the estimate of the main effect remains close to .07 and statistically significant. 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 and slightly higher than in the baseline. The estimates of the placebos are all statistically insignificant and very small in their economic significance. Moreover, the point estimate of mobile coverage remains robust when including any infrastructure placebo.

Table 4: Robustness (competing infrastructure)

	(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
town FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓	✓
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 and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Railroad and road networks are source from *Natural Earth*. The electricity grid is sourced from *Africa Infrastructure Country Diagnostic*. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7.4.2 Placebo tests with permuted connection year

We identify a causal effect under the assumption the the connection year of each country is exogenous. In the event-study plots, it was already shown that the effect only starts after the connection year. As a placebo test, we now assign permuted connection years to all countries (prior to the actual connection year). So, we re-estimate Equation (1) with connection years from 2000 (the earliest in the connected countries) to 2007 (the last year for which we can estimate before the speed upgrade). We also shift the rollout of the APs by the same number of years as the actual connection date was shifted. Column 1 in Table 5 assigns the year 2000 to all countries in the analysis. It contains all 10 countries and 220 towns as no country in the data was connected before the year 2000. If we re-estimate Equation (1) with the connection year 2000, the effect is not statistically significant anymore and the point estimate is very close to zero. When re-estimating

Equation (1) with any connection year after 2000, some countries drop as they were connected before. The effect is only once statistically significant at the 10 percent level and in all other cases statistically insignificant. This indicates that the connection years are exogenous. We perform different specifications of this placebo exercise: First, we estimate on all countries instead of only the ten countries we have in the analysis (Table B.3). We next shorten the pre-treatment window, such that we can run the exercise with placebo connection years before 2000. We do this again for the ten countries in our analysis and for all countries (Table B.4 and B.5). Finally, we extend the post-treatment window as with earlier placebo connection years we can estimate with a longer post-treatment period (Table B.6 and B.7). In none of the specifications the estimate is statistically significant. In fact, only one in 50 estimates is statistically significant at the 10 percent level.

Table 5: Placebo (connection years)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
post x treated	-0.00700	-0.0110	-0.0607*	-0.0207	0.00539	0.0341	0.0390	0.0352
	(0.0387)	(0.0408)	(0.0353)	(0.0407)	(0.0438)	(0.0637)	(0.0549)	(0.0486)
GSM coverage	0.0188	0.0372	0.0329	0.0536	0.0683	0.0903	0.0690	0.0230
	(0.0394)	(0.0381)	(0.0396)	(0.0423)	(0.0449)	(0.0733)	(0.0698)	(0.0610)
Observations	2,420	2,145	1,771	1,771	1,650	836	781	781
R-squared	0.936	0.940	0.948	0.947	0.951	0.930	0.927	0.930
#countries	10	9	7	7	6	3	2	2
#towns	220	195	161	161	150	76	71	71
share treated	.445	.4	.404	.404	.427	.447	.423	.423
town FE	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓	✓
placebo connection	2000	2001	2002	2003	2004	2005	2006	2007

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

7.5 Robustness

Different fixed effects As explained above, we apply country-year fixed effects to account for country-specific growth paths in their economies. For robustness, we re-estimate Equation (1) including the classical two-way fixed effects: towns and calendar years. This specification is less demanding in the set of fixed effects. The estimate presented in Column (2) of Table B.8 remains robust. However, the estimate of the control variable GSM coverage turns statistically highly significant. In Subsection 7.6, we estimate further models with classical two-way fixed effects which allow for a bigger sample containing more countries and estimate novel DiD/event-study designs (Roth and Sant'Anna, 2021; Callaway and Sant'Anna, 2020; Sun and Abraham, 2020).

Error Correlation within regions Another potential concern is that model errors are correlated within regions. This might be the case when the effects of the AP might generate further spillover effects in the town's surrounding area. In theory, it could also be the case that one AP serves more than one town, if both towns are located within 10 km to the AP. In our preferred specification, we cluster the standard errors at the town level as the treatment, the access point construction, is occurring there. To take this into account, we apply a higher level of clustered standard errors as robustness. We re-estimate Equation (1) correcting standard errors for clusters at the level of states. Column (3) presents the estimates with a higher level of clustered standard errors. The standard error of our variable of interest increases only very slightly.

Linear time trends In Column (4), we also test the robustness of our results against the inclusion of linear time trends on the town level. To account for possible differential trends among towns, we re-estimate Equation (1) including a linear town-specific yearly trend. This is the most demanding specification. The estimate even increases slightly to .10 and is also statistically significant at the 5% level. Thus, we can show that after the SMC arrival, the connected towns grow in a nonlinear manner.

APs during the post-observation period Thus far, we have tested the robustness of our results to alternative assumptions about the variance-covariance matrix. In Column (5), we include towns that were connected only within three years after the SMC landed. In our main specification, these towns were excluded as they neither belong clearly to the treatment nor the control group and would thus confound our analysis. Including them, we count them as treated when they get an AP and therefore have internet available right away. Thus, for these towns, the treatment year is equal to the construction year of the AP and not of the SMC connection year. With this approach, we can add them without confounding our analysis. However, for these towns the assumption of the exogeneity of the treatment might not be valid anymore. Therefore, they are not included in the main specifications. However, for robustness, we investigate how including them affects our results. Moreover, within our 10 countries in the analysis, we can add further 37 towns to increase the estimation sample. We estimate Equation (1) as in our preferred specification with town and country-year fixed effects and cluster standard error at the town level. As the estimate remains, including slightly later connected towns does not affect the results.

No not treated towns In Column (6), we add to the control group also the towns which until 2019 do not have an AP. These towns are similar to the other towns in our analysis. However, they do not get an AP. Therefore, they are comparable to the control group as they cannot access the Internet when it became nationally available. At that time, it might not yet been known which towns will get an AP in the future.

While this sample increases to 349 towns, the share of treated towns declines to 28 percent. The estimation results remain unaffected.

No buffer In Column (7), we remove the 2 km buffer and estimate on the original *Africapolis* built-up areas. We adjusted the built-up areas because of the blurring of the NTL data. When going back to the smaller area, we might lose some pixels at the town's border. However, these pixels might be of low intensity. With this robustness check, we can thus not only show that our results do not depend on the adjustment of the built-up area but also that city growth does not predominantly happen at the city border. In fact, the estimate not only remains, but increases slightly to .08 and strongly statistically significant (at the 1% level).

Extending the post-treatment 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 6, 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 (Column (8)). 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, six countries still have internet at basic speeds available at the end of the new sample. The event study estimates are shown in Appendix Figure A.12 and indicate that the growth rate increases further to more than 20 percent.

7.5.1 Ethnic favoritism

A further concern could be that in the rollout specific 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 can show descriptively that many countries construct APs for more than one ethnic group before the treatment period (Figure A.14). This indicates that not a specific ethnic group is favored by giving them access to the Internet. For the countries in our analysis, all countries but Angola provided at least two different ethnic groups with APs. And Angola only established very few APs in total. Therefore, the low number of equipped ethnic groups is not surprising. On the other hand, Ethiopia and Togo provided internet access for even six different ethnic groups very early.

Second, we perform our analysis constructing country-ethnic group entities instead of countries. By estimate Equation (1) including town fixed effects and country-ethnicity-year fixed effects, treatment and control group towns are compared within an ethnic group. If ethnic favoritism were at play and would drive the found effects, our estimate should vanish as towns with certain ethnic groups should grow, and less importantly get an AP, while towns with other ethnic groups remain on a worse growth path. The results are shown in Column (7) of Table B.8. 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. Only in Botswana this is not the case. In the remaining nine countries, there are eleven ethnic groups and thirteen country-ethnic group entities in the estimation. The result remains robust, showing that even comparing treatment and control group towns of the same ethnic group, internet availability has a positive effect on local economic activity.

7.6 External validity

Applying the classical two-way fixed effect model of Column (2) in Table B.8, we can re-estimate Equation (1) on a broader sample. Comparing treatment and control group towns in the whole sample through the year fixed effect, we can allow also for countries containing either only control or treated towns. Table 6 repeats the step-wise selection of non-nodal cities from Table 1. With this approach, we estimate on 491 (including nodal cities) to 352 towns in 17 to 19 countries. In one country, only the capital (and/or the landing point) is connected, in another country only economic centers with more than 100,000 inhabitants are connected. It can be seen easily that this sample contains more control towns as countries which started later with the rollout are added primarily. In fact, the number of treated towns increases only by three from 98 to 101 in Column (5).

Comparing the results with the ones from the stepwise procedure in Table 1, the estimate of the main effect again increases slightly from Column (1) to (4) and also when adding mobile coverage as control variable in Column (5). Moreover, the estimates are slightly bigger, reaching an effect size of nearly 10 percent. In contrast, the estimates are statistically significant throughout all columns at the 5% level and at the 1% level in our preferred specification in Column (5). Here, the estimate of mobile coverage is statistically significant at the 10% level and positive with a medium sized point estimate. In comparison to Column (2) in Table B.8, where we applied the same fixed effects on the more restrictive sample, the estimate of the main effect increases by nearly .04 and is statistically significant at a higher level. The significance level of the mobile coverage control is lower. 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).

The event study graph shows parallel-trends before the treatment (Figure A.11). Especially in the four years prior to the treatment, the point estimates are close to zero. Only the estimate in year -5 is statistically significant at the 5% level and is strongly negative. This is not the case in the main specification in Figure 6, where all pre-treatment coefficients are statistically insignificant. After the treatment, both event-study estimates are very comparable. In both cases, the point estimate increases especially two and even more three years after the treatment and becomes statistically significant at the 5% level only in the last observation period. As in Table 6, the point estimates slightly exceed the ones in the main specification in post-treatment period.

Table 6: Robustness (external validity)

	(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
town FE	✓	✓	✓	✓	✓
year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
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 and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

One concern is this setting is that the classical two-way fixed effect estimator does not account for the staggered timing of the treatment and thus the potential heterogeneous effects of the individual treatment. Recent literature developed estimators for this setting (Roth and Sant'Anna, 2021; Callaway and Sant'Anna, 2020; Sun and Abraham, 2020). Figure A.13 shows event-study estimates for the respective estimators. All three approaches show very similar results. 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. In contrast to Figure A.11, only the point estimate of year 2 is statistically significant and the point estimate in year 3 also declines slightly in comparison to the year before. However, the point estimate in year 2 is bigger than in Figure A.11. Another differences to Figure A.11 is that in all three estimations only one pre-treatment estimate is statistically significant at the 5% level. Again, the point estimate in year -5 (in the approach by Sun and Abraham (2020)) is negative and statistically significant at the 5% level.

7.7 Heterogeneity: coastal countries

Storeygard (2016) investigates coastal countries due to the design of estimating on the distance to a primate city with a harbor. Hjort and Poulsen (2019) analyze coastal countries as they exploit the landing of SMC. So far, we have used the additional information about the connection year through a neighboring country we have on landlocked countries for estimating on a bigger sample. Nonetheless, one might have concerns about the validity of the exogeneity assumption of the timing of the connection year. Therefore, we reduce the sample one more time to estimate only on coastal countries for which the ground work for the identification is already been made by **?**. As being connected earlier, these countries moreover allow for a longer post-treatment period. However, therefore, heterogeneous effects cannot only be assigned to the countries' location, but might be rooted in the earlier connection years.

A priori, it might not be clear whether the Internet has different effects for coastal and landlocked countries and if it does, which geographic location profits more from an internet connection. Coastal countries are not necessarily more developed, in terms of their GPD per capita, than landlocked countries. Botswana has by far the highest GDP per capita. Nevertheless, one could argue that more developed countries have higher growth rates as some development has to be existing for the Internet to have an economic effect. On the other hand, less developed countries might have higher growth potential and the Internet could work as a substitute for worse nondigital infrastructure. In this case, countries could be leapfrogging and overtake more developed countries.

An advantage of investigating coastal countries separately is that they were connected earlier. Therefore, it is possible to investigate them with a long post-treatment period without allowing the upgrade SMCs to confound the results. Therefore, in Table 7 we re-estimate Equation (1) on a sample with five post-treatment years. For robustness, we also re-estimate Equation (1) on the original sample including only three post-treatment years (Table B.9). We estimate on five countries, which contain 75 towns in either the treatment or control group of which slightly more than half is in the treatment group. For coastal countries, the estimated effect is generally bigger than for the whole sample. In all specifications, the estimates are statistically significant at least at the 5% level. In our preferred specification, where we control for mobile coverage, the main effect is .27 (Column (5)). Table B.9 shows a similar pattern with however lower estimates.

Table 7: Heterogeneity (coastal countries)

VARIABLES	(1)	(2)	(3)	(4)	(5)
post x treated	0.195**	0.224***	0.265***	0.262***	0.271***
	(0.0761)	(0.0836)	(0.0874)	(0.0897)	(0.0884)
GSM coverage					0.102
					(0.0687)
Observations	1,313	1,248	1,040	975	975
R-squared	0.955	0.937	0.928	0.897	0.898
#countries	5	5	5	5	5
#towns	101	96	80	75	75
share treated	.515	.49	.525	.507	.507
town FE	✓	✓	✓	✓	✓
year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
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 and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

8 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 to 3.9 percent, implying a .9 to 1.5 annual per capita growth when internet penetration is increased by 10 percentage points (with penetration ranging between 13.5 percent in Greece and 37.2 percent 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. However, in our set-up 1999 to 2001 are also the first countries connected while many countries were connected (a lot) later. Two major differences are that we (i) cannot investigate broadband penetration and (ii) compare cities within countries and not 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.

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 and not across towns. Hence, though in both cases local economic activity is measured, the comparison is different. Finally, the selection of cities and towns differs slightly 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 the named differences. 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 similar positive effect on local economic growth.

Finally, we want to compare our results to Storeygard (2016) who also estimates local economic growth across cities. Though, not estimating the effects of a digital infrastructure, he is most closely related to our work regarding 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.

9 Conclusion

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

We find that the connection of towns to the World Wide Web, on average, leads to an increase in light intensity of about 7 percent, 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 productivity (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. Furthermore, our results suggest that this growth is only partly driven by growing populations in connected towns. So, the effect is mainly of an economic development and not a migration effect. Finally, we can show that one mechanism that led to the growth effects is a change of the industry structure. In regions where internet availability exists, manufacturing has higher growth rates. While the industry shares in employment of manufacturing increase, shares of agriculture decrease.

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 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 the Internet. 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. Moreover, the effects of the Internet are not bound to a high uptake. Hence, we recommend to rollout this infrastructure further even when only a low, but positive, uptake is expected. An uptake by some firms might generate 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, but that could be an interesting direction for further research.

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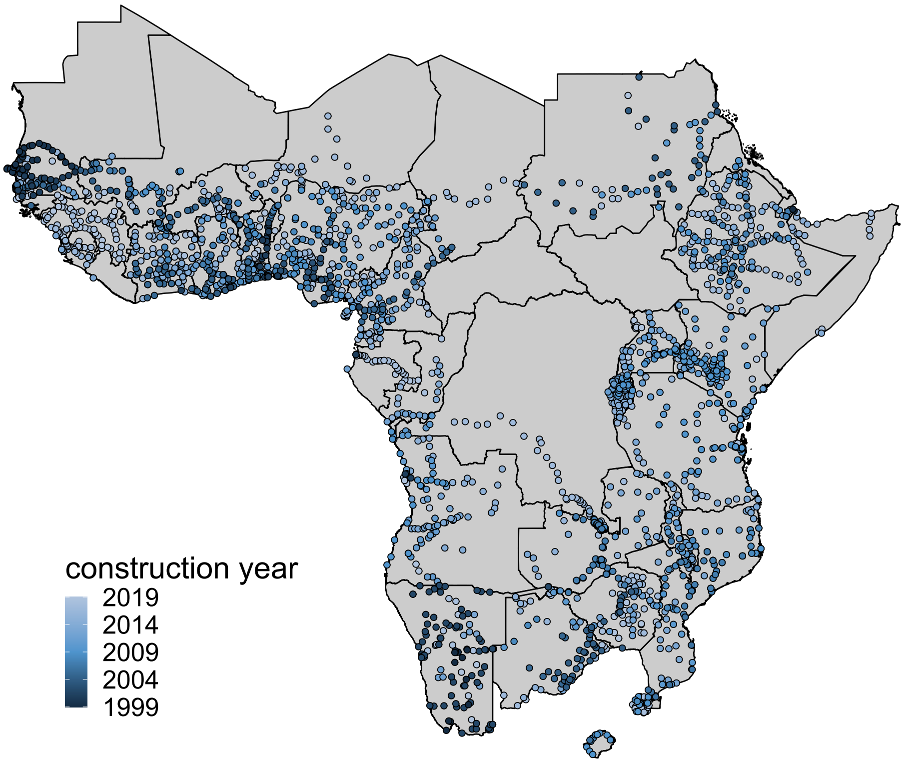
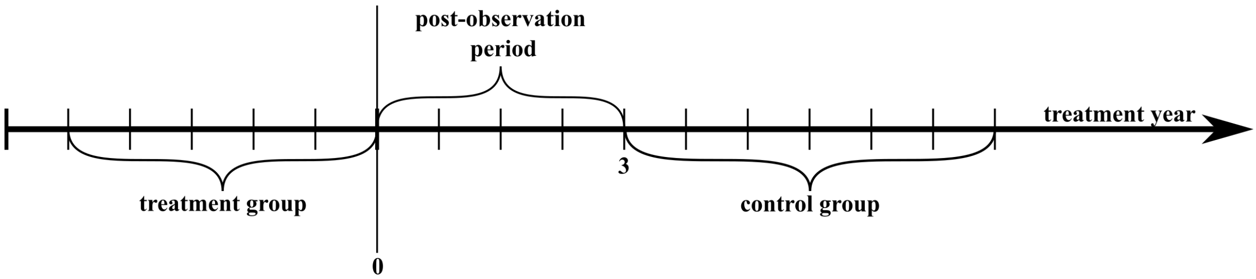
A Appendix: Figures

Figure A.1: Access points and their construction years



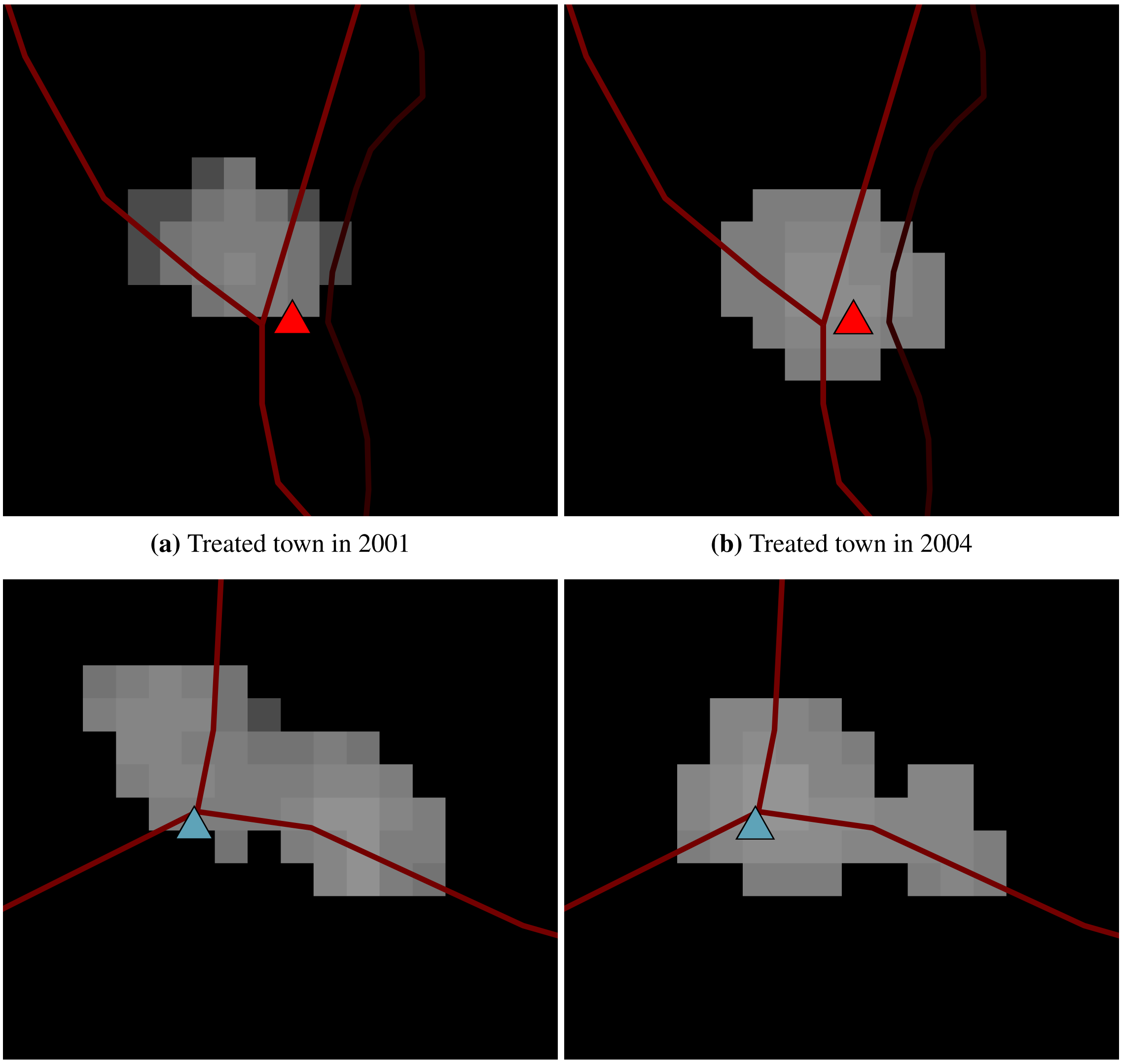
Notes: The figure depicts the location and construction date of all SSA access points. Brighter blue dots correspond to later constructed APs.

Figure A.2: Timeline identification



Notes: The figure gives an overview, of the timeline of our identification strategy.

Figure A.3: Development of illuminated towns in Benin



(a) Treated town in 2001

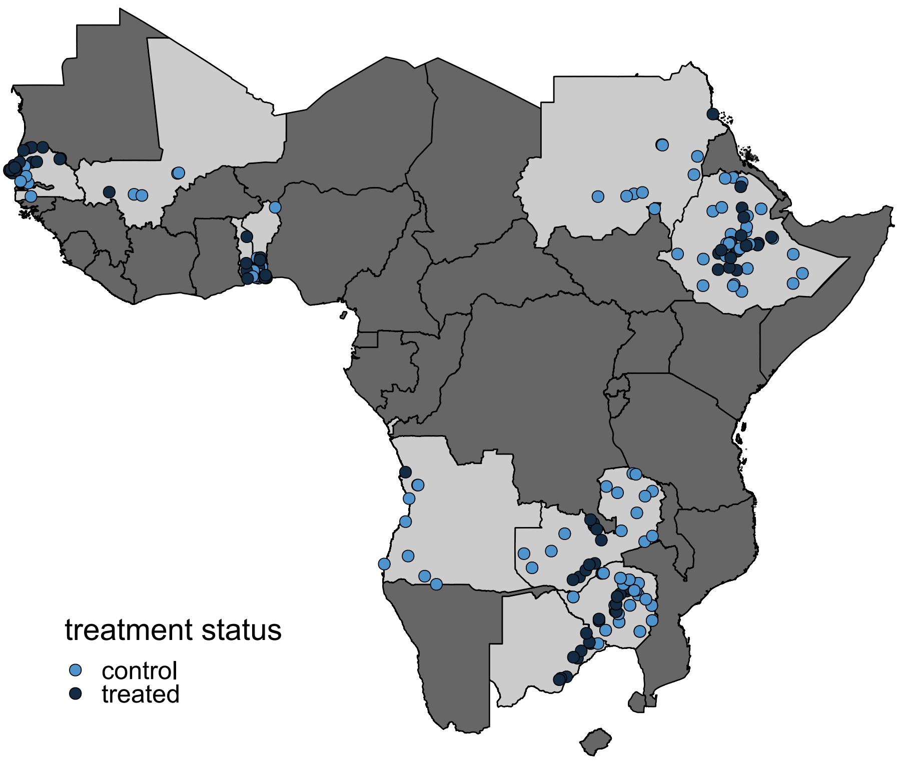
(b) Treated town in 2004

(c) Control group town in 2001

(d) Control group town in 2004

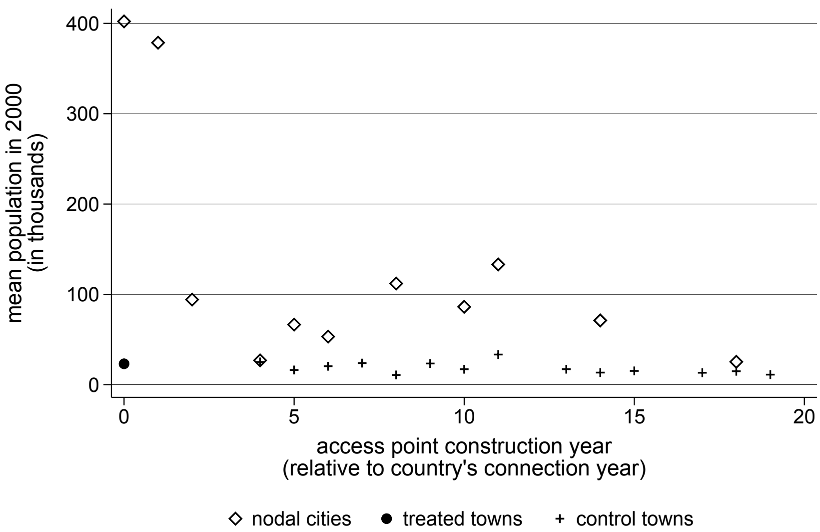
Notes: The panels show a treatment and control group town from Benin, with gray nighttime lights pixels from 2001 and 2004. Access points are marked with a triangle (red if constructed until 2001 and blue if constructed afterwards). The dark red line represents a major road connecting and the darker red line the railway. The black-to-white scale indicates light intensity, with brighter colors reflecting higher light intensities.

Figure A.4: Countries and towns location in the estimation sample



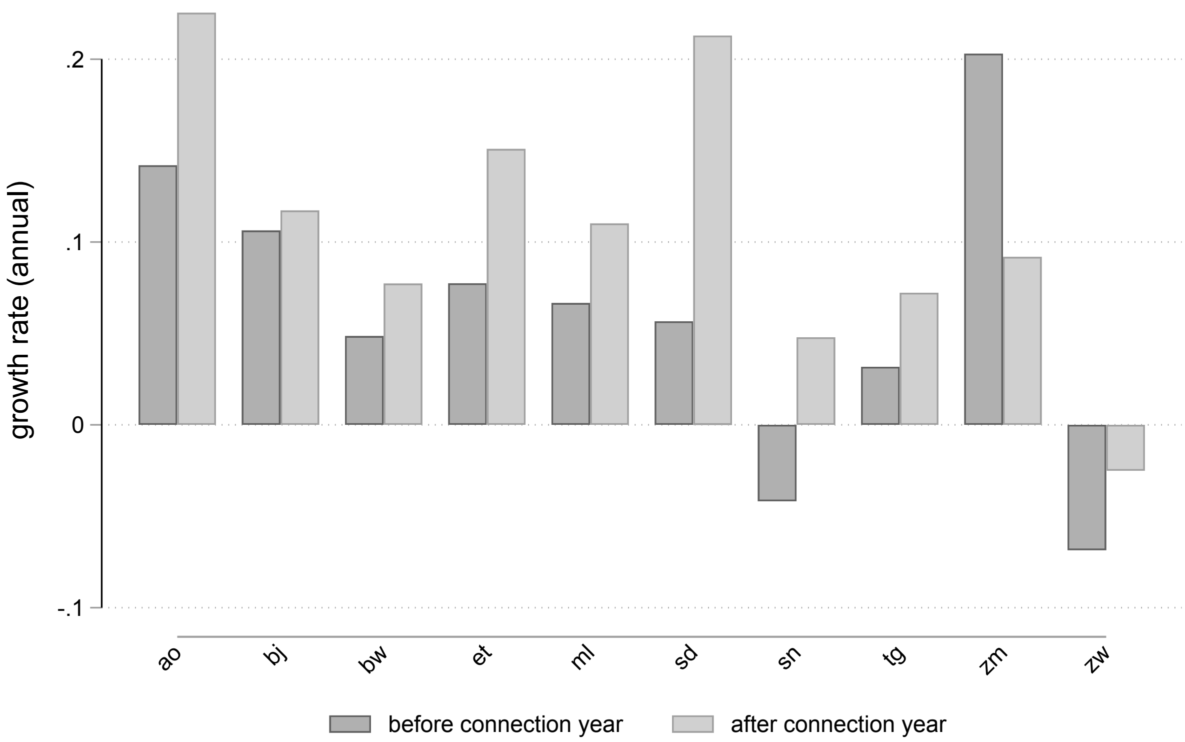
Notes: This figure depicts the countries in our analysis (brighter gray) and for each country the towns in the treatment and control group.

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



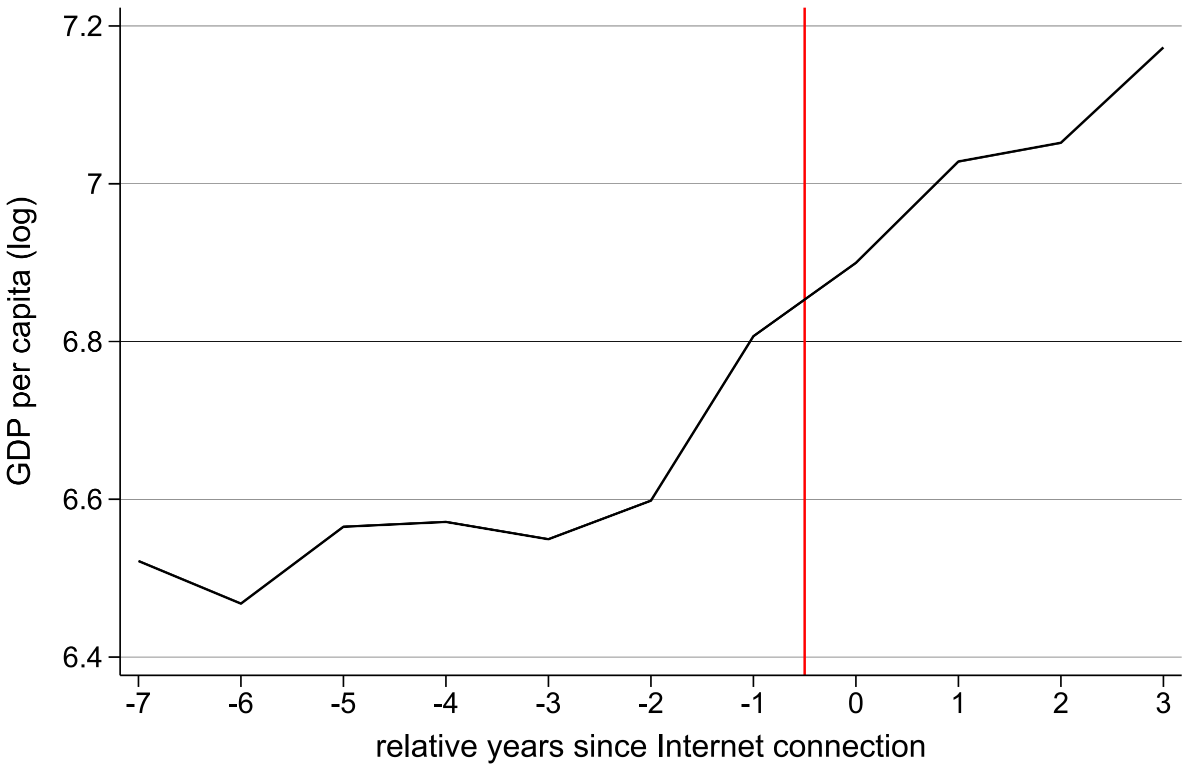
Notes: The figure depicts the average population size of connected cities and towns by year relative to the connection year. The black dot in the lower left corner represents the treated towns, while the control towns are represented by the plus symbol and the nodal cities by a diamond. For treated towns and nodal cities that were connected in earlier years than the arrival of an SMC are shown in year zero as well for clarity.

Figure A.6: Comparison of countries (GDP per capita growth rates)



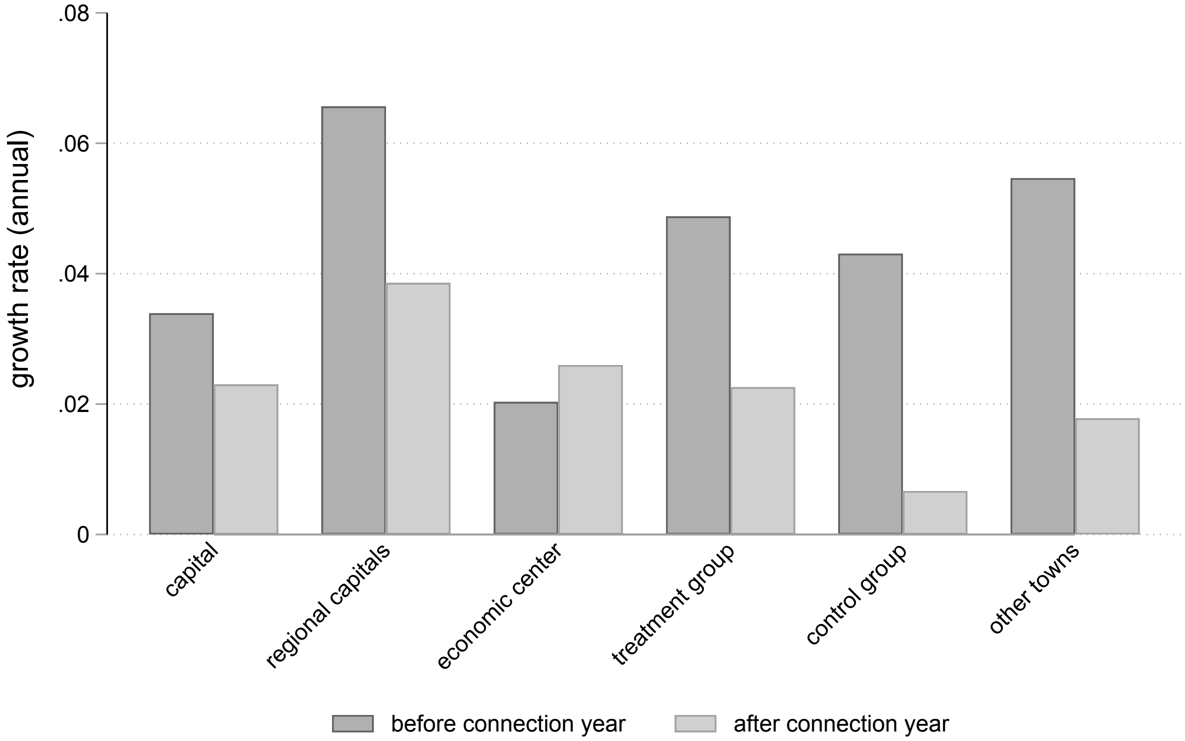
Notes: This figure shows the annual GDP per capita growth rates of the different countries.

Figure A.7: Trend of GDP per capita growth



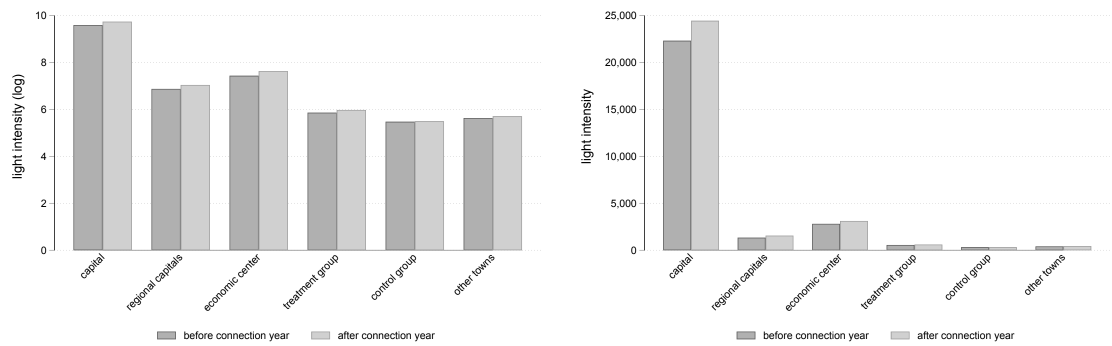
Notes: This figure shows the annual GDP per capita growth before and after the internet connection was established.

Figure A.8: Comparison of city types (growth rates)



Notes: This figure shows the annual growth rates of the different city types measured by nighttime light intensity.

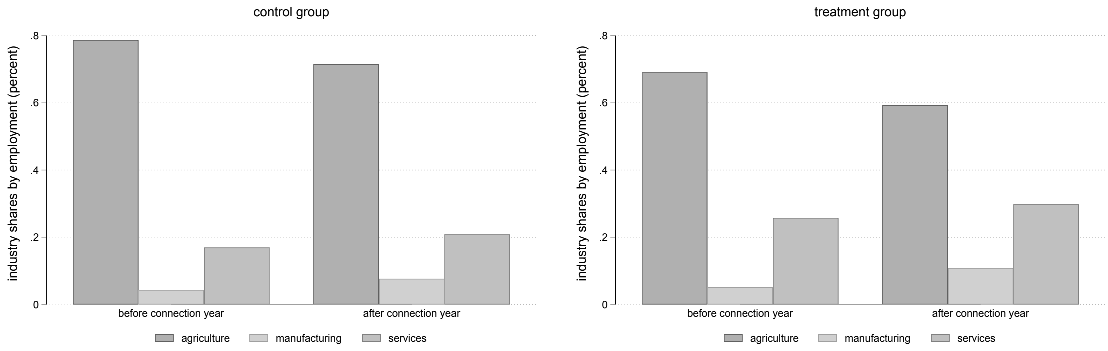
Figure A.9: Comparison of city types (light intensity)



(a) **(b)**

Notes: This figure shows the size of the different city types measured by nighttime light intensity. The left panel shows the logarithmic transformation of the right panel.

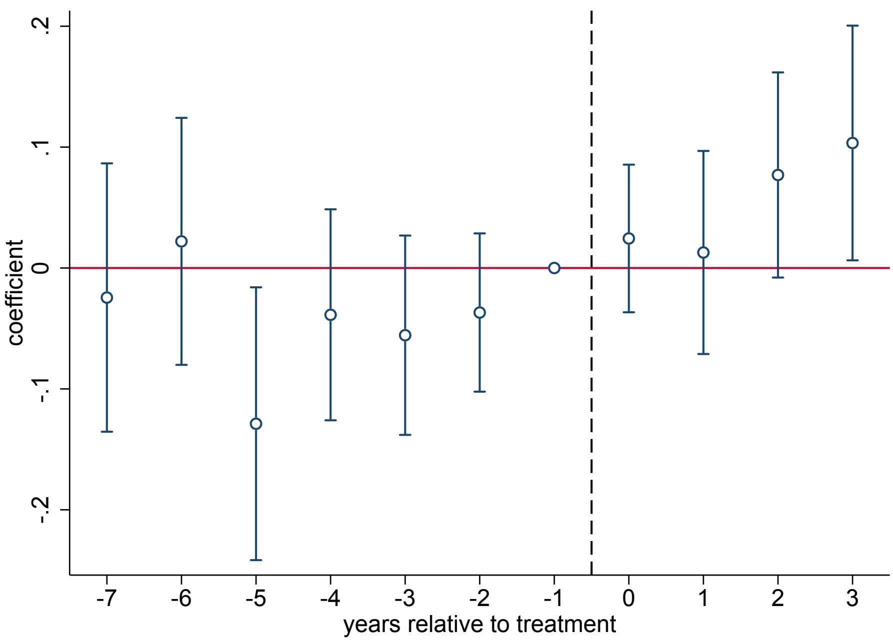
Figure A.10: Comparison on industry shares



(a) **(b)**

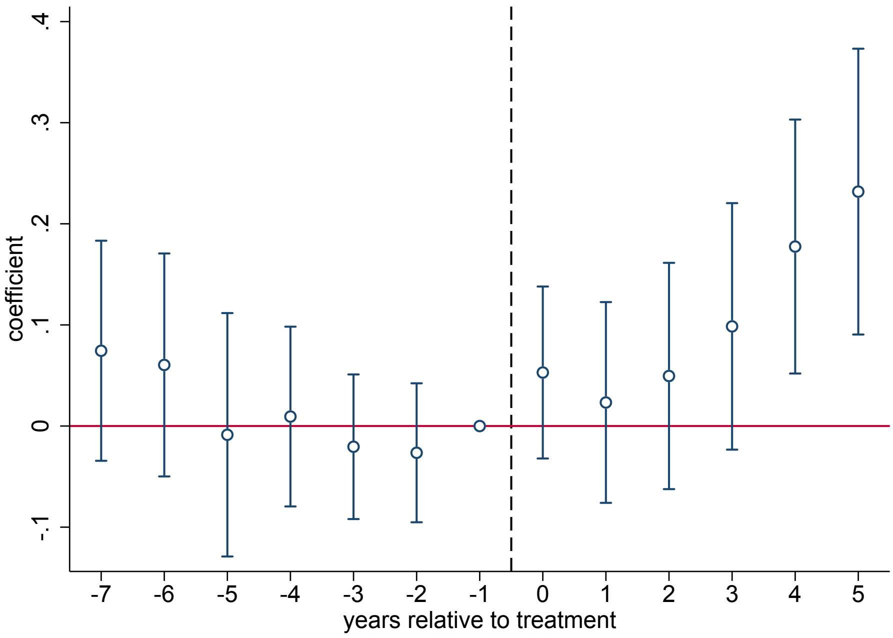
Notes: The figures depict the changes in the industry shares before and after the internet connection for the treatment (a) and control group (b).

Figure A.11: Robustness event study (external validity)



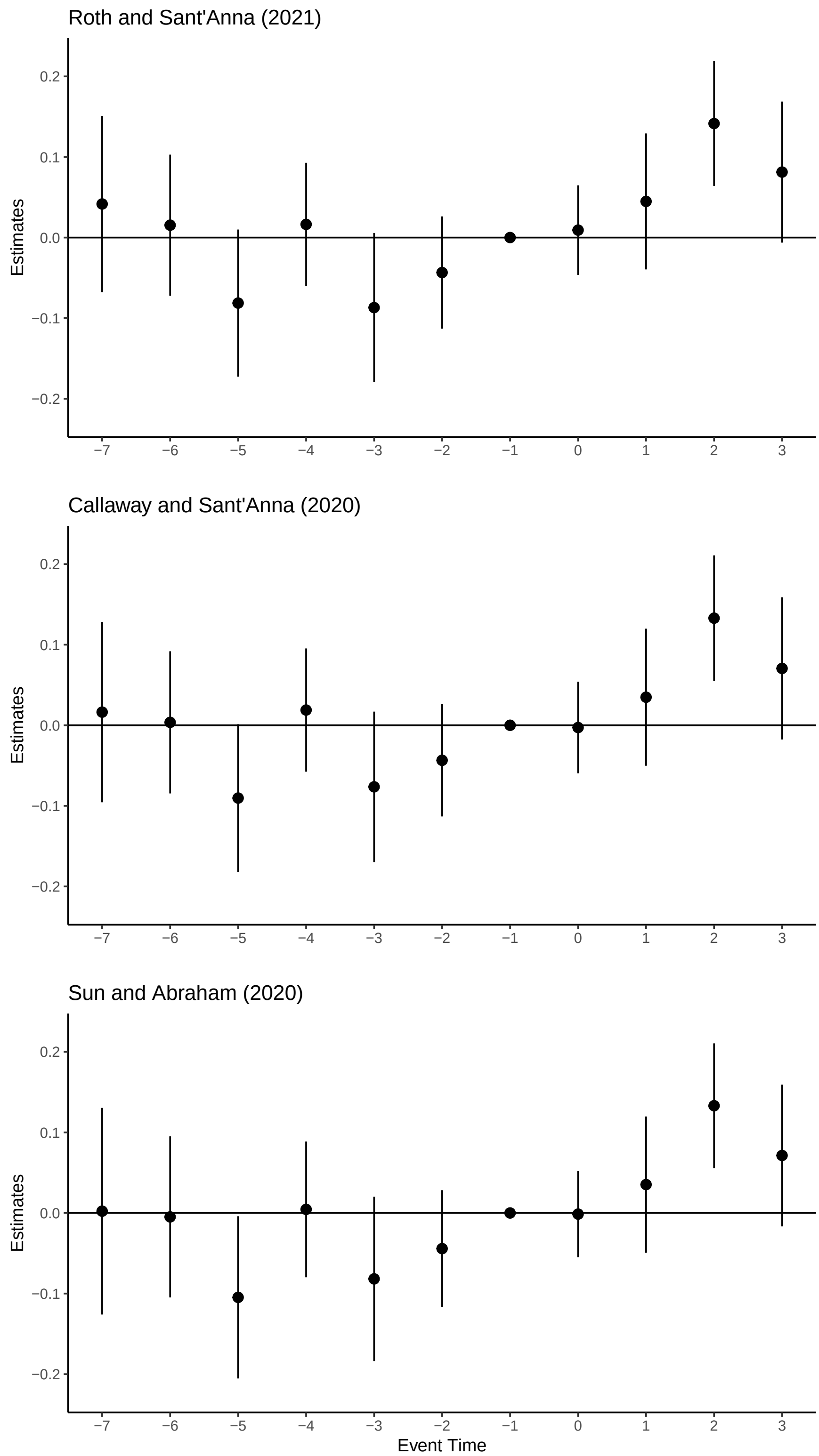
Notes: For external validity, more relaxed fixed effects are applied and therefore more countries are included.

Figure A.12: Event-study coefficients with longer post-treatment period



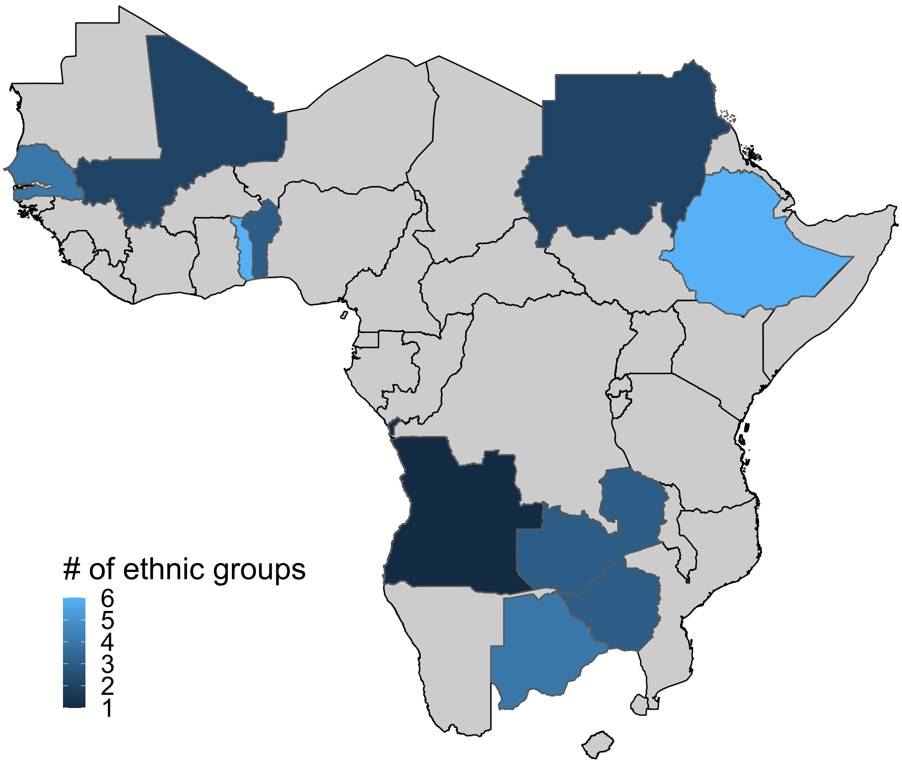
Notes: Coefficients for event study specification with five post-treatment years. Robust standard errors clustered by town for 95% confidence interval reported as bars.

Figure A.13: Robustness event study (external validity)



Notes: Staggered adoption, applying XX

Figure A.14: 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 an 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: Placebo (connection year)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
post x treated	-0.00667	-0.00537	-0.0415	-0.0162	-0.0116	0.00421	0.0118	-0.0148
	(0.0364)	(0.0359)	(0.0316)	(0.0347)	(0.0351)	(0.0424)	(0.0517)	(0.0493)
GSM coverage	-0.0158	-0.0110	-0.0179	0.000322	0.00454	-0.00163	0.0284	-0.00187
	(0.0329)	(0.0309)	(0.0314)	(0.0324)	(0.0330)	(0.0415)	(0.0567)	(0.0563)
Observations	3,289	3,014	2,640	2,640	2,519	1,705	990	847
R-squared	0.933	0.940	0.947	0.947	0.951	0.943	0.935	0.934
#countries	15	14	12	12	11	8	4	3
#towns	299	274	240	240	229	155	90	77
share treated	.462	.431	.438	.438	.454	.477	.378	.429
town FE	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓	✓
placebo connection	2000	2001	2002	2003	2004	2005	2006	2007

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.4: Placebo (connection year)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
post x treated	-0.0235	-0.0210	-0.0265	-0.00700	-0.00939	-0.0617	-0.0317	-0.00782	-0.0219	-0.0142	-0.00713
	(0.0360)	(0.0365)	(0.0370)	(0.0387)	(0.0431)	(0.0417)	(0.0473)	(0.0508)	(0.0747)	(0.0706)	(0.0657)
GSM coverage	-0.0815	-0.0404	-0.0230	0.0188	0.0246	-0.00727	-0.00541	0.0234	0.0910	0.0902	0.100
	(0.0508)	(0.0456)	(0.0388)	(0.0394)	(0.0409)	(0.0449)	(0.0469)	(0.0498)	(0.0852)	(0.0883)	(0.0877)
Observations	1,760	1,980	2,200	2,420	2,340	2,093	2,254	2,250	1,216	1,207	1,278
R-squared	0.944	0.941	0.939	0.936	0.936	0.940	0.938	0.941	0.921	0.917	0.918
#countries	10	10	10	10	9	7	7	6	3	2	2
#towns	220	220	220	220	195	161	161	150	76	71	71
share treated	.445	.445	.445	.445	.4	.404	.404	.427	.447	.423	.423
town FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
placebo connection	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.5: Placebo (connection year)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
post x treated	-0.0386	-0.0267	-0.00667	-0.0124	-0.0533	-0.0381	-0.0325	-0.0366	-0.0410	-0.0498
	(0.0358)	(0.0358)	(0.0364)	(0.0382)	(0.0367)	(0.0407)	(0.0421)	(0.0514)	(0.0659)	(0.0658)
GSM coverage	-0.0568	-0.0434	-0.0158	-0.0267	-0.0571	-0.0513	-0.0312	-0.0202	0.0330	0.0742
	(0.0392)	(0.0329)	(0.0329)	(0.0335)	(0.0359)	(0.0372)	(0.0386)	(0.0520)	(0.0749)	(0.0831)
Observations	2,691	2,990	3,289	3,288	3,120	3,360	3,435	2,480	1,530	1,386
R-squared	0.938	0.936	0.933	0.933	0.936	0.934	0.935	0.921	0.921	0.922
#countries	15	15	15	14	12	12	11	8	4	3
#towns	299	299	299	274	240	240	229	155	90	77
share treated	.462	.462	.462	.431	.438	.438	.454	.477	.378	.429
town FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
placebo connection	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.6: Placebo (connection year)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
post x treated	-0.0169	-0.0392	-0.0222	-0.00700	-0.0145	-0.0548	-0.0423
	(0.0445)	(0.0398)	(0.0400)	(0.0387)	(0.0407)	(0.0369)	(0.0421)
GSM coverage	0.00852	0.0120	0.0186	0.0188	0.0298	-0.0173	-0.0609
	(0.0430)	(0.0402)	(0.0393)	(0.0394)	(0.0398)	(0.0413)	(0.0420)
Observations	2,068	2,244	2,354	2,420	2,222	2,090	2,387
R-squared	0.938	0.937	0.937	0.936	0.940	0.944	0.941
#countries	9	9	10	10	9	7	7
#towns	188	204	214	220	202	190	217
share treated	.516	.475	.458	.445	.386	.342	.3
town FE	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓
placebo connection	1997	1998	1999	2000	2001	2002	2003

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.7: Placebo (connection year)

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
post x treated	-0.0355	-0.0204	-0.00667	-0.0208	-0.0386	-0.0264
	(0.0397)	(0.0392)	(0.0364)	(0.0367)	(0.0306)	(0.0367)
GSM coverage	-0.0123	-0.00664	-0.0158	0.00490	-0.0283	-0.0530*
	(0.0351)	(0.0344)	(0.0329)	(0.0332)	(0.0317)	(0.0320)
Observations	2,926	3,113	3,289	3,344	3,421	3,828
R-squared	0.933	0.935	0.933	0.941	0.946	0.944
#countries	13	15	15	15	14	14
#towns	266	283	299	304	311	348
share treated	.504	.488	.462	.428	.379	.339
town FE	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓
placebo connection	1998	1999	2000	2001	2002	2003

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.8: Robustness

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
post x treated	0.0703**	0.0580*	0.0703*	0.102**	0.0625*	0.0600*	0.0797***	0.121***	0.0720*
	(0.0349)	(0.0338)	(0.0358)	(0.0449)	(0.0336)	(0.0323)	(0.0265)	(0.0392)	(0.0374)
GSM coverage	0.0486	0.0908***	0.0486	0.0193	0.0233	-0.00762	0.0193	0.0611	0.0482
	(0.0342)	(0.0320)	(0.0330)	(0.0332)	(0.0310)	(0.0308)	(0.0249)	(0.0380)	(0.0408)
observations	2,420	2,420	2,420	2,420	2,827	3,839	2,343	2,860	1,804
R-squared	0.943	0.927	0.943	0.962	0.951	0.927	0.978	0.937	0.939
#countries	10	10	10	10	10	10	10	10	9
#ethnic group-countries									13
#towns	220	220	220	220	257	349	213	220	164
share treated	.445	.445	.445	.445	.525	.281	.502	.445	.445
town FE	✓	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓		✓	✓	✓	✓	✓	✓	
year FE		✓							
ethnic group-country x year FE									✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓	✓	✓	✓
cluster			state-level						
linear time trends				town-level					
late APs					✓				
no not treated towns						✓			
no buffer							✓		

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 100,000 inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table B.9: Heterogeneity (coastal countries)

VARIABLES	(1)	(2)	(3)	(4)	(5)
post x treated	0.110	0.131*	0.165**	0.161*	0.165**
	(0.0691)	(0.0772)	(0.0798)	(0.0820)	(0.0815)
GSM coverage					0.0797
					(0.0622)
Observations	1,111	1,056	880	825	825
R-squared	0.957	0.941	0.931	0.902	0.903
#countries	5	5	5	5	5
#towns	101	96	80	75	75
share treated	.515	.49	.525	.507	.507
town FE	✓	✓	✓	✓	✓
year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
w/o regional capitals			✓	✓	✓
w/o population >100k				✓	✓

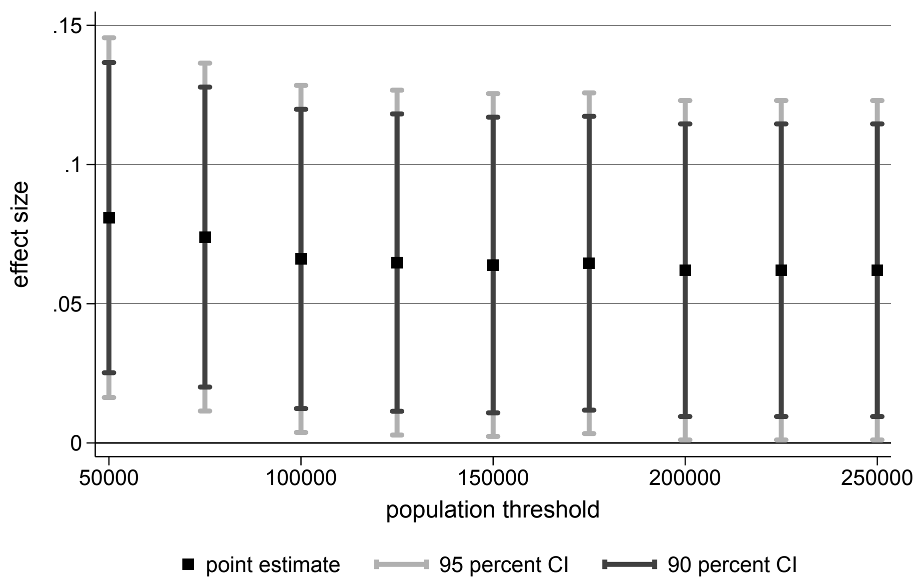
Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer as in Table 1. GSM mobile-phone coverage is calculated as the percentage share of town area covered with signal. Sample successively restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100,000 inhabitants and all specifications include town and year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

C Appendix: Further robustness checks

Spatial correlation To account for potential spillover effects, we cluster standard errors at the state level for robustness. However, it might be the case that spatial correlation between the location of towns requires correction of the standard errors. Following Conley (1999) we calculate the standard error to account for spatial correlation. Results remain.

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 C.1 shows that the estimate remains independently of the chosen population threshold.

Figure C.1: 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.

Definition of control group A further concern might be that towns being connected through an AP constructed many years after the first internet connection are not comparable to the treated towns which were connected through an AP constructed before the first internet connection. However, Table C.1 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 to the control group. The last column repeats the main effect estimate.

Table C.1: Robustness (connected control towns)

	(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
town FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
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 100,000 inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Levels outcome measure The growth rate of light intensity is the most important outcome in this analysis. Nonetheless, changes in levels are also informative. Our results also hold when estimating the levels (absolute light intensity) instead of the growth rate (logarithm) (Table C.2). Especially, nodal cities, in the first columns of Table C.2, growth a lot stronger in levels.

Table C.2: Robustness (light intensity (levels))

	(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
#towns	290	279	233	220	220
share treated	.493	.473	.468	.445	.445
town FE	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
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 and a 2 km buffer. 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 100,000 inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Longer post-treatment trends and shorter pre-treatment trends For robustness, we show that the results do not depend on the chosen window around the treatment year. Table C.3 shows in Column (2) results for a longer post-treatment period. This reduces the sample size to six countries which were connected that early for the first time that they have at least five post-treatment years before the speed-upgrade SMC arrived. Column (3) reduces the pre-treatment period by two years to five pre-treatment years. The number of countries and towns remains as the data on NTL goes a lot further back in time than the connection year of the first country. In both cases the estimate increases and also its statistical significance increases in comparison to the baseline specification of Column (1). Column (2) shows that growth rates increase further even five years after the treatment. Column (3) indicates that there is no divergence in the years prior to the treatment. In fact, treated and control group towns have a marginal tendency to converge before the treatment and diverge strongly after the treatment.

Table C.3: Further robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)
post x treated	0.0703**	0.156***	0.0904***	0.0615*	0.0890**	0.0791**
	(0.0349)	(0.0555)	(0.0343)	(0.0333)	(0.0400)	(0.0327)
GSM coverage	0.0486	0.0743	0.0579	0.0472	0.0544	0.0509
	(0.0342)	(0.0484)	(0.0367)	(0.0314)	(0.0381)	(0.0335)
observations	2,420	1,729	1,980	2,690	2,739	2,196
R-squared	0.943	0.926	0.948	0.945	0.939	0.949
#countries	10	6	10	12	11	12
#towns	220	133	220	247	222	247
share treated	.445	.436	.445	.417	.459	.417
town FE	✓	✓	✓	✓	✓	✓
country x year FE	✓	✓	✓	✓	✓	✓
w/o capital+landing point	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓
balanced panel	✓	✓	✓			
pre-treatment years	7	7	5	7	7	5
post-treatment years	3	5	3	3	5	3

Notes: Light intensity is measured as the logarithmic sum of light intensities of DMPS-OLS pixels within town area and a 2 km buffer. 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 100,000 inhabitants. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Unbalanced panel Estimating on a balanced panel has the advantage of not depending on sample composition close to the period boundaries. Relaxing this restriction, however, allows to estimate on a bigger sample and therefore show that the results have high external validity. Table C.3 repeats the before shown estimations on an unbalanced sample. Therefore, in the baseline specification, the sample increases by two countries (Column (4)). Also in Column (5), the sample shrinks only by one country, instead of four as in Column (2) in the balanced sample. In Column (6), the sample size again remains at the higher level. The estimates are only slightly lower in comparison to the balanced sample. Again, it can be observed that the main estimate increases from Column (4) to Column (5) when a longer post-treatment period is applied. The same holds for the comparison of Column (4) and Column (6).

Parts of SSA as fixed effects Table C.4 show the results when re-estimating Equation (1) with part-year fixed effects instead of country-year fixed effects. The parts are East, Southern, West, and Central Africa. This specification allows for more countries, as it is not necessary for a single country to have a treatment and control group. On the other hand, comparison is made within the parts of SSA, such that the growth path of different parts is considered. Again, nodal cities are removed column-wise. Countries were only the capital city and only economics centers were connected are dropped therefore. As before, the estimate increases column by column. However, it is statistically significant at the 1 percent level in all specifications. Moreover, the point estimate has a higher level. In our refereed specification (Column (5)), it is .125.

Table C.4: Robustness (parts of SSA as fixed effects)

	(1)	(2)	(3)	(4)	(5)
post x treated	0.0904***	0.0997***	0.118***	0.122***	0.125***
	(0.0266)	(0.0283)	(0.0317)	(0.0337)	(0.0337)
GSM coverage					0.0320
					(0.0265)
observations	4,895	4,697	3,718	3,553	3,553
R-squared	0.965	0.951	0.942	0.923	0.923
#countries	16	15	15	14	14
#towns	445	427	338	323	323
share treated	.364	.34	.334	.313	.313
town FE	✓	✓	✓	✓	✓
part x year FE	✓	✓	✓	✓	✓
w/o capital+landing point		✓	✓	✓	✓
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 and a 2 km buffer. 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 100,000 inhabitants and all specifications include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

D Appendix: Mobile coverage

In our preferred specification, we control for mobile coverage. And we we control for mobile coverage, the main estimate increases and is estimated more precisely. Next, we show how mobile coverage affects the variation of the outcome variable. Therefore, we follow the step-wise removal of nodal cities. In Table D.1, Internet availability is negatively associated with mobile coverage in all specifications. This means that control group towns catch up to the treatment group with respect to the coverage of the mobile network. This effect is irrespective of controlling for population and light intensity, which are even jointly not significant as control variables.

Table D.1: Mobile coverage

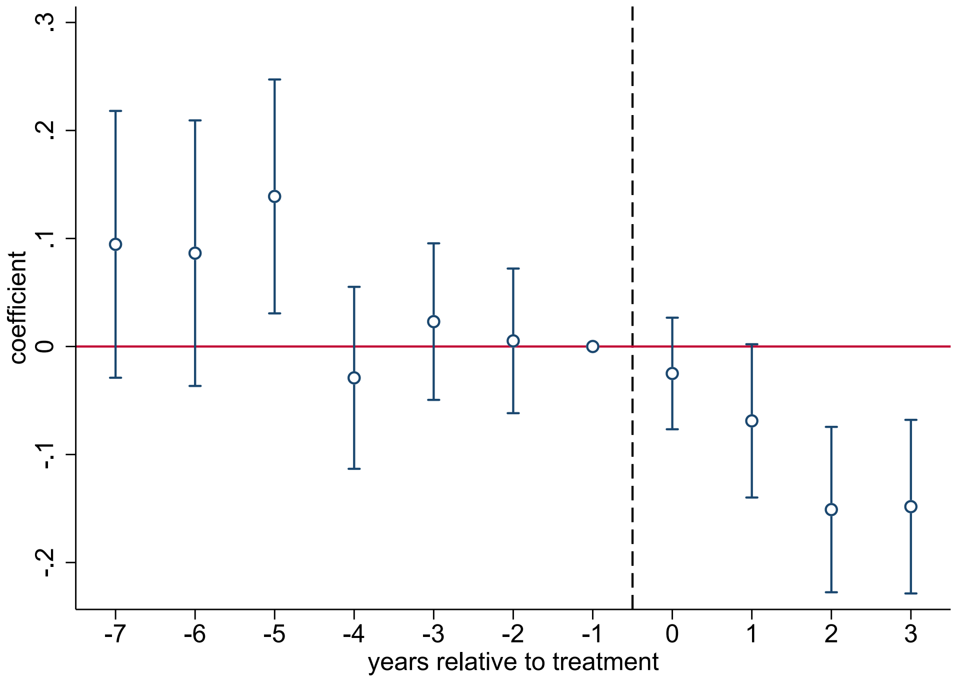
VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)
post x treated	-0.123***	-0.134***	-0.155***	-0.142***	-0.144***	-0.145***	-0.146***
	(0.0333)	(0.0342)	(0.0364)	(0.0374)	(0.0368)	(0.0374)	(0.0369)
population (ln, gpw)					0.141		0.127
					(0.196)		(0.193)
light intensity						0.0413	0.0393
						(0.0294)	(0.0291)
Observations	3,190	3,069	2,563	2,420	2,420	2,420	2,420
R-squared	0.816	0.816	0.816	0.817	0.817	0.817	0.817
#countries	10	10	10	10	10	10	10
#cities	290	279	233	220	220	220	220
share treated	.493	.473	.468	.445	.445	.445	.445
City FE	✓	✓	✓	✓	✓	✓	✓
Country x Year FE	✓	✓	✓	✓	✓	✓	✓
w/o capital+landingpoint		✓	✓	✓	✓	✓	✓
w/o regional capitals			✓	✓	✓	✓	✓
w/o population ¿100k				✓	✓	✓	✓

Notes: Mobile coverage as share of built-up area with the most basic technology (GSM/2G). All specifications are estimated on a sample restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100,000 inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Figure D.1 indicates that in the early years before the internet connections, the treatment group had a stronger rollout of the mobile network. While in the years right before the connection, the rollout speed was similar between the treatment and control group, after the connection, the control group caught up with respect to mobile coverage. This interpretation is inline with Figure D.2 which plot mobile coverage separated between the treatment group and the control group towns without any fixed effects. While for treated towns the rollout stops slightly above 80 percent coverage shortly after the internet connection, control group towns continue with the rollout in a linear manner and therefore catch up in the years after the internet connection was established.

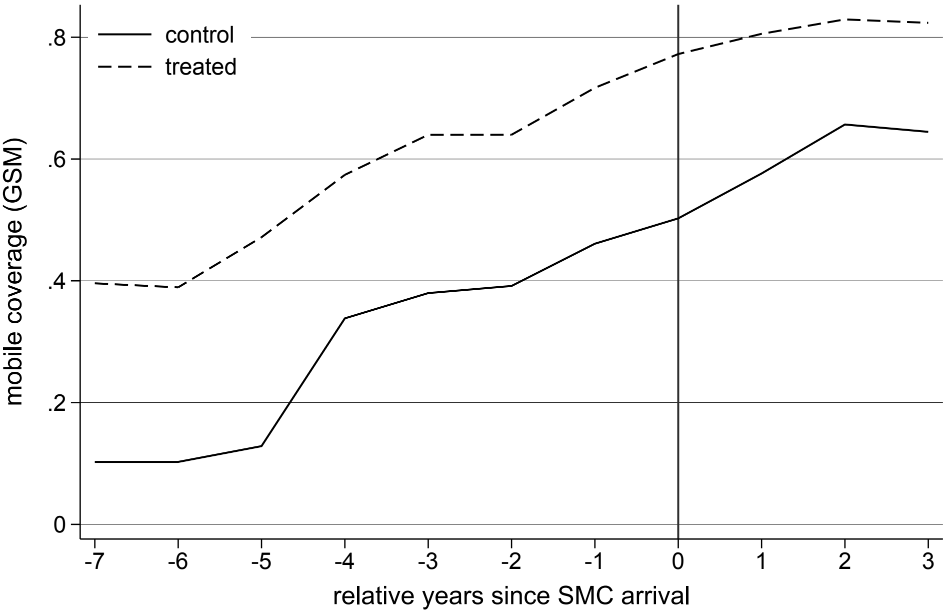
When controlling for mobile coverage, we therefore control for the difference in having a different infrastructure available. As it might take some time for an infrastructure to affect economic outcomes as we have seen for internet availability, we also include different lags for mobile coverage instead of current mobile

Figure D.1: Event-study coefficients for mobile coverage



Notes: Coefficients for event study specification of Column (4) from Table D.1. Robust standard errors clustered by town for 95% confidence interval reported as bars.

Figure D.2: Trends for mobile coverage



Notes: Coefficients for event study specification of Column (4) from Table D.1. Robust standard errors clustered by town for 95% confidence interval reported as bars.

coverage. Table D.2 shows that mobile coverage induces economic growth with a lag of one year. All other lags remain insignificant. However, in all different lag specifications, the main effect is robust.

Table D.2: Mobile coverage

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)
post x treated	0.0703**	0.0707**	0.0647*	0.0646*	0.0646*	0.0610*
	(0.0349)	(0.0349)	(0.0346)	(0.0343)	(0.0343)	(0.0342)
GSM coverage	0.0486					
	(0.0342)					
GSM coverage (lag 1)		0.0734**				
		(0.0359)				
GSM coverage (lag 2)			0.0235			
			(0.0353)			
GSM coverage (lag 3)				0.0491		
				(0.0335)		
GSM coverage (lag 4)					0.0484	
					(0.0346)	
GSM coverage (lag 5)						0.0384
						(0.0362)
Observations	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
#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+landing point	✓	✓	✓	✓	✓	✓
w/o regional capitals	✓	✓	✓	✓	✓	✓
w/o population >100k	✓	✓	✓	✓	✓	✓

Notes: Mobile coverage as share of built-up area with the most basic technology (GSM/2G). All specifications are estimated on a sample restricted by excluding landing point cities and capitals, regional capitals, and cities with more than 100,000 inhabitants and include town and country-year fixed effects. Robust standard errors clustered by town reported in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.