Drivers of Digital Connectivity in Sub-Saharan Africa: The Role of Access to Electricity

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Despite a relatively low access to electricity, Sub-Saharan Africa has experienced a rapid diffusion of mobile telephony. However, little is yet known about whether mobile internet access will spread at a similar pace. In this paper, we use a logistic model and country-level panel data from 36 Sub-Saharan African countries from 2000 to 2016 to investigate the impact of access to electricity on access to and usage of mobile internet. We find a positive and significant impact of access to electricity on internet access. However, we find no significant impact of access to electricity on access to mobile telephony or internet usage. Beyond access to electricity, income is the key determinant of access to mobile telephony, while literacy appears to be a key determinant of internet access. Both income and literacy have significant impact on internet usage.

Keywords: electricity, digital connectivity, Africa

INTRODUCTION

A number of studies has emphasized the potential of digital connectivity, including voice communications and internet access, to support economic growth and job creation (Czernich *et al.* ,2011;Thompson Jr. & Garbacz,2011), especially in developing countries where the impact appears to be larger than in developed economies (ITU,2018;Hjort & Poulsen,2019). Yet, Sub-Saharan Africa (SSA) is lagging behind the rest of world, with 8 percentage point increase in mobile internet penetration rate between 2015 and 2019, compared to 15 percentage point increase at the global scale between 2010 and 2014 – from the same level of penetration 18%.[1] Empirical studies like Bohlin *et al.* (2010) and Lee *et al.* (2011) have investigated the determinants of digital connectivity but few have taken into consideration access to electricity, a precondition still not satisfied by a large number of potential users in SSA: in 2016, 57% of the world population without access to electricity live in SSA, corresponding to 58% of its population.[2]

There are two main channels through which access to electricity can affect digital connectivity. From the supply side, access to the electricity lowers the cost of running telecommunications networks, as it enables operators to switch from more expensive power sources such as privately owned fuel-based electric generators. Provided enough competition in the retail market, this cost reduction can be passed-through to consumers via lower price or higher quality of service and, as a result, greater uptake and usage of digital connectivity. From the demand side, providing access to electricity to previously unconnected users enables them to recharge their communications devices at lower cost and, therefore, can increase their uptake and usage of digital connectivity.[3] In addition, as emphasized by Lenz *et al.* (2017), the lack of access to electricity is a constraint to development, thereby limiting the demand for goods and services, particularly for digital connectivity.

In this paper, we use country-level panel data over the period 2000-2016 to investigate the drivers of digital connectivity in SSA, with an emphasis on the impact of access to electricity. More specifically, we build a panel of 36 countries and distinguish between access, measured by the penetration rate of basic mobile telephony – typically used for traffic and short text messages – internet or smartphones; and usage, measured by international internet traffic per user. Our empirical strategy proceeds in two steps.

First, we assess the impact of access to electricity on access to digital connectivity using a logistic diffusion model. Like in Czernich *et al.* (2011), we assume that the ceiling of this curve depends on access to electricity as well as socio-economic attributes such as price, quality, income and education. Using a nonlinear least squares estimator, we find that access to electricity has a positive and statistically significant impact on internet access, but not on access to mobile telephony. Beyond access to electricity, income is a strong determinant of access to mobile telephony, while literacy is a significant determinant of internet access. Network investment has a positive and significant impact on access to digital connectivity.

Second, we assess the impact of access to electricity on the usage of digital connectivity using Ordinary Least Squares (OLS) estimator, controlling for country and year fixed-effects as well as quality, income and education. We find no statistically significant impact of access to electricity on usage. Instead, quality, income and education are the most significant determinants of internet usage.

The findings of this paper are related to the literature on the determinants of digital connectivity. While Armey & Hosman (2016) investigate the impact of access to electricity on internet subscription in developing countries, we focus more specifically on Sub-Saharan Africa and extend the analysis to access to mobile telephony and internet usage. Mothobi & Grzybowski (2017) emphasize the role of infrastructure in the adoption of mobile-money in Sub-Saharan Africa in 2011. We complement their study by taking into account internet usage and extending the analysis to more Sub-Saharan African countries.

The remaining of the paper is organized as follows. Section 2 highlights related literature on the determinants of digital connectivity with an emphasis on the role of access to electricity. Section 3 provides some background information about digital connectivity and access to electricity in Sub-Saharan Africa. Section 4 describes the data and presents some descriptive statistics about the relationship between access to electricity and digital connectivity. Section 5 presents the econometric models, the estimation strategy and the results. Section 6 concludes.

RELATED LITERATURE

The economic literature on the determinants of digital connectivity typically focuses on long run factors such as prices, income, urbanization, education, regulation and market competition. For instance, Bohlin *et al.* (2010) find a positive impact of per capita income, urbanization and regulation on the diffusion of new generations of mobile telecommunications. Likewise, Lee *et al.* (2011) and Lin & Wu (2013) highlight the role of education and content quality on digital connectivity in OECD countries. Gruber (2001) find a positive impact of the number of operators and market size on the speed of diffusion of mobile telephony in Central and Eastern Europe. Unlike our paper, these papers focus on advanced economies where basic infrastructures such as electricity are widely available.

Armey & Hosman (2016) provide one of the first evidence about the impact of access to electricity on digital connectivity in low-income countries, with a focus on internet access. Like in our paper, they rely on country-level panel data of 40 low-income countries, of which 29 from Sub-Saharan Africa, over the period 2000-2009. Using a dynamic panel data estimator (Arellano & Bond,1991), after a transformation of the logistic diffusion model, they find a positive and statistically significant impact of access to electricity on internet access. However, access to electricity is measured by the Gini coefficient of nighttime light intensity andthey did not investigate the impact on internet usage.

Mothobi & Grzybowski (2017) also provide some evidence about the impact of access to electricity on digital connectivity. However, they focus on infrastructure deficit in general, measured by the average nighttime light intensity obtained from satellite data. Interestingly, they rely on individual level survey data from 11 Sub-Saharan Africa countries which enable them to measure access to electricity at the household level. Using a Logit model, they find that individuals are more likely to own a mobile phone in areas with brighter nighttime light or in households with access to electricity. On the contrary, mobile-money services are more likely to be used in areas or households without access to electricity.

One reason why access to electricity was overlooked in earlier papers stems from the fact that it typically affects all standard determinants of digital connectivity such as price, quality, income, and literacy. Indeed, both the fixed cost of expanding telecommunicationsnetworks as well as the cost of running it are expected to fall with access to electricity (GSMA, 2014). Therefore, greater access to electricity is expected to increase investment in mobile networks, inducing a fall in price and an improvement in quality. In the same vein, several papers provide evidence in support of a positive impact of access to electricity on income. In the short and medium run, Kirubi *et al.* (2009) show that access to electricity can raise income through an improvement in productivity as workers adopt electric equipment and tools. Lenz *et al.* (2017) show that households save money as they get access to electricity, potentially increasing demand for digital connectivity.

However, other studies emphasize that the impact of access to electricity on income, and more generally on development outcomes such as literacy, mostly occurs in the long run and is dependent upon its productive usage. For instance, Dinkelman (2011) finds that the large- scale roll-out of electricity in rural South Africa increased employment only 5 years after the program. In general, the impact on income is indirect, working through industrial development (Rudd, 2012), productivity improvement of micro and small enterprises (Grimm *et al*., 2013) or human development (Lipscomb et al. ,2013). Qualitative analyses conducted by Kirubi *et al.* (2009) in Kenya suggest that the business model of rural electrification can be sustainable only if it is being used for productive purposes. In Rwanda, Lenz *et al.* (2017) find that electric consumption and uptake of appliances remains low, 3.5 years after electrification. In addition, Bernard (2012) stresses affordability as a major reason why electricity connection rates and consumption remain low in rural areas.

BACKGROUND ON ACCESS TO ELECTRICITY AND DIGITAL CONNECTIVITY IN SUB-SAHARAN AFRICA

The rate of access to electricity in Sub-Saharan Africa was low compared to other regions such as North Africa. According to estimates from the International Energy Agency (IEA, 2017), 600 million individuals, that is 57% of the population, lacked access to electricity in the region, compared to less than 1% in North Africa. While most countries maintained their historical rates of progress, a few, particularly in East Africa, has sped up since 2012. Indeed, the yearly growth rates of access to electricity rose from 0.8% in East Africa and 1.1% in West Africa, before 2012, to respectively 6.2% and 2.6% afterwards. The performance gap between these two sub-regions stemmed from a delay in financial support. Data from the World Bank and the African Development Bank show that East Africa had access to international financial support earlier than West Africa. In the other Sub-Saharan Africa countries, progress in access to electricity remained steady, with an average growth rate of 1 percentage point per year.

In general, progress in access to electricity is driven by strong commitment from government. In Kenya, for instance, the government successfully implemented two power projects, namely the "Last Mile Connectivity Project" and the "Off-Grid Solar Access Project", providing access to electricity to 14 million Kenyans between 2012 and 2016. Recent energy projects in Sub- Saharan Africa typically target rural areas, with an expansion of the national grid using hydro-power, geothermal, natural gas, as well as decentralized off-grid systems based on mini- grids or solar home systems. These projects are complemented with regional interconnections of the electric grids, with earlier ones in East Africa, followed by West and

Central Africa. In addition, regulatory reforms and market liberalization enable the entry of private companies in the form of independent power producers. Data from the projects and operations database of the World Bank and the African Development Bank suggests that these reforms where implemented earlier in East Africa.

Regarding digital connectivity in Sub-Saharan Africa, internet access has been lagging while mobile telephony is widespread. According to estimates from the World Bank, the penetration rate of the internet, whether fixed or mobile, was 20% in 2016, compared to 72% for mobile telephony. Within Sub-Saharan Africa, the Southern region led the diffusion of mobile internet (71% in 2016), followed by the West (25%), the East (16%) and the Centre (8%). Smartphone penetration remained at a comparable level to internet subscription. According to estimates from the GSM Association (GSMA), the penetration rate of smartphone in Sub- Saharan Africa was 20% in 2016.

International financial institutions, government and private companies are undertaking initiatives to speed up the diffusion of the internet in Sub-Saharan Africa. For instance, the World Bank and the African Development Bank are funding the deployment of submarine and terrestrial optic fiber backbones across the region.[4] Governments typically rely on the allocation of frequency spectrum and taxation to provide incentive to operators to increasing the coverage of their network.[5] They also implement digital literacy programs and mobilize universal service funds to invest in areas where private investment is not profitable.[6] Private stakeholders tend to develop innovative strategies to overcome the cost of bringing the internet to the rural poor. Network operators share their network infrastructure, while equipment providers design low-cost smartphones compatible with the standards of living of low-income consumers.[7]

DATA AND DESCRIPTIVE STATISTICS

Data, Variables and Summary Statistics

Our estimation relies on a panel of 36 Sub-Saharan African countries, from 2000 to 2016. We drop islands countries (Mauritius, Comoros and Seychelles) as well as Togo, Eswatini, South Sudan, Somalia and Djibouti due to many missing observations or outliers. Unlike Armey & Hosman (2016), our dataset covers the period 2010-2016 when, as discussed in the background section, access to electricity accelerated in several African countries, providing larger variations for statistical inference.

We assemble data on access and price of digital connectivity, investment in mobile network infrastructure, as well as data on access to electricity and socioeconomic characteristics from three sources: the International Telecommunications Union (ITU), the GSMA Intelligence (GSMA) and the World Development Indicators database (World Bank). Table 1 presents the main variables and their sources.

Access to digital connectivity is measured by the penetration rate of mobile telephony, internet or smartphones. Data on mobile telephony subscribers and internet users are estimates from the ITU. Data on smartphone penetration are estimates from the GSMA, a proprietary database used in other academic studies.[8] Usage of digital connectivity is defined as the volume of communications between end-users, namely the duration of calls, the number of text messages and internet traffic. Data on usage comes with several missing values. Eventually, we use international internet traffic per user, from the ITU, as a proxy for usage, recognizing that, during the period covered by our analysis, most internet content in Africa originate from outside the continent (Kende & Karen, 2015). However, we also estimate mobile internet traffic per user from a small sample of countries for which data was available, by taking the ratio of average revenue per mobile internet user, from the GSMA, to the average price of mobile internet from the ITU. Price data comes from ITU's ICT Price Basket online database which collects the price of the least expensive mobile telephony (call and text message) and internet.

Access to electricity is measured by the percentage of the population connected to a grid or off-grid power source, obtained from the World Development Indicators database of the World Bank.[9] Following the findings from the literature, especially Bohlin *et al.* (2010) on the role of income and Lin & Wu (2013) on the role of education, we collect data on Gross Domestic Product (GDP) per capita, a proxy for income, and literacy rates have also been retrieved from the same database. Finally, we also collect data on capital expenditures which we accumulate over the period of this study to proxy for the quality of mobile connectivity.

Table 2 presents the yearly average of our main variables. On average, access to electricity increases by roughly 1 percentage point per year. However, as discussed in section 3, the rate of access has accelerated since 2012. Mobile penetration rose from 2.3% in 2000 to 85.5% in 2016, that is 83.2 percentage point increase in 16 years. Over the same period, internet penetration rises only by 18.5 percentage point. On average, smartphone was introduced in 2007 and reached a penetration rate of 23.7% nine years later. Overall, internet and smartphones have diffused less rapidly in Sub-Saharan Africa than mobile telephony.

Usage of digital connectivity has increased tremendously between 2000-2016. Average international internet traffic grew at an annual rate of 60% over that period, from 0.2 Gigabits per second (Gbps) per user to 354 Gbps per user. Likewise, mobile internet traffic grew at an annual rate of 40% between 2012 and 2016, from 26.7 Megabits per second (Mbps) per user in 2012 to 101 Mbps per user in 2016. These trends in usage accord well with a decline in the price of mobile telephony and a rise in investment.

TABLE 1
MAIN VARIABLES

Variable	Definition	Units	Source
CELLULAR[1]	Unique mobile subscriber penetration rate until 2009	0-100	GSMA
SM ART PHONE[2]	Percentage of the population with a smartphone	0-100	GSMA
MOBINT[3]	Unique mobile internet subscriber penetration rate	0-100	GSMA
INTLTRAF FIC	International internet traffic per user	Mbps	ITU
DT AT RAF FIC	Mobile internet traffic per user	MB	GSMA
MOBPRICE	Prepaid price of 1min local call (off-peak; on-net)	US dollars	ITU
MOBINFRA[4]	Capital stock per capita in mobile network	US dollars	GSMA
GDP PC	GDP per capita	US dollars PPP	World Bank
LITERACY[5]	Literacy rate	0-100	World Bank
ELEC[6]	Percentage of the population with access to electricity	0-100	World Bank

[1] Number of unique mobile subscribers divided by population size, during 2000-2009, i.e. before smartphones emerge.
[2] Number of unique SIM cards that are used in a smartphone device, divided by population size
[3] Number of unique mobile broadband subscribers divided by population size.
[4] Cumulative capital expenditures in mobile network divided by population size.
[5] Missing values filled by interpolation.
[6] Based on data collected from industry, national surveys and international sources. Estimated number of individuals with access to electricity divided by population size.

TABLE 2
UNWEIGHTED AVERAGE VALUE OF THE MAIN VARIABLES

year	cellular	smartphone	mobint	intltraffic	dtatraffic	mobprice	mobinfra	gdppc	literacy	elec
2000	2.6	.	.	189.3	.	0.1	1.9	3411.3	58.7	25.8
2001	4.3	.	.	329.8	.	0.2	4.9	3539.5	58.7	26.4
2002	5.8	.	.	395.0	.	0.2	8.6	3612.9	59.2	27.4
2003	7.5	.	.	622.3	.	0.2	13.2	3671.6	59.3	28.7
2004	9.9	.	.	1262.3	.	0.2	17.7	3930.6	59.2	29.2
2005	13.7	.	0.4	1835.3	.	0.2	22.0	4129.6	59.0	29.9
2006	19.4	.	0.3	3385.1	.	0.2	27.0	4275.2	58.8	31.3
2007	27.5	0.2	0.7	4392.0	.	0.2	34.2	4538.8	58.9	32.8
2008	37.3	0.5	1.2	85906.2	.	0.2	42.9	4674.6	59.3	33.0
2009	46.3	1.0	1.6	115127.1	.	0.2	53.1	4589.7	60.1	34.1
2010	.	2.0	2.9	146662.7	.	0.2	63.3	4578.9	60.8	34.7
2011	.	3.7	4.2	173039.8	.	0.2	74.9	4731.8	61.7	36.3
2012	.	6.2	6.6	232336.8	26.5	0.1	86.9	4843.1	62.3	37.4
2013	.	9.6	10.0	275165.0	31.3	0.1	99.9	4889.6	62.7	38.2
2014	.	13.8	13.3	174902.6	55.3	0.1	115.5	4941.4	63.2	40.0
2015	.	19.4	18.1	257820.3	74.6	0.1	131.9	4875.3	63.3	41.2
2016	.	25.3	22.9	354326.1	101.0	0.1	145.2	4824.0	63.6	43.7

Correlation Between Access to Electricity and Digital Connectivity

We start by conducting a descriptive analysis of the relationship between access to electricity and digital connectivity, as measured by the penetration rate of mobile telephony, internet and smartphones, as well as the international internet traffic. Figures 1 and 2 present the relationship between the annual change in access to electricity within a country and the annual change in internet penetration and usage respectively. In Figure 1, the relationship is upward sloping, meaning that countries with larger increase in access to electricity tend to experience faster increase in internet adoption. However, the linear fit of the scatter-plot in Figure 2 is almost flat, suggesting that the growth in internet usage intensity is less sensitive to increase in access to electricity.

While these patterns suggest a positive relationship between access to electricity and digital connectivity, the observed correlation could be driven by several confounding factors. More specifically, investment, income and the level of education rise with access to electricity, but they also affect digital connectivity. In addition, mobile telephony, the internet and smartphones are new technologies whose diffusion typically follows an S-Shaped curve (Lee *et al.*, 2011). Therefore, their adoption would have accelerated irrespective of the expansion of access to electricity. We consider econometric models in the next section to address these concerns.

FIGURE 1
ACCESS TO ELECTRICITY AND MOBILE INTERNET

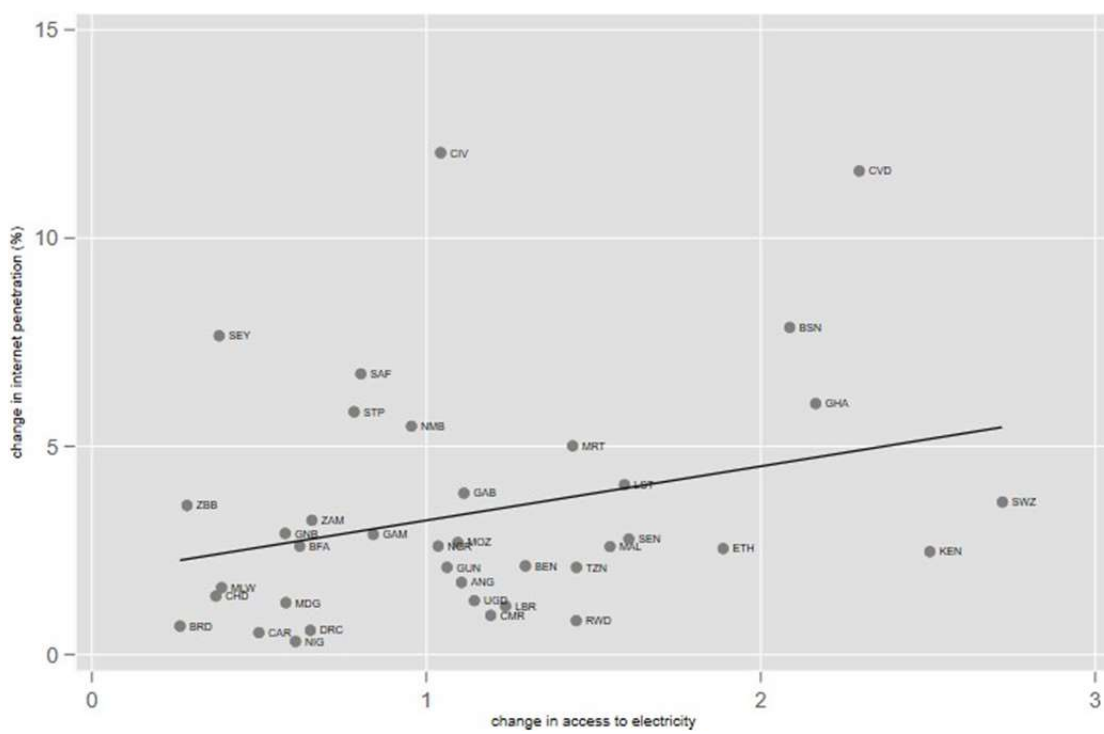
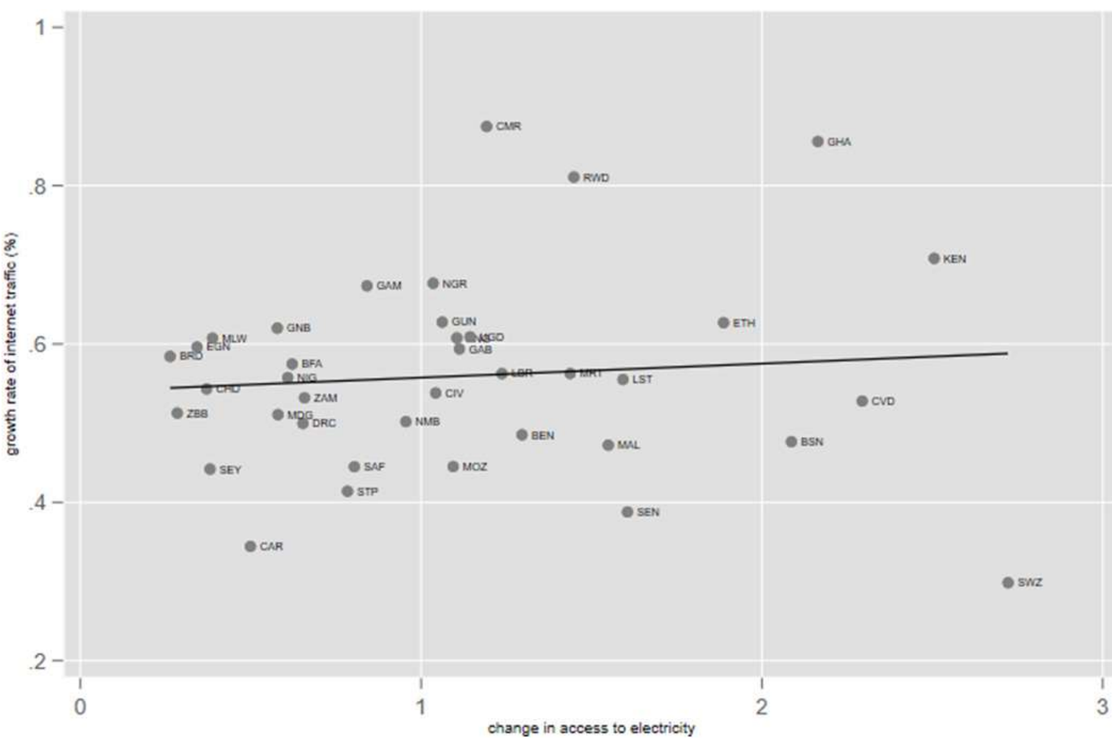


FIGURE 2
ACCESS TO ELECTRICITY AND INTERNET USAGE



ECONOMETRIC ESTIMATION

The Impact of Access to Electricity on Digital Connectivity

In this section, we model the diffusion of mobile connectivity, following the works of Griliches (1957) and Geroski (2000). We choose the following logistic curve in order to fit the diffusion of mobile connectivity:

$$n_{jt} = \frac{n_{jt}^*}{1 + exp[-\beta(t - \tau)]}$$

where n_{jt} is the population share of actual users of digital connectivity and n_{jt}^* is the share of potential users. The parameters β and τ are respectively the speed of diffusion and the inflection year, that is the year when the speed of diffusion is maximal. They are assumed to be country and year independent. Equation (1) follows from the assumption that the growth rate of users is proportional to the share of non-users.

n_{jt} is measured by the penetration rate of mobile telephony, internet or smartphones in country j in year t, denoted by PEN_{jt}.

Following the specification by Czernich et al. (2011), we assume that the share of potential users n_{jt}^* depends on price, quality, income, education and access to electricity.[10] On the basis of that assumption, n_{jt}^* can be expressed as:

$$n_{jt}^* = \gamma_0 + \gamma_1 ELEC_{jt} + \gamma_2 GDPPC_{jt} + \gamma_3 LITERACY_{jt} + \gamma_4 LNk_{jt} + \gamma_5 MOBPRICE_{jt}$$

where $ELEC_{jt}$ denotes our measure of access to electricity. Its coefficient is expected to be positive or statistically non-significant. Indeed, the lack of access to electricity acts as a constraint on the share of potential ICT users as it is costly to recharge phones or to extend the network coverage in areas deprived from electricity. The coefficient γ_1 measures the marginal effect of access to electricity on the share of potential ICT users.

$GDPPC_{jt}$ denotes GDP per capita, a proxy for income. The effect of income, captured by the coefficient γ_2, is expected to be positive.

$LITERACY_{jt}$ denotes the literacy rate in country j in year t. Its effect is also expected to be positive, particularly for internet usage. Indeed, most internet contents in Sub-Saharan Africa are provided in foreign languages. Therefore, higher literacy rate means more end-users able to consume contents on the internet.

$LN\ k_{jt}$ denotes the natural logarithm of capital expenditures per capita, is a proxy for network quality. Its coefficient γ_4 is expected to be positive as investment enables access to unconnected consumers by increasing network coverage and the quality of digitalconnectivity.

Finally, $MOBPRICE_{jt}$ denotes price in the modeling of the penetration rate of mobile telephony, internet and smartphones. Its coefficient γ_5 is expected to be negative, as lower price should enable poorer consumers to enter the market and, as a result, raises the share of potential users.

The expression of n^*_{jt} from Equation (2) has been introduced into Equation (1) with an added error term ε_{jt}. The coefficients of the final model are estimated by nonlinear least squares. We assume that variations in access to electricity are not driven by digital connectivity due to the following two reasons. First, access to electricity aims at powering the whole economy and not just the digital sector. Second, providing access to electricity is costly and hardly predictable. Until 2016, access to electricity by households in Africa was made on-grid and requires heavy investment in power production capacity and in transportation and distribution networks. As a result, annual progress in access to electricity results from earlier decisions that are not correlated with yearly change in digital connectivity. While government may simultaneously plan to improve access to electricity and digital connectivity, the unpredictable nature of electricity projects introduces randomness in the variation in access to electricity.

The nonlinear least squares estimates are reported in Table 3. The impact on mobile telephony is estimated by restricting the sample to 2000-2009, before any significant uptake of mobile internet.

The first panel reports the estimates of the impact of access to electricity on access to mobile telephony. The point estimate is positive but statistically not significant, suggesting that access to mobile telephony is unrelated to access to electricity. Such outcomes is well aligned with the rapid diffusion of mobile telephony across the region despite low access to electricity. They also align with the fact that mobile telephony only requires dumb phones that typically consume significant less energy and require less frequent charge than smartphones. Key determinants of access to mobile telephony are income, investment and price: our estimates suggest that an increase in GDP per capita or investment in mobile network are associated with a statistically significant increase in the penetration rate of mobiletelephony.

The impact on internet access is different: access to electricity comes with increased internet access. Both smartphone and mobile internet penetrations increase with access to electricity. The impact is positive and strongly significant for smartphone penetration, highlighting the higher consumption of energy compared to dumb phones and the need for frequent recharge. Income appears less a significant determinant of smartphone adoption than electricity. The coefficient of income, though positive is not statistically significant. Literacy is a strong determinant of internet access as its coefficient is positive and statistically significant.

These findings account for the non-linearity of the diffusion process. After accounting for the access to electricity, income, literacy, network quality and service price, it turns out that the smartphone and mobile internet are diffusing faster than mobile telephony. The estimated diffusion speed of smartphone and mobile internet is roughly twice that of mobile telephony, probably reflecting higher technology readiness: smartphone or internet users typically tran- sition from mobile telephony. The inflection point is estimated at 2007 for mobiletelephony, and between 2015 and 2016 for mobile internet and smartphones.

The Impact of Access to Electricity on the Usage of Digital Connectivity

The econometric model can be expressed as:

$$USAGE_{jt} = \gamma_0 + \gamma_1 ELEC_{jt} + \gamma_2 GDPPC_{jt} + \gamma_3 LITERACY_{jt} + \gamma_4 LNk_{jt} + \mu_j + v_t + s_{jt} \quad (3)$$

where $USAGE_{jt}$ denotes internet usage, measured by international internet traffic per user (b) or mobile data traffic per user (q).

μ_j and v_t are country and year fixed effects, capturing country-specific usage of internet and trend in data traffic.

The OLS estimates of Equation (3) are reported in the last panel of Table3. Access to electricity has a positive but not significant impact on internet usage. Rather, income, literacy and network investment turns out to be the most significant determinant of internet usage. These findings hold when international internet traffic is restricted to the period after 2007 when smartphones took off. Using a limited sample of 30 countries and 5 years for which mobile internet traffic data is available, we also find no statistically significant impact of access to electricity on usage.

TABLE 3
ACCESS TO THE ELECTRICITY AND MOBILE CONNECTIVITY

	mobpen	*mobpen*[+]	*smartpen*	*mobint*	*ln*(b)	*ln*(b)[++]	*ln*(q)
access to electricity γ_1	0.053	0.034	0.324***	0.297*	0.009	0.026	-0.007
	(0.047)	(0.044)	(0.104)	(0.163)	(0.013)	(0.018)	(0.015)
gdp per capita γ_2	2.990**	3.040**	0.100	0.336	0.049***	0.076***	0.100
	(1.222)	(1.302)	(0.300)	(0.830)	(0.018)	(0.020)	(0.235)
literacy rate γ_3	-0.024	-0.027	0.032	0.252**	0.026**	0.045**	0.013
	(0.038)	(0.038)	(0.050)	(0.109)	(0.011)	(0.019)	(0.037)
log(mob. capital stock) γ_4	8.820***	9.136**	13.816***	8.708**	0.255**	0.262	1.275
	(3.361)	(3.646)	(3.347)	(4.079)	(0.129)	(0.257)	(0.808)
price of voice and sms γ_5	-27.653**	-33.209**					
	(13.856)	(16.223)					
diffusion speed β	0.239***	0.252***	0.518***	0.500***			
	(0.077)	(0.085)	(0.066)	(0.159)			
inflection point τ	7.767**	7.870**	15.648***	14.676***			
	(3.524)	(3.502)	(0.876)	(1.747)			
constant of the ceiling γ_0	8.398*	9.503*	-38.812***	-39.103**			
	(4.368)	(4.993)	(10.304)	(16.701)			
country fixed effects					yes	yes	yes
year fixed effects					yes	yes	yes
Observations	256	247	390	292	599	373	133
Countries	39	38	39	39	38	38	30
Time span	2000-09	2000-09	2007-16	2005-16	2000-16	2007-16	2012-16
R squared	0.950	0.950	0.920	0.771	0.906	0.793	0.720

Robust standard errors in parentheses. Significant at 1%(***), 5%(**) and 10%(*).

[+] Sample without South Africa, the market with the largest penetration of smartphone before 2009.

[++] Sample restricted to the period after 2007 when smartphones took off.

CONCLUSION

Our empirical investigation shows that access to electricity is a strong driver of internet access in Sub-Saharan Africa, but less for access to mobile telephony and internet usage. Beyond access to electricity, income is the key determinant of access to mobile telephony, while literacy appears to be the key determinant of internet access. However, both income and literacy have significant impact on internet usage.

These findings suggest that access to electricity could be an important enabler of internet access in Sub-Saharan Africa. Public policies seeking to expand digital connectivity in this region should therefore take into consideration the issue of access to electricity, especially in those areas where it is not available or affordable. Private sector investors with interest in digital connectivity may find it profitable to support access to electricity through a variety of business models, for instance by bundling connectivity services with access to off-grid electricity in rural areas.

However, as suggested by our findings, access to electricity alone is not sufficient to drive usage. Income growth, literacy and network investment are critical to support increased usage. Therefore, public policies seeking to increase internet usage should promote digital literacy while implementing regulations that favor network investment and promote the diffusion of contents or use cases that enable increased income for users. Private sector investors should promote quality digital connectivity and services that enable increased income while being adapted to the level of digital literacy of end-users.

This paper relies on aggregate measures of digital connectivity and access to electricity, limiting the assessment of the impact of access to electricity on digital inclusion, especially in rural areas where it is the most deficient. Access to individual or regional level data would enable the estimation of the heterogeneous effects according to users' characteristics, with a focus on rural residents and women. Moreover, our estimation did not account for network effects, as providing electricity to rural users could trigger more communications from urban users. Future studies should address these issues.

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ENDNOTES

1. GSMA Intelligence
2. International Energy Agency - World Energy Outlook 2017.
3. Before the arrival of the internet, mobile users typically rely on kiosks with electric generators to recharge their devices. With the arrival of the internet, the cost of recharging rises to higher power consumption of internet-capable devices, up to $90 per year in Kenya – 6 per cent of GDP per capita – according to estimates by David Wogan. See https://blogs.scientificamerican.com/plugged-in/charging-a-mobile-phone-inrural-africa-is-insanely-expensive/
4. Among other projects are the Central African Backbone funded by the African Development Bank and the Africa Coast to Europe project supported by the World Bank.
5. In Niger, the government reduced two mobile-specific taxes in June 2017, while Ghana remove a 20% customs duty on imported handsets (GSMA, 2018).
6. In Rwanda, the government launched a Digital Ambassador Program in 2017 covering 12 districts and reaching 27.000 individuals. In Zimbabwe, the government approved a $250 million scheme from the country's universal service fund to deploy more than 600 base stations in rural areas (GSMA, 2018).
7. Figures from GSMA (2018) suggest almost 50% decline in the price of smartphones in Sub-Saharan Africa between 2012 and 2017.
8. See for instance Houngbonon & Jeanjean (2016)
9. Retrieved as of the 12th June, 2018

10. Alternative specifications assume that socio-economic variables affects the diffusion speed (Lee et al., 2011) or both the saturation level as well as the diffusion speed (Gruber & Verboven, 2001). However, our specification provides the best fit for the data, with R-squared greater than 90%, compared to less than 85% when we specify the diffusion speed as a function of socio-economic variables. Armey & Hosman (2016) also assume that the ceiling is affected by access to electricity, but they transform the logistic model into a dynamic model.

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