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Access to Electricity and ICT Usage: A Country-level Assessment on Sub-Saharan Africa*

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Abstract

While several determinants of ICT usage has been investigated in the literature, the impact of access to electricity has been so far overlooked. In this paper, we rely on country-level data on the penetration rates of mobile telephony, Internet and smartphones, as well as average revenue per user (ARPU) to evaluate the impact of access to electricity on ICT usage in Sub-Saharan Africa. Using a panel of 40 countries from 2000 to 2016 and a logistic diffusion model, we find a positive and statistically significant impact of access to electricity on the penetration rate of the Internet and smartphones, but no significant effect on the diffusion of basic mobile telephony. Accounting for both the extensive and intensive margins, we find that ICT usage increases by 0.43 US dollar per connected user, meaning that mobile ARPU would have declined by 0.1 percentage point more per year without the expansion of access to electricity. These findings are robust to the measurement of access to electricity, and to the inclusion of controls for income, education, urbanization, price, competition and network investment.

Keywords: Electricity, ICT, Africa.

JEL Classification: L94, L96.

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1 Introduction

The usage of information and communications technologies (ICT) is proven to have positive effects on the economy (Roller & Waverman, 2001; Czernich *et al.*, 2011).¹ In particular, it is the driver of the revenue of network operators, online content providers, platform operators, equipment providers, and as input in many sectors of the economy. In developing countries, its usage is generating significant innovations in several sectors of the economy including banking and finance, energy, agriculture, health and education.² As a result, both corporate and government expect to rely on it to sustain economic growth. However, latest figures suggest that while basic mobile telephony is widespread, the usage of advanced ICT services such as the Internet is lagging behind.³ While several determinants of ICT usage has been investigated in the economic literature, the impact of access to electricity has been so far overlooked (Armey & Hosman, 2016).

There are two main ways in which access to electricity affects the use of mobile telecommunications services. Firstly, expanding access to the electricity lowers the cost of running the network, as it enables operators to switch from expensive fuel generators to the electric grid. In competitive markets, this cost reduction could be passed-through to consumers as a reduction in price and, as a result, usage would increase. Secondly, providing access to electricity to previously unconnected users enables them to recharge their power-intensive devices at lower cost and, therefore, increase their usage of mobile services, particularly the Internet.⁴ In addition, as suggested by Lenz *et al.* (2017), the lack of access electricity is a constraint to development, thereby limiting the demand for goods and services in general and particularly for mobile services.

In this paper, we rely on country-level data to investigate the impact of access to electricity on mobile usage in Sub-Saharan Africa. This region is of particular interest as it hosts half of the world population without access to electricity, that is, 60% of its population.⁵ More specifically, we build a panel of 40 countries over the period 2000-2016, measure access to

¹Gruber & Koutroumpis (2011) and Gruber *et al.* (2014) among others also find a positive impact of ICT on economic growth.

²See Mobile for Development reports from the GSMA.

³As a matter of fact, recent figures from the GSMA shows that in Sub-Saharan Africa, the number of Internet users is smaller than the number of smartphones, suggesting a limited usage of the Internet. See Sub-Saharan Africa Mobile Economy, GSMA Report 2017.

⁴Indeed, before the arrival of the Internet, mobile users typically referred to a kiosk with an electric generator to recharge their telephones. With the advent of smartphones, the cost of this service rises, up to \$90 per year in Kenya according to estimates by David Wogan, that is 6 per cent of GDP per capita. See <https://blogs.scientificamerican.com/plugged-in/charging-a-mobile-phone-in-rural-africa-is-insanely-expensive/>

⁵Latest figures from the International Energy Agency point out that more than half a billion people in Sub-Saharan Africa do not have access to electricity. Energy Access Outlook, 2017.

electricity by the percentage of people living in households connected to a power source, and measure ICT usage by the penetration rates of basic mobile telephony⁶, Internet and smartphones, as well as the average revenue per user (ARPU). Our methodology proceeds in two steps.

First, we estimate the impact of access to electricity on the extensive margin of ICT usage with a logistic diffusion model. We assume that the ceiling of this curve depends on access to electricity as well as other key determinants such as income, education, urbanization, price, competition and network investment. Using nonlinear least squares estimation strategy, we find that access to electricity does not affect the diffusion of basic mobile telephony, but rather the diffusion of Internet and smartphones. A percentage point (pp) increase in access to electricity is predicted to raise the penetration rate by 0.37 pp for Internet and 0.16 pp for smartphones. The impact on the penetration rate of mobile telephony is positive but not statistically significant.

Second, we account for both the extensive and intensive margins using the average revenue per user (ARPU). Ordinary least squares estimates, controlling for country and year fixed-effects as well as investment in the mobile network, market concentration and economic development, show that access to electricity raises the monthly revenue of mobile services by 0.43 US dollar per connected user. Counterfactual simulations suggest that the mobile ARPU would have declined by 0.1 pp more without the expansion of access to electricity. Put it differently, 3% of the decline in the mobile ARPU has been avoided thanks to access to electricity. These findings are consistent with the positive impact of access to electricity on the use of the Internet. They are robust to using the Gini coefficient of nighttime lights as an alternative measure of access to electricity.

The findings of this paper are related to the literature on the determinants of ICT usage. While Armeij & Hosman (2016) investigate the impact of electricity on the number of Internet users in developing countries, we focus more specifically on Sub-Saharan Africa and extend the analysis to telecoms revenue. 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 the average revenue per user, smartphones penetration and a measure of access to electricity.

The remaining of the paper is organized as follows. Section 2 provides a brief summary of the literature on the determinants of ICT usage and the impact of access to electricity on development outcomes. Section 3 provides some background information about ICT usage and access to electricity in Sub-Saharan Africa. Section 4 describes the data and presents descriptive statistics about the correlation between access to electricity and ICT usage. Sec-

⁶That is, calls and SMS.

tion 5 presents the econometric models, the estimation strategy and the results. Section 6 concludes.

2 Related literature

Access to electricity affects both the demand and the supply for telecoms services. Demand for telecoms service typically depends on price and income. However, the actual price incurred by the user includes not only the market price, but also the cost of charging the phone, a decreasing function of access to electricity. As a result, everything else equal, access to electricity is expected to raise the demand for telecoms services. Income also depends on access to electricity. Early studies such as Jumbe (2004) and Wolde-Rufael (2006) emphasize the bi-directional causal relationship between access to electricity and income. Recent studies suggest that a positive impact on income would stem from industrial development (Rud, 2012), greater performance of micro and small enterprises (Grimm *et al.* , 2013) and more generally from human development (Lipscomb *et al.* , 2013).

Nevertheless, detailed analyses conducted by Kirubi *et al.* (2008) in Kenya or Lenz *et al.* (2017) in Rwanda show that the impact of electricity on income, particularly in rural areas, hinges upon the implementation of an integrated development approach. In addition, even if access to electricity raises income, the effect not only occurs in the long run, as suggested by Dinkelman (2011), but also depends on users preferences. Some of them may consider telecoms services as a normal good, raising the demand as their income increase, while others may consider it as an inferior good, shifting their demand towards more valued goods. In addition, the demand for electricity is typically low in rural areas (Bernard, 2012).

On the supply side, both the fixed cost of expanding the network as well as the cost of running it typically falls with access to electricity. Greater access to electricity would increase competition through the entry of new operators, investment in new base stations, or through price-cutting strategies as a result of lower marginal cost. This mechanism is expected to reduce the price and therefore increase the demand for telecoms services. To the best of our knowledge, no paper has yet investigated the impact of access to electricity on the price of telecoms services.

Armey & Hosman (2016) investigate the impact of access to electricity on the diffusion of the Internet. Using a panel of 40 low-income countries, of which 29 from Sub-Saharan Africa, over the period 2000-2009, they find a positive and significant impact of electricity availability on Internet usage. The concept of electricity availability, they argue, follows from the fact that grid power is unreliably measured and inequitably distributed in low-income coun-

tries. Therefore, they use the Gini coefficient of nighttime light as a measure of electricity availability. A within-country decrease in the Gini coefficient means greater availability of electricity, both in quantity and quality. ICT usage is measured by the percentage of people using the Internet. We shall focus on Sub-Saharan Africa and extend the analysis to basic mobile telephony, smartphones and telecoms revenue.

Mothobi & Grzybowski (2017) use individual level survey data from 11 Sub-Saharan Africa countries in 2011. Using the average nighttime light and a household’s dummy variable to measure access to electricity, 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 less deprived areas or households. While this paper suggest a positive impact of electricity on ICT usage, there is still a lack of evidence on the intensive margin of ICT usage and for Sub-Saharan Africa as a whole.

More generally, the economic literature on the determinants of ICT usage typically focuses on long run factors such as income, urbanization, education, regulation and market competition. For instance, Bohlin *et al.* (2010) emphasize a positive impact of per capita income, urbanization and regulation on the diffusion of new generations of mobile telecommunications. Lee *et al.* (2011) and Lin & Wu (2013) highlight the role of education and content quality on ICT usage in OECD countries.⁷ Gruber (2001) found a positive impact of the number of operators and market size on the speed of diffusion of mobile telephony in Central and Eastern Europe. However, these papers focus on advanced economies where basic infrastructures such as electricity are widely available. In this paper, we assess the impact of access to electricity in developing economies where up to 1 billion people are still deprived of, half of which live in Sub-Saharan Africa.⁸

3 Background on Access to Electricity and ICT Usage in Sub-Saharan Africa

Compared to North Africa, Sub-Saharan Africa has a very low level of access to electricity. According to estimates from the International Energy Agency (IEA, 2017), 600 million individuals, that is 57% of the population, lack access to electricity in the region in 2016, compared to less than 1% in North Africa. While most countries maintain their historical rates of progress, since 2012, a few has shifted upward their trend in access to electricity. Table A-1 in the Appendix presents the list of these high-performing countries. Remarkably, they are all located in East and West Africa.

⁷Yamakawa *et al.* (2013) shows that these long run factors also apply for developing countries.

⁸Energy Access Outlook, 2017.

Estimates from IEA (2017) suggest that the yearly growth rates of access to electricity in these high-performing countries rise 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 stems from a delay in financial support. As can be seen from Figures A-1 and A-2 in the Appendix, East Africa has earlier access to financial support whether from the World Bank or the African Development Bank, the two major financiers of power projects in the region. 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 implements the "Last Mile Connectivity Project" and the "Off-Grid Solar Access Project", providing access 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 suggest that these reforms were implemented earlier in East Africa.

Regarding ICT usage in Sub-Saharan Africa, the Internet has been lagging behind while mobile telephony is widespread. According to estimates from the GSMA, the penetration rate of mobile Internet was 26% in 2016, compared to 80% for mobile telephony. Within Sub-Saharan Africa, the Southern region lead the diffusion of mobile Internet (71% in 2016), followed by the West (25%), the East (16%) and the Centre (8%) (See Figure A-3).

International financial institutions, States 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.⁹ States typically rely on the allocation of frequency spectrum and tax breaks to provide incentive to operators to increase the coverage of their network.¹⁰ They also implement digital literacy programs and mobilize universal service funds to invest in areas where private investment is not profitable.¹¹ Private stakeholders

⁹Among 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.

¹⁰In Niger, the government reduced two-mobile specific taxes in June 2017, while Ghana remove a 20% due on imported handsets (GSMA, 2018).

¹¹GSMA (2018) reports that the government of Zimbabwe approved a \$250 million scheme from the country's universal service fund to deploy more than 600 base stations in rural areas.

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 the region.¹²

4 Data and Descriptive Statistics

4.1 Data

We build a panel of 40 Sub-Saharan African countries from 2000 to 2016. We exclude islands such as Mauritius, Comoros and Seychelles. We drop other countries such as Togo, Swaziland, South Sudan, Somalia and Djibouti that have many missing values. The period 2000-2016 is interesting because, not only ICT usage basically starts from the early 2000s but also, as discussed in section 3, access to electricity has accelerated from 2012, providing exogenous variations that will be useful in the econometric estimation.

Access to electricity is measured by the percentage of the population connected to a grid or off-grid power source. Data on access to electricity come from the World Development Indicators (WDI) database of the World Bank.¹³ We check that these data are consistent with the ones provided by the International Energy Agency. However, given the critics of Arney & Hosman (2016) about the reliability of this variable, we test the robustness of our findings using their measure, the Gini coefficient of nighttime light, as a proxy for access to electricity.

We measure the extensive margin of ICT usage by the penetration rates of mobile telephony, mobile Internet and smartphones. The penetration rate of mobile telephony and Internet are estimates from the ITU. We rely on the number of individuals using the Internet, instead of the number of users with Internet-compatible devices as provided by the GSMA, because it is a better measure of actual usage. It includes, however, Internet usage from fixed broadband. To the extent that mobile telephony makes up to 97 per cent of telecoms subscriptions in Sub-Saharan Africa, this estimate is closer to actual Internet usage through mobile phones.¹⁴ In addition, the average revenue per user (ARPU) is used as a monetary measure of ICT usage. It is provided by the GSMA and includes all mobile services, in particular voice, SMS, Internet, mobile-money and other value-added services.

¹²Figures from GSMA (2018) suggest almost 50% decline in the price of smartphones in Sub-Saharan Africa between 2012 and 2017.

¹³Retrieved as of the 12th June, 2018.

¹⁴According to the International Telecommunications Union, there were 842,830,670 subscriptions for mobile telephony in Africa in 2016, against 25,159,530 for fixed telephony.

Additional data include capital expenditures and the Herfindahl-Hirshman Index of market concentration (HHI) obtained from the GSMA Intelligence database.¹⁵ These variables will be useful to control for network investment and competition in the econometric analysis. We also retrieved data on economic development, the level of education and access to other infrastructures such as water from the WDI database. Economic development is measured by the Gross Domestic Product (GDP) per capita and the rate of urbanization. The level of education is measured by the gross enrollment in secondary school. Table 1 summarizes the definition and sources of the main variables.

Table 2 presents their yearly average. Access to electricity increases by less than 1 point per year. However, and in accordance with the discussion in section 3, the growth rate has accelerated since 2010. The average ARPU has been divided by 3 between 2000 and 2016, driven by a convergence between countries. This trend accords well with a strong decline in market concentration and a fast penetration of mobile telephony, rising from a mere 2% in 2000 to 84% in 2016. Internet penetration has been rising, but at much smaller rate. It has been outpaced by smartphones penetration since 2014, suggesting that users are constrained in their usage of the Internet despite having access to the appropriate device.

¹⁵The HHI is calculated as the sum of squared market shares of active operators within a given market.

Table 1: Main Variables

Variable	Definition	Units	Source
<i>ELEC</i> ¹	Percentage of the population with access to electricity	0-100	World Bank
<i>MOBPEN</i> ²	Percentage of the population with a mobile phone	0-100	GSMA
<i>INTPEN</i> ³	Percentage of the population using the Internet	0-100	GSMA
<i>SMARTPEN</i> ⁴	Percentage of the population with a smartphone	0-100	GSMA
<i>ARPU</i> ⁵	Average revenue per mobile subscriber	US dollars	GSMA
<i>CAPEXPS</i>	Capital expenditures per subscriber	US dollars	GSMA
<i>HHI</i> ⁶	Herfindahl-Hirshman Index of market concentration	0-1	GSMA
<i>URBAN</i>	Percentage of the population residing in urban areas	0-100	World Bank
<i>GDPPC</i>	GDP per capita	US dollars PPP	World Bank
<i>SECOND</i>	Gross enrollment rate in lower secondary education	0-100	World Bank
<i>NLG</i> ⁷	Gini coefficient of nighttime lights	0-1	NOAA

¹ Based on data collected from industry, national surveys and international sources. Estimated number of individuals with access to electricity divided by population size.

² Number of mobile subscriptions, including multiple, divided by population size.

³ Number of individuals who have used the Internet in the last 3 months, irrespective of the device and the technology (fixed or mobile). However the penetration rate of fixed telephony is less than 1% in Sub-Saharan Africa.

⁴ Number of unique SIM cards that have been registered on the mobile network and are used in a smartphone device at the end of the period, divided by population size.

⁵ Total revenue from mobile services (calls, SMS, MMS, Internet, value added services, handset...) divided by the number of subscribers.

⁶ Sum of the squares of market shares. Based on market shares estimates by the GSMA.

⁷ Nighttime light data from the US National Oceanic and Atmospheric Administration (NOAA).

Table 2: Average Value of the Main Variables

year	elec	arpu	mobpen	intpen	smartpen	capexps	hhi	urban	gdppc	second	gini
2000	25.7	27.6	2.0	0.6	.	79.4	6863.8	34.6	3293.6	41.6	0.82
2001	25.0	29.1	3.0	0.7	.	64.8	6113.0	35.0	3272.5	39.7	0.83
2002	24.9	26.4	4.3	0.9	.	49.7	5942.3	35.2	3227.6	39.9	0.83
2003	27.0	23.6	6.0	1.4	.	40.7	6070.7	36.2	3272.5	40.6	0.84
2004	27.3	20.7	8.0	1.8	.	29.8	6088.9	36.2	3442.0	42.1	0.83
2005	27.8	18.5	11.7	2.2	.	23.3	5900.7	36.7	3598.2	44.7	0.83
2006	29.2	18.2	17.1	2.7	.	23.0	5769.8	37.2	3702.7	46.4	0.83
2007	30.7	16.6	24.9	3.0	0.2	23.3	5585.4	37.7	3903.0	47.7	0.83
2008	30.9	15.7	34.8	3.7	0.4	21.1	5265.4	38.2	4058.3	49.4	0.84
2009	31.9	13.1	42.7	4.5	0.9	18.4	5135.3	38.6	3989.2	51.5	0.82
2010	32.6	10.9	51.5	6.1	1.8	15.8	4857.7	39.1	3967.9	53.4	0.81
2011	34.2	10.3	58.8	7.4	3.4	14.3	4777.3	39.6	4065.7	55.4	0.82
2012	35.1	10.0	67.9	9.1	5.9	14.7	4682.6	40.6	4241.2	57.5	0.81
2013	36.1	9.9	73.1	11.4	9.2	14.4	4677.5	41.1	4263.1	58.0	0.80
2014	37.7	10.0	78.9	13.9	13.2	14.9	4661.6	41.6	4303.9	58.6	
2015	39.2	9.8	82.4	17.1	18.5	16.1	4610.6	42.1	4214.8	58.0	
2016	41.6	9.6	83.9	19.2	24.2	14.3	4650.3	42.6	4138.3	60.5	

4.2 Correlation between Access to Electricity and ICT Usage

We start by conducting a descriptive analysis of the relationship between access to electricity and ICT usage. Assuming that access to electricity is more critical to Internet usage, we focus on the correlation between these two factors. On Figures 1 and 2 we present the relationship between access to electricity within a country and variations in Internet usage and mobile ARPU respectively. Overall, the relationship is upward sloping, meaning that countries with greater increase in access to electricity tends to experience faster increase in Internet penetration and a smaller decrease in ARPU.

To be more specific, we focus on the high-performing countries, that is countries that experienced a shift in their trend of access to electricity (See Table A-1). As discussed in section 3, these countries are all located in West and East Africa. Therefore, we split the set of countries into two groups corresponding to the two regions. Table 3 highlights a significant acceleration in the growth rate of access to electricity after 2012. In West Africa, the growth rate more than doubles, from 1.05 to 2.64 percentage point, whereas in East Africa, it accelerates from 0.75 to 6.18 percentage points. Meanwhile, Table 3 shows that Internet usage and mobile ARPU follow suit. More specifically, the growth rate of the penetration rate of Internet increases by 9-folds in West Africa and 5-folds in East Africa. Likewise, while mobile ARPU has been falling in both regions, the rate slows down significantly, and even becomes

positive in East Africa. Interestingly, in East Africa where the access to electricity increases the most, we observe that not only Internet usage rises more, but also mobile ARPU starts rising slightly, contrary to West Africa.

While these patterns suggest a positive impact of access to electricity on ICT usage, the observed correlation could be driven by several confounding factors. For instance, the rise in mobile ARPU is potentially driven by greater diffusion of the Internet. However, as a diffusion process in its initial phase, access to Internet would have accelerated irrespective of the expansion of access to electricity. We account for this feature by using a logistic diffusion function to model the penetration rate of Internet. An additional factor driving this trend is the introduction of 4G technology. We introduce capital expenditures in the econometric models to account for investment in new technology. Furthermore, as discussed in section 2, within-country variations in economic development, education and mobile market competition could drive change in ICT usage. The econometric models in the next section account for these limitations.

Figure 1: Access to Electricity and Internet Usage

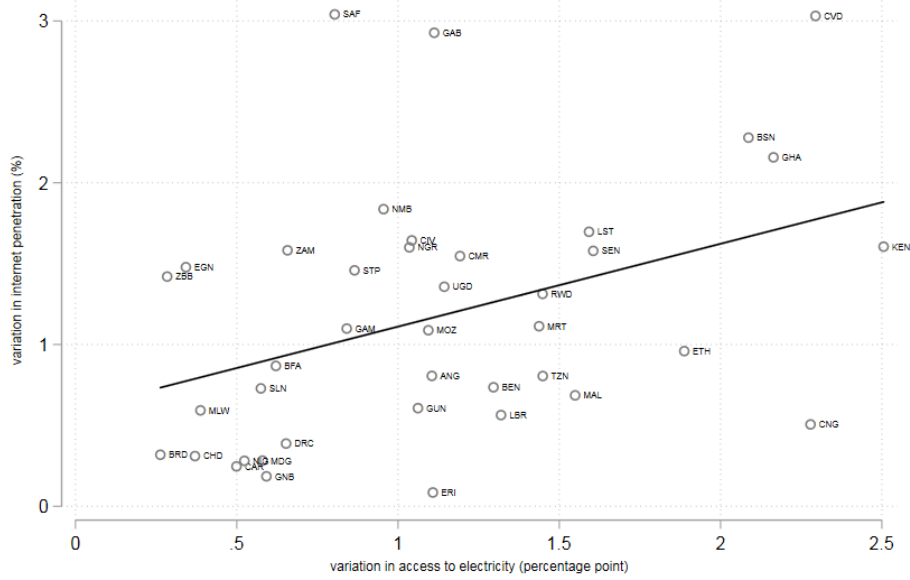


Figure 2: Access to Electricity and Mobile ARPU

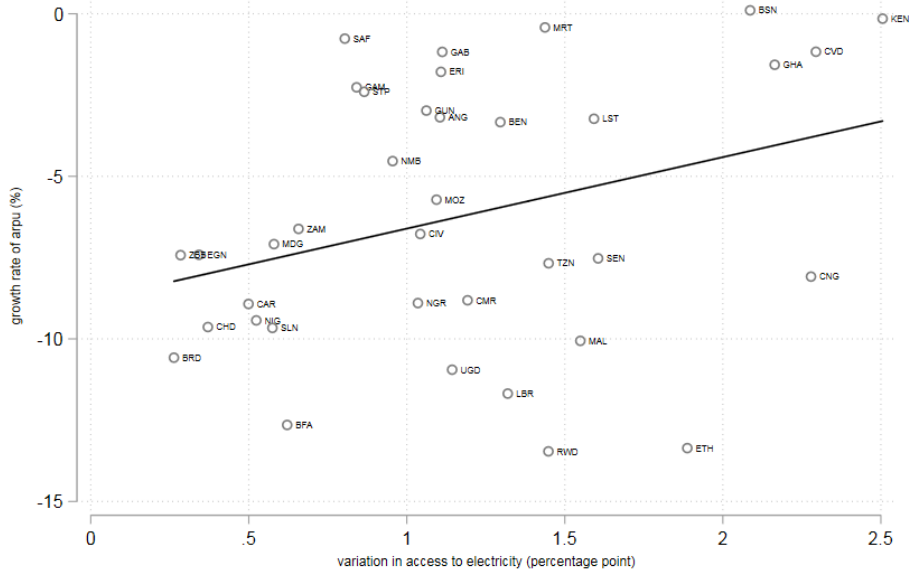


Table 3: Annual Variation in Access to Electricity, Internet and ARPU

	West Africa		East Africa	
	Before	After	Before	After
Electricity (percentage point)	1.05	2.64	0.75	6.18
Internet (percentage point)	0.30	2.61	0.62	2.86
ARPU (US dollars)	-2.08	-0.19	-1.47	0.08

See the list of countries and the periods corresponding to "before" and "after" in Table A-1 in the Appendix. For most countries, the break in the trend of access to electricity occurs in 2012.

5 Econometric Estimation

5.1 The Impact of Access to Electricity on the Diffusion of Mobile Services

In this section, we focus on the extensive margins of ICT usage using the penetration rate of mobile telephony, Internet and smartphones. Following the works of Griliches (1957) and Geroski (2000), the extensive margin of technology diffusion can be modeled by the following logistic curve:

$$PEN_{jt} = \frac{\gamma}{1 + \exp[-\beta(t - \tau)]} + \varepsilon_{jt} \quad (1)$$

Where PEN_{jt} denotes the penetration rate of mobile telephony, Internet or smartphones in country j in year t . ε_{jt} corresponds to the residuals.

γ is the ceiling of the diffusion curve, that is, the maximum penetration rate. β and τ are respectively the speed of diffusion and the inflexion year.

Following the discussion in section 2, we assume that the ceiling of the diffusion curve depends on access to electricity. This assumption means that the lack of access to electricity acts as constraint on the maximal number of ICT users as it is costly to extend the network to deprived areas or to recharge phones.

Following the determinants of ICT usage found in the literature, we also assume that the ceiling depends on economic development, measured by the rate of urbanization, and the level of education, measured by the gross enrollment rate in secondary school.

We test the underlying mechanisms by including GDP per capita, price, investment and competition as additional controls. For mobile telephony, we use the ARPU as a proxy for price, whereas for the Internet we use the price per Gigabyte.¹⁶ Investment is measured by the capital expenditures per subscriber. Competition is measured by the HHI. Less competition is typically associated with higher price and, as result, delay adoption by the poor.

On the basis of these assumptions, the ceiling of the diffusion curve can be expressed as:

$$\gamma_{jt} = \gamma_0 + \gamma_1 ELEC_{jt} + \gamma_2 URB_{jt} + \gamma_3 SEC_{jt} + \gamma_4 GDPPC_{jt} + \gamma_5 PRICE_{jt} + \gamma_6 CAPEX_{jt} \quad (2)$$

And the diffusion speed can be expressed as:

$$\beta_{jt} = \beta_0 + \beta_1 HHI_{jt} \quad (3)$$

The new expressions of γ_{jt} and β_{jt} , from Equations (2) and (3) respectively, have been introduced into Equation (1). The coefficients have been estimated using nonlinear least squares. The estimates are reported in Table 4.

¹⁶Price per Gigabyte comes from data collected by the think tank Research ICT Network. It corresponds to the price of the least expensive 1 GB Internet package.

It turns out that access to electricity has a positive and significant impact on ICT usage. The coefficient γ_1 of access to electricity in specifications (1), (2) and (3) in Table 4 is positive and statistically significant at the 1% level. More specifically, 10 percentage point (pp) increase in access to electricity is predicted to raise the penetration rate by 2.14 pp for mobile telephony, 6.65 pp for Internet and 2.54 pp for smartphones. These magnitudes suggest that access to electricity is more important for Internet usage than for basic mobile telephony. This result confirms the correlation from Table 3 and the coefficients of the controls, namely urbanization rate and enrollment in secondary school, are consistent with the findings from the literature. Overall, ICT usage increases with urbanization and education.

Estimates from specifications (1') in Table 4 suggest that most of the impact of access to electricity on the diffusion of basic mobile telephony stems from the effects on income, price and competition. After controlling for these variables, the coefficient of access to electricity falls by 30% and is no longer significant. Therefore, the remaining channel, that is the cost of recharging the phone, cannot explain the positive relationship between access to electricity and the diffusion of basic mobile telephony. This finding is consistent with the fact that basic mobile terminals sold in Africa were designed to save energy. Therefore, rising level of income, increasing competition with the subsequent reduction in price, on top of urbanization and education, are the main driving forces of the widespread use of mobile phones in Africa, irrespective of access to electricity.

However, estimates from specifications (2') and (3') in Table 4 suggest that the cost of recharging the phone plays a significant role in the usage of the Internet. After controlling for income, price, investment and competition, the magnitude of the impact falls, but remains significant. The impact on the share of Internet users falls by 44% and is statistically significant at the 1% level, while the impact on the penetration of smartphones drops by 38% and is significant at the 5% level. Hence, while the cost of recharging the phone plays a significant role, the other channels are also important in explaining the impact of access to electricity on Internet usage. The estimates show that Internet and smartphones penetration increase with income and investment, but fall with price and market concentration.

Table 4: Access to Electricity and the Diffusion of Mobile Telephony: Nonlinear Least Squares Estimates

	mobile penetration		internet penetration		smartphones penetration	
	(1)	(1')	(2)	(2')	(3)	(3')
constant of the ceiling γ_0	-6.949*	-10.195***	-13.691***	-8.521***	-14.794***	-15.384***
	(3.705)	(3.654)	(3.476)	(1.710)	(2.902)	(3.163)
pop. share with access to electricity γ_1	0.214***	0.150	0.665***	0.374***	0.254***	0.157**
	(0.080)	(0.091)	(0.143)	(0.047)	(0.056)	(0.062)
urbanization rate γ_2	1.259***	1.310***	-0.037	0.014	0.552***	0.581***
	(0.115)	(0.121)	(0.055)	(0.039)	(0.090)	(0.098)
gross enrollment rate in secondary γ_3	0.567***	0.620***	0.359***	0.258***	0.197***	0.354*
	(0.069)	(0.069)	(0.084)	(0.033)	(0.047)	(0.187)
GDP per capita γ_4		0.499**		0.239**		0.206***
		(0.227)		(0.095)		(0.052)
ARPU or price per GB γ_5		-0.389*		-0.202***		
		(0.220)		(0.059)		
capital expenditures per subscriber γ_6				0.140***		0.173***
				(0.033)		(0.055)
diffusion speed β_0	0.391***	0.520***	0.233***	0.410***	0.590***	0.586***
	(0.028)	(0.063)	(0.026)	(0.055)	(0.062)	(0.059)
Herfindahl-Hirschman Index β_1		-0.227***		-0.176***		
		(0.079)		(0.058)		
year of inflexion τ (+2000)	9.583***	9.306***	15.822***	13.071***	15.118***	15.240***
	(0.260)	(0.255)	(1.770)	(0.625)	(0.449)	(0.466)
Observations	528	528	518	518	314	314
R squared	0.925	0.927	0.889	0.897	0.893	0.898

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1 Price is measured by ARPU in specification (1) and the price per GB in specification (2).

5.2 The Impact of Access to Electricity on Mobile ARPU

While the previous section deals with the extensive margin of ICT usage, in this section, we want to account for the intensive margin. Without reliable data on the quantity of mobile services consumed, we rely on the average revenue per user, assuming that the demand for ICT services can be expressed as follows:

$$q = \frac{f(x)}{p} \quad (4)$$

Where $f(x)$ is a function of characteristics that will be clarified below. This assumption means that the elasticity of demand is constant and equals 1. Although restrictive, Iimi (2005) find a demand elasticity of 1.3 in Japan for mobile services.

Under this assumption, let's consider an individual i in country j during the period t with a consumption of mobile services denoted by q_{ijt} . This latter is nil if the individual has not

yet subscribed to any mobile service. Let e_{ijt} denotes a dummy equals 1 if the individual has access to electricity and 0 otherwise. Finally, let x'_{ijt} and x''_{jt} respectively denote sets of individual and product characteristics. f is assumed to be a linear function of these variables. The revenue generated by this individual can be expressed as:

$$y_{ijt} \equiv p_{jt} * q_{ijt} = \alpha + \beta e_{ijt} + \gamma x'_{ijt} + \delta x''_{jt} + \varepsilon_{ijt} \quad (5)$$

The coefficient β corresponds to the revenue difference with and without access to electricity. Summing Equation (5) over all individuals and dividing by the number of subscribers yields:

$$\bar{Y}_{jt} = \alpha + \beta \bar{E}_{jt} + \gamma X'_{jt} + \delta X''_{jt} + \epsilon_{jt} \quad (6)$$

Where \bar{Y}_{jt} corresponds to the average revenue per user in country j during the period t . \bar{E}_{jt} is the ratio of the number of individuals with access to electricity to the number of mobile users. X'_{jt} is a set of individual characteristics averaged at the country level. Following the results from section 5.1, it includes GDP per capita as a proxy for income, the rate of urbanization as a proxy for the location. X''_{jt} is a set of product characteristics, including capital expenditures per subscriber as a proxy for investment in mobile networks, and the Herfindahl-Hirschman Index as a proxy for competition. Variation in cost is driven by technological progress which is common to all countries. Therefore, we add a time trend into Equation (6). Moreover, preferences for mobile services are specific to each country. We account for them by including country fixed-effects into Equation (6). The final econometric model can be expressed as:

$$ARPU'_{jt} = \alpha + \beta ELEC'_{jt} + \gamma_1 GDP_{jt} + \gamma_2 URB_{jt} + \delta_1 CAPEX_{jt} + \delta_2 HHI_{jt} + \mu_j + \nu_t + \epsilon_{jt} \quad (7)$$

$ARPU'_{jt}$, the average revenue per unique user, is the ratio of total mobile revenue to the number of unique subscribers. We obtain the number of unique subscribers using an estimate of the number of SIM cards per subscriber provided by the GSMA. $ELEC'_{jt}$, the share of electricity users is the ratio of the number of adults with access to electricity to the number of unique mobile subscribers.

β , the difference in mobile revenue per user with and without access to electricity, includes two components, that is, the variation in ARPU due to the acquisition of new mobile users and the variation due to an intensive usage of mobile services by existing users. We cannot distinguish between these two components because we do not observe the number of mobile

users with access to electricity. The first component is expected to be negative because earlier mobile users are typically the ones with the highest willingness to pay. The second is expected to be positive or nil because, as suggested by the results in section 5.1, access to electricity removes at least the constraint from using the Internet. Therefore, a positive β means that the gain from the intensive usage outweighs the drop in ARPU due to the acquisition of new users with lower willingness to pay.

Equation (7) is estimated using OLS. Our source of identification stems from within-country variations in the expansion of access to electricity. As discussed in Figure 2, yearly variations ranges from 0.2 to 2.5 percentage points. We assume that these variations are not driven by the consumption of mobile services because 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.¹⁷ As a result, yearly progress in access to electricity results from earlier decisions that are not correlated with the determinants of yearly change in mobile consumption. While government can simultaneously plan to improve access to electricity and the consumption of mobile services, the unpredictable feature of access to electricity introduces a randomness in its variations. However, we will implement an instrumental variable strategy to check the robustness of the estimates.

The fixed-effects OLS estimates of the model (7) are reported in Table 5. The estimate of β is positive and statistically significant at the 1% level. We find that providing access to electricity to a mobile user increases the monthly ARPU by \$43.4 cents. Counterfactual simulations presented in Table A-2 in the Appendix show that, given the telecoms revenue gain from access to electricity, the ARPU would have declined by a 0.1 percentage point further without access to electricity. To the extent that mobile ARPU falls by 3.6% per year, this means that 3% of the decline in mobile ARPU is avoided by the expansion of access to electricity.¹⁸ This finding is consistent with the positive and significant impact of access to electricity on the usage of the Internet found in Table 4.

The coefficients of the controls turn out as expected. In particular, an increase in capital expenditures, market concentration or the rate of urbanization is associated with higher ARPU. The coefficient of GDP per capita is positive but not statistically significant.

¹⁷According to data from World Development Indicators, electricity production from renewable, typically off-grid, represents less than 2 percent of total production in 2014.

¹⁸This ratio is calculated as: $\frac{-0.1}{-3.6-0.1} = 0.03$

5.3 Robustness check

Following Arney & Hosman (2016), we check the robustness of our findings with respect to the measure of access to electricity. Hence, we use the Gini coefficient of nighttime lights as an alternative measure of the availability of electricity. The estimated equation can be expressed as:

$$ARPU_{jt} = \alpha' + \beta' NLG_{jt} + \gamma_1' GDP_{jt} + \gamma_2' URB_{jt} + \delta_1' CAPEX_{jt} + \delta_2' HHI_{jt} + \delta_3' NL_{jt} + \nu_j + \nu_t + \varepsilon_{jt} \quad (8)$$

Where NLG_{jt} is the Gini coefficient of nighttime lights. We collect nighttime lights data from the US National Oceanic and Atmospheric Administration. These data were collected at the lowest geographical level. Then the Gini coefficient is calculated using the distribution of the mean nighttime lights per country. A fall in the Gini coefficient means greater availability of electricity. Thus, the coefficient β' should be negative to be consistent with the main result.

On top of the controls used in Equation (7) we also add the total nighttime light at the country level, measured in pixels. As suggested by Henderson *et al.* (2012), this later is a good proxy for economic growth. We focus on the years 2000, 2008, 2012 and 2013 to get enough variations in the Gini coefficient.

The outcomes of the estimation are reported in Table 5. The coefficient of the new measure of access to electricity is negative, but less precisely estimated. A percentage point fall in the Gini of nighttime lights is associate with \$58 cents increase in the ARPU. This finding lends support to our main finding that access to electricity raises ICT usage. Given that the average Gini coefficient falls by 0.02 point (Table 2) between 2000 and 2013, the predicted impact on the ARPU is 1.2 US dollar. Meanwhile, the average access to electricity increases by 10 percentage points during the same period. As a result, the point estimate of the impact of the Gini coefficient of nightlight corresponds to 0.12 US dollar increase in ARPU for a percentage point increase in access to electricity.

Table 5: Access to Electricity and Mobile Revenue: Fixed-effects OLS Estimates

Dependent variable: ARPU	(1)	(2)
access to electricity (β)	0.434*** (0.157)	
gini coefficient of night light		-58.53* (28.83)
GDP per capita	0.228 (0.274)	-0.012 (0.112)
urbanization rate	0.880*** (0.319)	-0.667 (0.522)
capital expenditures per subscriber	0.123*** (0.017)	0.134*** (0.020)
herfindahl-hirshman index	15.71*** (4.521)	16.44** (7.691)
night light		0.822* (0.406)
constant	-26.14 (20.76)	74.11*** (25.34)
Observations	642	120
Number of countries	40	35
R-squared	0.364	0.808
F-stat	13.76	66.48

ARPU is the average revenue per unique user. Robust standard errors in parentheses, corrected for heteroskedasticity and autocorrelation. Country and year fixed effects are included in all specifications. Significant at 1%(***), 5%(**) and 10%(*).

6 Conclusion

This paper shows that ICT usage, as measured by the penetration rate of the Internet, increases with access to electricity. While the diffusion of mobile telephony is positively correlated with access to electricity, this correlation is not statistically significant. In addition, providing access to electricity is associated with a mobile revenue gain of 0.43 US dollar per connected user. This effect means that mobile ARPU would have declined by a 0.1 percentage point more without access to electricity. These outcomes are robust to the measurement of access to electricity and accord well with findings from previous works, in particular Arney & Hosman (2016).

They highlight the importance of access to electricity in the diffusion of ICT, particularly the Internet, and have implications for both private and public stakeholders in the digital ecosystem. Private stakeholders, particularly mobile operators, platform operators, online content providers as well as equipment providers may find it profitable to extend their product lines to electricity services. Recent initiatives include M-KOPA Solar by Safaricom in Kenya and Orange Energy in the Democratic Republic of Congo. However, there is still a need to identify the relevant business models and assess the economic impact of these services.

While the impact on the ARPU is statistically significant, its economic significance is less evident. The yearly growth rate avoided due to access to electricity is 0.1 compared to 3.6% decline per year. This small effect could be due to the need to complement access to electricity with productive use. As suggested by Bernard (2012), the connection rate is very low in rural areas, from 12% in Botswana to 30% in Senegal and 39% in Ethiopia, with limited productive use. Awareness raising campaigns, local relevant ICT contents, digital literacy as well as encouraging the productive use of energy in rural areas could be the ways to increase connections and ICT usage.

In Sub-Saharan Africa, many government intend to speed up the development process thanks to a greater diffusion of the Internet. Public policies in this domain tend to focus on stricter regulatory requirements for universal deployment of the Internet by mobile operators. However, our findings suggest that without access to electricity a mandatory deployment of the Internet would generate fewer revenue for the network operators. Therefore, public policies towards the development of the digital economy should include a component dedicated to the expansion of access to electricity, particularly in rural areas.

In this paper, we rely on aggregate measures of mobile usage and access to electricity due to the lack of micro data. Access to individual or regional level data would enable the estimation of the heterogeneous effects according to users' characteristics. It would also enable the design of a causal estimation strategy. Moreover, we focus on the extensive margin of mobile usage.

However, access to electricity is expected to have greater impact on the intensive margin, typically the number of calls and SMS per user, the duration of calls, the volume of data per user and the asymmetry of communications between urban and rural areas. Future studies should address these issues.

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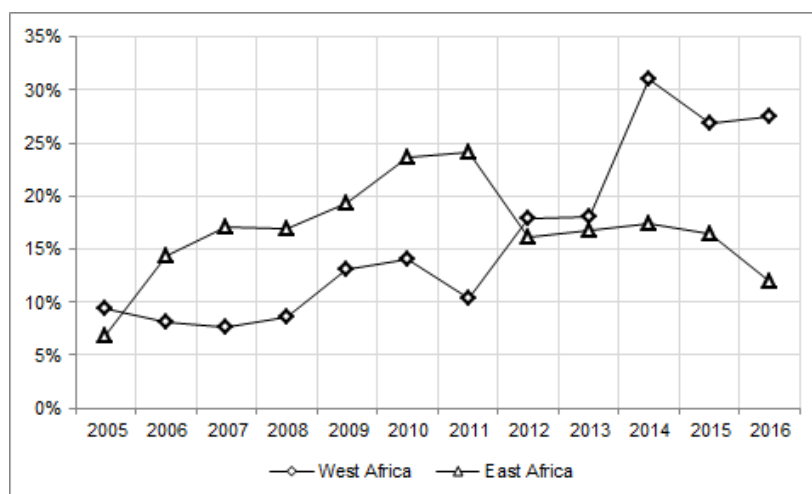
Appendix

Table A-1: Access to Electricity in High-Performing Countries (%)

	Eastern Africa						Western Africa				
	Malawi	Rwanda	Uganda	Tanzania	Ethiopia	Kenya	Liberia	Mali	Sierra Leone	Guinea	Ghana
2000	4.8	6.2	8.4	9.6	12.7	15.9	0.0	10.3	11.1	16.5	44.7
2001	5.3	5.9	8.6	10.2	10.8	17.1	0.0	10.8	11.4	17.4	46.7
2002	5.6	6.7	7.8	10.9	12.4	18.2	0.0	13.3	11.7	18.3	48.7
2003	6.2	7.6	10.2	11.1	13.9	16.0	0.0	14.7	12.0	19.2	48.3
2004	6.9	8.5	10.8	11.4	15.5	20.5	0.0	16.2	16.8	20.1	52.7
2005	6.5	4.8	8.9	12.7	14.0	21.7	0.0	17.7	11.3	20.2	54.7
2006	3.7	10.3	9.0	13.3	18.6	22.9	0.2	16.6	12.9	22.0	55.1
2007	7.1	11.2	12.7	13.9	20.2	24.0	3.0	20.7	13.2	22.9	58.8
2008	7.4	6.0	13.4	11.5	21.8	25.3	1.8	22.3	12.1	23.8	60.5
2009	7.8	13.1	10.0	11.2	23.4	23.0	1.9	24.0	14.0	24.8	62.9
2010	8.7	9.7	14.8	14.8	25.0	19.2	5.1	25.4	11.5	25.8	65.0
2011	7.6	10.8	14.6	14.2	23.0	29.0	4.1	27.0	14.2	26.8	64.1
2012	7.4	16.1	16.2	15.3	28.4	30.3	8.6	25.6	15.2	26.2	69.3
2013	9.0	15.2	13.9	16.4	30.0	31.6	9.8	30.2	13.5	28.9	70.7
2014	11.9	19.8	20.4	18.9	27.2	36.0	9.4	31.8	16.0	29.9	78.3
2015	10.8	22.8	18.5	18.5	33.4	41.6	13.8	37.6	16.5	31.0	75.7
2016	11.0	29.4	26.7	32.8	42.9	56.0	19.8	35.1	20.3	33.5	79.3
Before	0.3	0.4	0.7	0.7	1.3	1.2	0.8	1.5	0.3	0.9	1.8
After	0.9	3.3	4.3	14.3	7.9	6.4	5.2	2.4	1.3	1.8	2.5

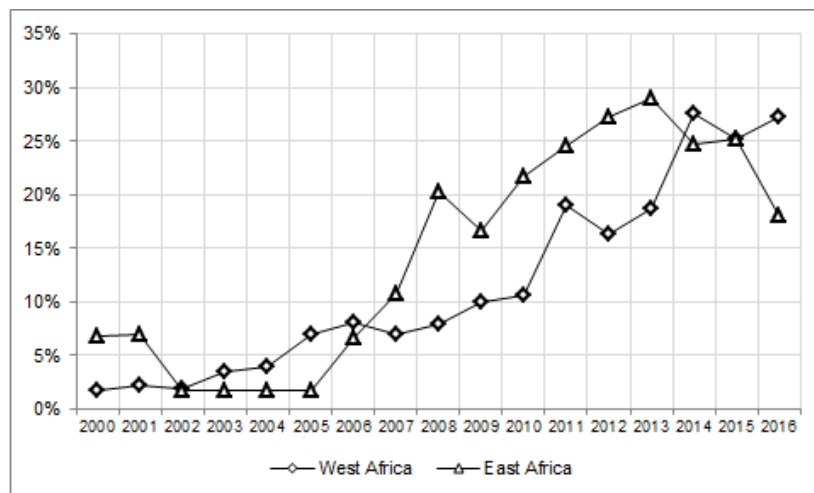
After trend break in bold. Average annual percentage variation in the bottom panel.

Figure A-1: Growth rate of the World Bank's financial commitment in the power sector



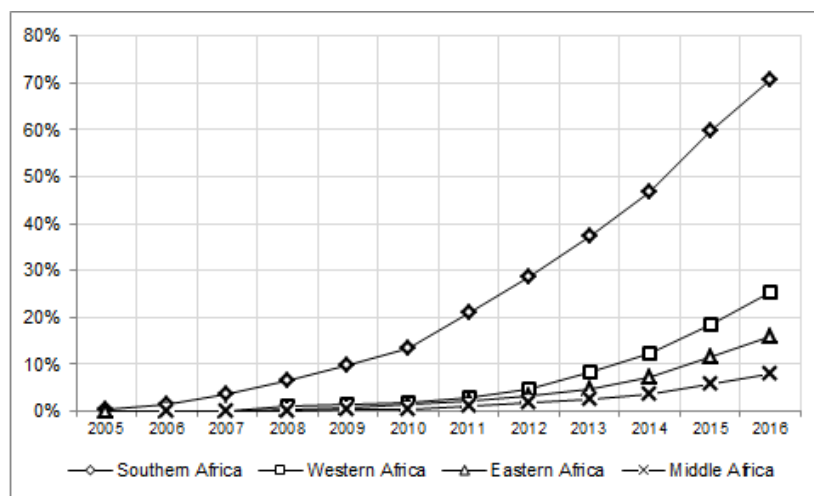
Note: Data from the World Bank's Projects and Operations Database. Each point corresponds to the five-year moving average of the mean growth rate of investment across the region.

Figure A-2: Growth rate of the African Development Bank's financial commitment in the power sector



Note: Data from the African Development Bank's Projects and Operations Database. Each point corresponds to the five-year moving average of the mean growth rate of investment across the region.

Figure A-3: Penetration of Mobile Internet in Sub-Saharan Africa



Note: Data from the GSMA Intelligence. Number of subscribers as a percentage of the population.

Table A-2: Counterfactual simulations

year	unique mobile users (Mob_t)	revenue (Rev_t)	arpu	arpu growth	electricity users ($Elec_t$)	arpu without electricity*	% arpu loss**
2000	8.5	2964.5	28.95		56.9		
2001	12.8	4368.2	28.50	-1.6%	64.0	28.26	-0.8%
2002	19.2	6595.2	28.56	0.2%	103.0	27.69	-3.1%
2003	27.7	9268.3	27.91	-2.3%	114.3	27.74	-0.6%
2004	42.4	13539.7	26.63	-4.6%	117.1	26.60	-0.1%
2005	63.6	18273.8	23.93	-10.2%	121.3	23.90	-0.1%
2006	91.3	26144.3	23.87	-0.2%	129.7	23.83	-0.2%
2007	120.7	34129.5	23.56	-1.3%	140.7	23.52	-0.2%
2008	159.7	46017.4	24.02	2.0%	144.1	24.01	0.0%
2009	188.1	48530.7	21.50	-10.5%	151.7	21.49	-0.1%
2010	219.5	49648.1	18.85	-12.4%	155.5	18.84	0.0%
2011	247.5	55475.3	18.68	-0.9%	170.8	18.65	-0.1%
2012	282.3	63785.5	18.83	0.8%	179.2	18.82	-0.1%
2013	314.9	68658.1	18.17	-3.5%	188.2	18.16	-0.1%
2014	349.5	73697.3	17.57	-3.3%	198.6	17.56	-0.1%
2015	385.1	76584.4	16.57	-5.7%	209.9	16.56	-0.1%
2016	414.7	74846.6	15.04	-9.3%	241.3	15.01	-0.2%
Average***				-3.6%			-0.1%

Mob_t , Rev_t and $Elec_t$ are expressed in million.

*The ARPU without electricity is calculated as $\frac{Rev_t - (12 \cdot 0.43) \cdot (Elec_t - Elec_{t-1})}{Mob_t}$

**The ARPU loss is calculated as $\frac{ARPU_{0t} - ARPU_t}{ARPU_{t-1}}$, where $ARPU_{0t}$ denotes the ARPU without electricity.

***The average is computed over the period 2011-2016 to make sure that the number of unique mobile users outpaces the number of people with access to electricity and to account for the period during which access to electricity accelerated.