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# International Connectivity and the Digital Divide in Sub-Saharan Africa

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## Abstract

In recent decades, international connectivity has improved significantly with the worldwide deployment of some 400 fiber submarine cables (SMCs), transmitting more than 99% of international telecommunications. If sub-Saharan African (SSA) has long remained excluded from this interconnection process, the maritime infrastructure network has recently densified and spurred an African connectivity catch-up. This paper estimates the impact of SMC deployment on the digital divide in a sample of 45 SSA countries covering the period of 1990–2014. Difference in differences (DID) estimations are conducted and highlight the particular contribution of SEACOM and EASSy cables, laid in 2009–2010, to Internet penetration in Eastern and Southern Africa. According to DID estimates, the rollout of these SMCs has yielded a 3–5 percentage point increase in Internet penetration rates in this region compared to the rest of SSA. This is a remarkable advancement, since this variation corresponds approximately to the average level of Internet penetration in the subcontinent prior to their arrival.

**Key words:** ICT, submarine cables, digital divide, Sub-Saharan Africa, infrastructure, connectivity.

**JEL Classification:** F02, L96, O33, O18.



## 1. Introduction

Information and communication technologies (ICTs)<sup>1</sup> are enabling production technologies with a proven impact on communication and transaction cost-reduction (Goldfarb & Tucker, 2019), particularly strong in the context of lacking infrastructures and large market failures that characterize many sub-Saharan African countries (Aker & Mbiti, 2010). By contributing to the emergence and dissemination of innovations in trade, agriculture, education, health, financial services, transportation, and public administrations (Aker & Mbiti, 2010; Aker & Blumenstock, 2014; World Bank, 2016; ), ICTs, mobile and Internet technologies in particular, have the potential to act as general-purpose technologies in the African development process (Bresnahan & Tajtenberg, 1995; Cardona et al., 2013).

Mobile and Internet technologies facilitate economic actors' access to simple as well as more complex telecommunications functions, from receiving health follow-up or agricultural extension programmes through text-messaging, to exchanging digital content remotely through Internet, or facilitating different kinds of transfers with the government, citizens, or businesses through mobile money. In sub-Saharan Africa (SSA), mobile phones have spread in response to missing landline infrastructures (Aker & Mbiti, 2010), representing today the principal communication engine and the main platform for Internet access. However, while the uptake of mobile phone technology has fostered the multiplication of digital innovations throughout the subcontinent, this dynamic bumps into the large Internet divide in the population. In fact, African countries' Internet penetration rates were not exceeding 54.3 percent of the population by 2015, with some countries like Niger, Sierra Leone, or Guinea-Bissau displaying penetration rates lower than five percent of the population (ITU, 2019). As a result, the expected dividends of ICT dissemination in the subcontinent, especially Internet-related technologies, are slow to materialize and to benefit the whole population (World Bank, 2016). Identifying key determinants of mobile and Internet adoption is therefore critical to make digital technologies a lever for growth, productivity, and job creation in the subcontinent.

In this regard, during the last decade, global connectivity has improved significantly with the worldwide deployment of more than 400 fibre submarine cables (SMCs) over the period of 1990–2018, transmitting more than 99% of international telecommunications (broadband Internet, phone calls, videos, text messages, diplomatic messages). While SSA remained relatively digitally isolated until 2009, its international connectivity, i.e. capacity for international telecommunications, has recently benefitted from this deployment, facilitating access to and reducing the cost of international telecommunications, in particular broadband Internet (OECD, 2014). Because SMCs are the first link into the international telecommunications access value chain (Schumann & Kende, 2013), a study of their impact on mobile phone and Internet penetration in sub-Saharan African countries is therefore an important step to apprehend the potential for and the main obstacles to digitization in Africa.

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<sup>1</sup> The term ICT used along this paper encompasses the different types of platforms by which information and communications flow (mobile phones, smartphones, computers, tablets, radio, etc.), their multiple usages (communication, information dissemination or collection, financial transactions, etc.), and the various contents transmitted through them (calls, text-messages, emails, websites, e-money, videos, radio broadcasts, etc.). Based on this definition, the digital divide results from the low penetration of ICTs (platforms, usages, and contents) in the population.

To our knowledge, such an empirical approach, focused on this critical connectivity infrastructure and applied to the subcontinent, is missing.

While the economic literature has widely focused on the consequences of ICT diffusion,<sup>2</sup> studies that reveal the conditions of their uptake, especially in Africa, are scant. In regards to mobile and Internet technologies, micro- or local-level empirical research has identified levers or obstacles to their uptake in the subcontinent. These determinants encompass the private network size (Bjorkegren, 2019), geographic constraints (Buys et al., 2009), demographic and individual characteristics such as revenue, age, gender, education, and urbanity (Birba & Diagne, 2012), physical infrastructure proximity (Buys et al., 2009; Mothobi & Grzybowski, 2017), and competition policy (Buys et al., 2009). Among international macro-level studies, Chinn and Fairlie (2007, 20210) highlight the importance of per capita income in explaining Internet penetration in a sample of 161 developed and developing countries. In addition, they stress the role of access to electricity, human capital, and institutional quality in reducing the Internet divide. Wallsten (2005) and Howard and Mazaheri (2009) have also examined the contribution of the regulatory framework to ICT access, but to our knowledge, none of these studies has emphasized the importance of improved international connectivity for digital technologies diffusion.

Yet, from the early works of Katz and Shapiro (1985) and Crémer and colleagues (2000), the quantity and quality of interconnections have been identified as critical determinants of the demand for telecommunications services. Thus, by increasing the number and the quality of interconnections linking African countries together and to the world telecommunications network, have SMCs spurred mobile telephony and Internet uptake?

This paper addresses this question by offering new empirical evidence on the consequence of improved international connectivity, resulting from SMC deployment, for mobile and Internet diffusion in SSA. The empirical analysis is conducted in two steps. First, within fixed-effect estimations of the effect of the successive arrivals of SMCs along African coasts over the 1990–2014 period on Internet and mobile phone penetration is conducted. Baseline estimates support that one additional SMC laid on the African coast is associated with an average two percentage point increase in Internet penetration rates in the recipient country. By contrast, mobile phone penetration is found to be rather unresponsive to the deployment of this infrastructure. Second, the concern for endogeneity in the timing and location of SMC rollout is addressed by narrowing the focus on the specific contribution of the SEACOM cable and the East African Submarine Cable System (EASSy), deployed along Eastern and Southern African coasts in 2009–2010, using a difference in differences (DID) approach.

These cables' arrival is considered as a quasi-experiment for recipient countries for two main reasons. First, they serve the whole Eastern and Southern-East African region, suggesting that their deployment follows regional rather than country-level considerations. In fact, SEACOM

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<sup>2</sup> SMC rollout is found to spur mobile and Internet adoption by firms (Cariolle et al., 2019; Hjort & Poulsen, 2019), and thereby, to improve productivity and innovation (Bertschek et al., 2013; Cardona et al., 2013; Cariolle et al., 2019; Paunov & Rollo, 2015, 2016), to foster job creation (Hjort & Poulsen, 2019), and to increase trade and foreign direct investments (Freund & Weinhold, 2004; Hjort & Poulsen, 2019). See Bertschek et al (2015) for a review of evidence-based studies on broadband Internet impacts.

and EASSy cables have been laid all along the southern and eastern African coasts, with no exception among coastal countries, whether in mature telecommunications markets like Kenya and South-Africa, or non-mature ones like Somalia or Madagascar. Second, the timing of this wave is also associated with a new generation of broadband cables (Weller & Woodcock, 2013; OECD, 2014) that induced an exogenous technological shift in the capacity for carrying international telecommunications in this area.

These assertions are supported by the existence of long-period pre-treatment overlapping trends in Internet penetration rates and Internet bandwidth per user in treated and untreated countries, diverging after the treatment. According to DID estimations, the deployment of SEACOM/EASSy has yielded a 3 to 5 percentage point increase in Internet penetration rates in recipient countries compared to rest of the subcontinent. This difference in Internet penetration represents approximately the SSA's average Internet penetration rate preceding the SEACOM/EASSy laying. These estimates are robust to various sample restrictions, aimed at addressing an eventual sample selection bias, consisting in excluding from the estimation sample countries hosting non-regional cables, emerging telecommunication markets, and landlocked countries.

The next section describes the institutional background of SMC deployment in SSA. The third section presents the baseline estimations results, while the fourth section exposes our identification strategy and the resulting estimates. The fifth section concludes.

## **2. Institutional background**

The divide digital is reflected by the uneven access to ICTs among individuals, communities, organizations and countries, based on, among others, geographical, economic and socio-cultural backgrounds. This section offers an overview of the interplay between the expansion of international connectivity infrastructures and access to ICTs in SSA.

### **2.1. International connectivity infrastructures and the digital divide**

The global network of submarine fibre-optic wires represents the first link in the telecommunications access chain (Figure 1) and the most efficient option for delivering international telecommunications services (e-mail, websites, phone calls, video content, etc.). In the absence of SMCs, a country has two solutions for international telecommunications: i) buying expensive and limited Internet bandwidth from a neighbouring country, which is connected to a SMC (which requires terrestrial wireline interconnection with that country); or ii) buying slower and costlier Internet bandwidth to satellite communication systems. SMC deployment is therefore the first step towards global Internet access, and is a subsequent catalyst for backbone (e.g. Internet Exchange Points, data centres, and high-capacity inter-city wirelines), middle-mile (e.g. mobile base stations, lower capacity wirelines), and last-mile (e.g. cell towers) terrestrial infrastructure investments (Schumann & Kende, 2013). These investments are necessary for telecom operators and Internet service providers to supply telecommunications services to the population, especially to people located in remote rural areas. Moreover, since most Internet contents are hosted in servers located outside the continent (mostly in the US and in Europe), SMCs are indispensable for African users to navigate on the

web, including on African websites. Their rollout is therefore a precondition for the digital divide reduction.

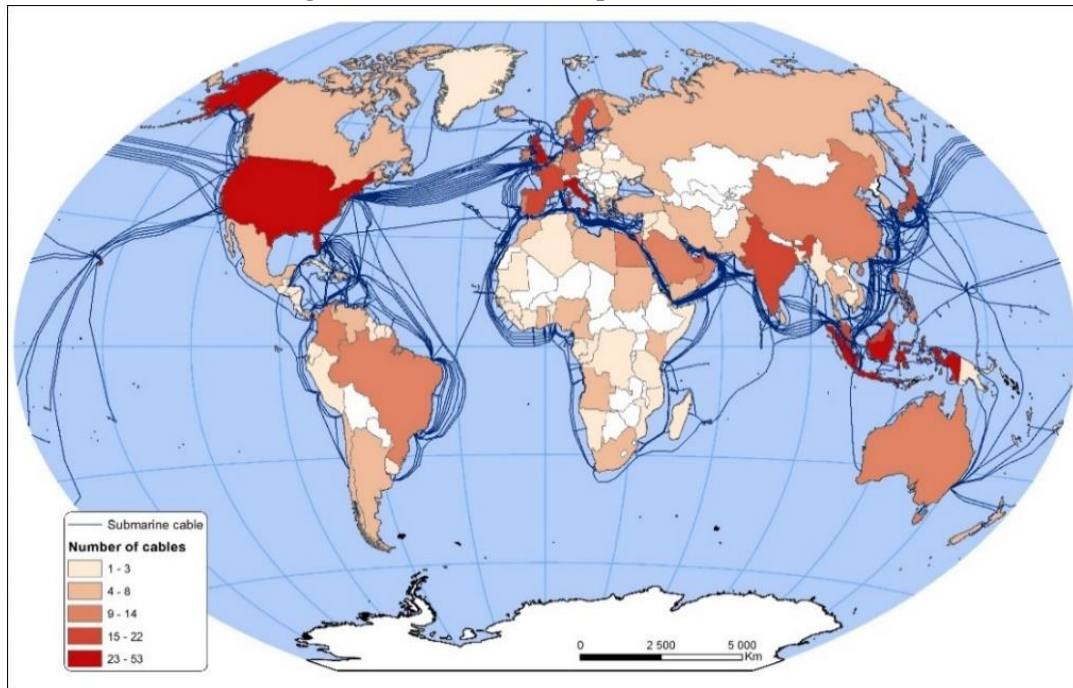
Overall, the number of SMCs connecting countries to the world telecommunications network fosters ICT adoption by enlarging the total bandwidth available for telecommunications, intensifying competition in the telecom sector, improving Internet redundancy, and encouraging terrestrial infrastructure extension (Weller & Woodcock, 2013; Schumann & Kende, 2013; Telegeography, 2016). Figure 2 maps the number of SMCs hosted by countries in 2019 and shows that SMC rollout in sub-Saharan Africa is still lagging behind other developing regions, such as Asia and South America. While some emerging telecom markets such as Kenya, Ghana, South Africa, and Nigeria do not host more than six SMCs, their number does not exceed three in most coastal African countries. Moreover, it is also striking that SSA’s integration into the world telecommunication network is strongly hindered by the number of African landlocked countries, whose access to international telecommunications relies on terrestrial infrastructure deployment and cross-border connectivity.

**Figure 1. Infrastructures and international telecommunications access value chain**



Source: adapted from Schumann and Kende (2013). SMC: Submarine cables. IXP: Internet Exchange Point.

**Figure 2. Number of fibre-optic SMCs in 2019.**



Source: author, data from Telegeography: <https://www.submarinecablemap.com/>.

## 2.2. Submarine cable deployment in sub-Saharan Africa

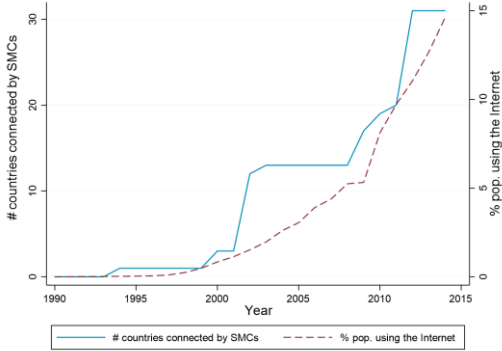
While SSA remained relatively digitally isolated from the rest of the world until the end of the 2000s, the SMC infrastructure has quickly developed. In 2019, SSA was connected to the world telecommunications network through 18 active multilateral SMCs (excluding bilateral SMCs), with eight being spread over the west coast, five over the east coast, and five passing by the Gulf of Aden.<sup>3</sup> Now, almost all coastal African countries are directly connected to the worldwide telecommunications network through SMCs. The expected benefits of such a deployment are very important for the subcontinent.

Graph 1, below, relates the cumulative number of African countries connected to the world telecommunications network to their share of population using the Internet. It shows that the exponential time evolution of Internet penetration tracks the growing cumulative number of African countries connected by the SMCs network. Graph 2 confirms this positive relationship by displaying the positive correlation of SMC rollout with Internet penetration rates and with the telecommunications sector revenue. Yet, despite these remarkable advances, less than 20% of the population had access to Internet in 2015. Beyond this graphical evidence, it is necessary to advance the comprehension of the contribution of SMC rollout to SSA's digital divide reduction, through a multivariate empirical approach.

<sup>3</sup> **West-coast cables:** SAT3/SAFE (800 gigabits capacity), GLO-1 (2.5 terabits), ACE (5 terabits), MainOne (10 terabits), NCSCS (12.8 terabits), WACS (14.5 terabits), SAIL (32 terabits), and SACS (40 terabits). **East-coast cables:** SEAS (320 gigabits), TEAMs (1.2 terabits), LION 2 (1.3 terabits), EASSy (10 terabits), SEACOM (12 terabits). **Eden Gulf cables:** Falcon (2.56 terabits), SEAMEWE 5 (24 terabits), AAE-1 (40 terabits), EIG (3.8 terabits), MENA (5.8 terabits).

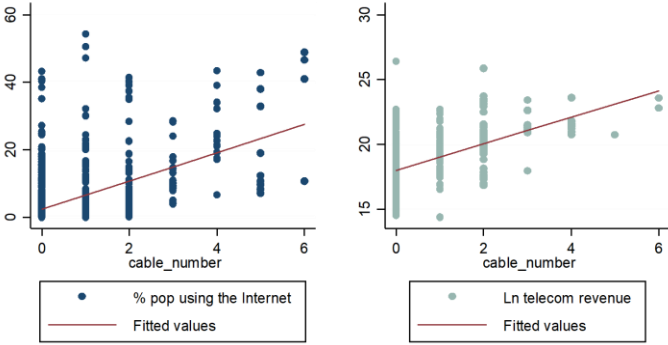


**Graph 1. Infrastructure capacity and Internet penetration in Africa**



Sources: ITU (2019) and <https://www.submarinecablemap.com/> (Telegeography). Sample: 49 African countries.

**Graph 2. SMC deployment and the telecom sector, sub-Saharan Africa, 1990–2014.**



Sources: ITU (2019) and <https://www.submarinecablemap.com/> (Telegeography). Sample: 49 African countries.

**3. Baseline empirical analysis**

This section presents our baseline empirical model, the data used to estimate it, and the resulting estimated relationships.

**3.1. Empirical model**

The telecommunications sector has strong network externalities. In fact, the benefits derived from ICT adoption increase with the telecommunications network size and the quality of interconnections (Katz & Shapiro, 1985; Crémer et al., 2000). Our empirical analysis of the effect of SMC deployment on the digital divide in SSA builds on this feature to estimate a demand for ICTs,

$$ICT_{i,t} = \alpha_0 + \alpha_1 SMC_{i,t} + \alpha_2 TI_{i,t} + \alpha_3 X_{i,t} + d_i + d_t + \varepsilon_{i,t} \quad (1)$$

The demand for ICT,  $ICT_{i,t}$ , is measured by a variable of Internet or mobile phone penetration in country  $i$  at time  $t$ . SMC connectivity ( $SMC_{i,t}$ ), i.e. the country’s capacity to carry international telecommunications through SMCs, is our main interest variable. The terrestrial connectivity infrastructure ( $TI_{i,t}$ ) is included as a control, together with the other determinants of ICT adoption ( $X_{i,t}$ ).  $\varepsilon_{i,t}$  is the error term. The next section further describes these variables. In addition, we include time and country fixed-effects to lower the concern for omitted variable bias (Röller & Waverman (2001); Akerman et al, 2015). Country fixed-effects,  $d_i$ , indeed control for supply and demand unobserved time-constant or slow-changing determinants of ICT

diffusion, such as geographic determinants of SMC deployment or structural demographic changes. Time fixed-effects,  $d_t$ , allow for controlling for timely unobservable events, common to all African countries, that could have influenced the infrastructure rollout over the continent, such as the financial crisis, but also technological progress related to upgrades of SMC or mobile technology (OECD, 2014).

### 3.2. Data

We estimate equation (1) using an original sample of 45 African countries covering the period of 1990–2014. Dependent ( $ICT_{it}$ ), interest ( $SMC_{it}$ ), and control variables ( $X_{it}$ ,  $TI_{i,t}$ ) are described below. Appendix A presents the sample composition, summary statistics, variables' sources, and definition.

#### 3.2.1. Dependent variables ( $ICT_{i,t}$ )

We use alternatively two variables of ICT penetration: the share of the population using the Internet, and the number of mobile phone subscriptions per 100 people. The Internet penetration variable is probably the outcome variable most affected by the arrival of SMCs, compared to the penetration of mobile telephony, which according to various studies has leapfrogged the poor wireline infrastructure coverage in the subcontinent (Aker & Mbiti, 2010; Mthobi & Grzybowski, 2017). Moreover, the share of the population using the Internet is a variable that encompasses various modalities of Internet use in Africa, from personal computers and Internet cafés to mobile Internet.

Using Internet and mobile phone penetration rates as dependent variables is justified by these variables' complementarity, since Internet penetration relies on mobile phone ownership rather than computer ownership in Africa (Aker & Mbiti, 2010).<sup>4</sup> In fact, in 2016, the average proportion of African households owning a computer was approximately 12.5% and less than 5% in landlocked countries such as Mali, Chad, Burkina Faso, and Niger (ITU, 2019). Other Internet penetration variables, such as the share of households with a fixed Internet connection, seems less meaningful in the SSA context, because it depends on the landline infrastructure coverage and often on household computers ownership, which is widespread in industrialized countries (Caselli & Coleman, 2001) but lacking in the subcontinent.

#### 3.2.2. Interest variable: SMC connectivity ( $SMC_{it}$ )

We consider that a country's international connectivity ( $SMC_{it}$ ) depends on being connected or non-connected to the worldwide telecommunications network through submarine cables. As stated in our empirical model, the laying of submarine cables is expected to reduce the digital divide by increasing the telecommunications network's capacity (in terms of traffic speed and size), size (i.e. the number of interconnections), and redundancy (Katz & Shapiro, 1985; Crémer et al., 2000). SMCs could also reduce Internet and other telecommunications tariffs because of

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<sup>4</sup> Studying the effect of SMCs on mobile Internet would have thus been of great interest, but unfortunately, the time coverage of information on mobile broadband penetration in Africa is very limited and cannot be used as dependent variable in panel data analysis.

scale economies and the stronger competition environment that may result from their deployment (Weller & Woodcock, 2013; Schumann & Kende, 2013; OECD, 2014).

In the first part of the empirical analysis, the main interest variable is the number of SMCs laid at a given point of time in a given country. In section 4, we focus on a specific wave of SMCs, the SEACOM/EASSy cables, which has induced a remarkable positive shift in East and South-Eastern African countries' connectivity.

### 3.2.3. Control variables ( $X_{i,t}$ , $TI_{it}$ )

First, we control for the following socio-economic and demographic factors driving the demand for ICTs, emphasized by the literature (Röller & Waverman, 2001; Chinn & Fairlie, 2007, 2010; Howard & Mazaheri, 2009; Birba & Diagne, 2013; Akerman et al., 2015): the (log) gross domestic product (GDP) per capita, the share of public expenditure in the GDP, the gross secondary enrolment rate, the (log) population size, the share of the population between 15 and 64 years of age, and the share of urban population. This set of controls is justified by the fact that a richer, larger, adult, educated, and urban population is more likely to use ICTs. Larger public expenditures can also be positively associated with telecommunications outcomes when public resources are allocated to infrastructure deployment and maintenance, or negatively if the public sector encompasses oversized and inefficient public telecommunications operators.

Second, considering that democratic governments are more likely to promote policies and regulations that facilitate access to and use of ICTs, we also control the degree of democratic freedom (Milner, 2006). Unfortunately, due to limited country and time coverage of information on the quality of telecommunication regulations in sub-Saharan Africa, we could not directly control for the regulatory framework in our specification. However, because regulatory quality exhibits limited variability across time and countries in the subcontinent, the inclusion of country and time dummies partially capture this feature.<sup>5</sup>

Third, a critical source of connectivity to be controlled for, and a direct consequence of telecommunications policies and regulations, is the terrestrial network coverage ( $TI_{it}$ ) (Muto & Yamano, 2009; OECD, 2014; Mothobi & Grzybowski, 2017). If retrospective data on the terrestrial infrastructure deployment ( $TI_{it}$ ) is missing in Africa, panel data on the number of Internet exchange points (IXPs) are available. IXPs are physical Internet hubs that permit the reduction of communication latency, by promoting direct interconnections between countries, and the saving of bandwidth through an efficient allocation of local, regional, and international traffic. IXPs also allow the sharing of Internet and other communications traffic at low cost, which in turn reduces the cost of telecommunication services (Kende & Urphy, 2012; Schuman & Kende, 2013; OECD, 2014; Internet Society, 2015). Overall, the IXP network is not only a central element of the terrestrial connectivity infrastructure, but also a marker of the quality of regulations and the result of proactive telecommunication policies. We therefore include the number of active IXPs in a country at a given point of time as a key control variable in our estimation framework.

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<sup>5</sup> We also proceed in the robustness section 4.5 to sample restriction aimed at addressing an eventual selection bias possibly induced by policy related factors, such as national regulations.

Last, we control for the share of the population with access to electricity, since the quality and coverage of the power infrastructure is critical for ICT adoption (Chinn & Fairlie, 2007, 2010). Since this variable is sporadically documented for African countries, missing data are replaced by five-year moving averages.<sup>6</sup>

### 3.3. Baseline results

Equation (1) is estimated using a panel of 45 African countries over different timeframes. Results are presented in Table 1. In columns (1) and (4), estimations are conducted over the 1990–2014 period. The number of SMCs is, as expected, positively correlated with Internet penetration (column (1)) and mobile phone penetration (column (4)). According to estimates reported in column (1), the deployment of one additional SMC is associated with a 2.4 percentage point increase in the share of the population using Internet. The relationship between SMC rollout and mobile penetration reported in column (4) is, however, non-significant in the usual confidence level.

In the remaining columns, equation (1) is estimated over two different sub-periods: the 1990–2007 period (columns (2) and (5)), associated with a relative stagnation of Internet bandwidth capacity, and the 2007–2014 period. This last period coincides with the deployment in SSA of a new generation of cables that brought broadband Internet to the subcontinent (Weller and Woodcock, 2013), which, as a result, experienced a remarkable progression in Internet bandwidth per user (see Graph 3 hereafter). Estimates show that, while the first period of SMC rollout is associated with a greater diffusion of mobile phone technology, the second period of SMC deployment correlates with the expansion of Internet adoption. Therefore, this evidence confirms that the rapid diffusion of mobile phone penetration was prior to the recent broadband SMC deployment (Aker & Mbiti, 2010; Mthobi & Grzybowski, 2017), which in turn, seems to have spurred the Internet uptake in the late 2000s/early 2010s.

Estimating the effect of the successive arrivals of SMCs on ICT penetration in African countries with country and time fixed-effects, as specified in equation (1), comes down to estimating a staggered DID model where countries receive the treatment (i.e. SMC laying) at different points of time and remain exposed to it afterwards (Athey & Imbens, 2018). Such an approach makes the underlying assumption that successive arrivals of SMCs are exogenous to the host country's context and policies. However, the timing and the number of SMCs may be related to country-level policy factors that preclude from the causal interpretation of estimated coefficients. This assumption is relaxed in the next section and addressed by estimating within a DID framework the impact of a specific wave of regional SMCs whose deployment may have acted as a quasi-experiment in cables-recipient countries.

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<sup>6</sup> When a five-year average cannot be calculated, we use the previous five-year average value.

**Table 1. Baseline estimations**

	(1)	(2)	(3)	(4)	(5)	(6)
Dep var.	% pop using the Internet			# mobile subs. / 100 people		
	1990- 2014	1990- 2007	2007- 2014	1990- 2014	1990- 2007	2007- 2014
# SMCs	<b>2.384***</b> (0.737)	<b>0.979</b> (0.653)	<b>2.479***</b> (0.696)	<b>3.604</b> (2.702)	<b>6.440*</b> (3.432)	<b>-1.125</b> (1.273)
# IXPs	2.147** (0.994)	0.842* (0.458)	1.810 (2.615)	5.698* (3.359)	4.678** (2.270)	1.949 (4.129)
Ln GDP/cap	2.905* (1.580)	1.132 (0.823)	-3.776 (8.077)	2.345 (2.673)	2.594 (1.916)	-19.75 (17.20)
Public Exp.	-0.0015 (0.005)	0.00220 (0.0025)	-0.0149 (0.011)	0.0017 (0.009)	0.00434 (0.0051)	-0.0141 (0.027)
Ln pop. size	3.781 (4.557)	2.708 (3.565)	8.598 (15.25)	10.13 (12.82)	-8.031 (10.41)	5.675 (33.43)
% of 15–64yrs	1.286** (0.521)	0.969* (0.488)	2.070 (1.612)	3.558*** (1.116)	2.843** (1.129)	1.240 (1.386)
% urban pop	0.0388 (0.264)	-0.0744 (0.222)	0.727 (0.807)	1.021 (0.951)	0.200 (0.731)	4.165* (2.123)
Democracy	-0.0792 (0.256)	-0.170 (0.172)	1.032 (0.679)	-0.847 (0.702)	-0.717* (0.421)	0.294 (1.304)
2 <sup>ary</sup> Education	-0.112 (0.107)	-0.0757 (0.0946)	-0.0927 (0.154)	-0.441 (0.302)	-0.269 (0.274)	-0.458 (0.308)
Elect. access	-0.143 (0.118)	-0.116 (0.0948)	- -	0.101 (0.370)	-0.0364 (0.241)	- -
Country fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	733	560	216	903	727	219
# Countries	45	45	43	45	45	43
Within <i>R</i> <sup>2</sup>	0.639	0.490	0.570	0.816	0.663	0.848

White-robust and clustered standard errors in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The access to electricity variable is dropped in columns (2) and (4) because of multi-collinearity, probably with country fixed-effects.

## 4. Causal analysis

This section presents the DID estimation framework (Card & Krueger, 1994; Heckman et al., 1998) adopted to study the impact of SMC arrivals on Internet and mobile phone penetration in the subcontinent. The first subsection exposes the DID design, by identifying a specific wave of SMCs that could constitute a quasi-experiment for countries hosting these cables. The second subsection challenges the relevance of this design by testing the hypothesis of parallel trends in Internet and mobile penetration rates in the treatment and control groups. The third and fourth subsections present the resulting DID estimation framework and estimates, while the fifth subsection checks their robustness.

### 4.1. DID design

We focus on a specific wave of regional SMCs – the SEACOM and EASSy laying in 2009–2010 – which induced a dramatic improvement in the recipient region’s connectivity. This wave could have acted as a quasi-experiment for countries hosting these cables for two principal reasons. On the one hand, SEACOM/EASSy have been laid in all Eastern and Southern coastal countries with no exceptions, and therefore seemed to follow regional geographic

considerations, unrelated to the maturity of national telecom markets or the quality of telecommunications policies. On the other hand, this wave of SMCs is associated with a dramatic and exogenous shift in international telecommunications carrying capacity. These assertions are challenged in the next subsection through a parallel trend analysis.

First of all, we are interested in SMCs that yielded a substantial increase in countries' international connectivity. Among the different waves of SMCs laid in SSA (Graph 3), only cables deployed regionally – that is, connecting at least four sub-Saharan African countries together – are considered. Such SMCs are of interest because their regional deployment is motivated by the small size of SSA markets and the high fixed cost of this infrastructure, requiring public and private telecom operators and investors from neighbouring countries and abroad to share them (Jensen, 2006). We therefore assume that their laying is less influenced by national contexts or policies than regional-level considerations. The following waves of regional cables are first considered:

1. The SAT3, WASC, SAFE cables, deployed in 2002, connecting 10 countries: South Africa, Angola, Gabon, Cameroon, Nigeria, Benin, Ghana, Ivory Coast, Senegal, and Mauritius to Asia and Europe.
2. The SEACOM and EASSy cables, deployed over the East coast in 2009-2010, connecting 16 countries: South Africa, Mauritius<sup>7</sup>, Madagascar, Comoros, Tanzania, Kenya, Botswana, Mozambique, Eritrea, Uganda, Ethiopia, Somalia, Rwanda, Sudan, Mauritius, and Djibouti to Asia and the Middle-East.
3. The WACS and ACE cables, deployed in 2012, connecting 16 countries: South Africa, Namibia, Angola, the DRC, the Congo, Cameroon, Nigeria, Togo, Ghana, Sierra Leone, Ivory Coast, Cap Verde, Liberia, Benin, Guinea, Gambia, and Mauritania to Europe.

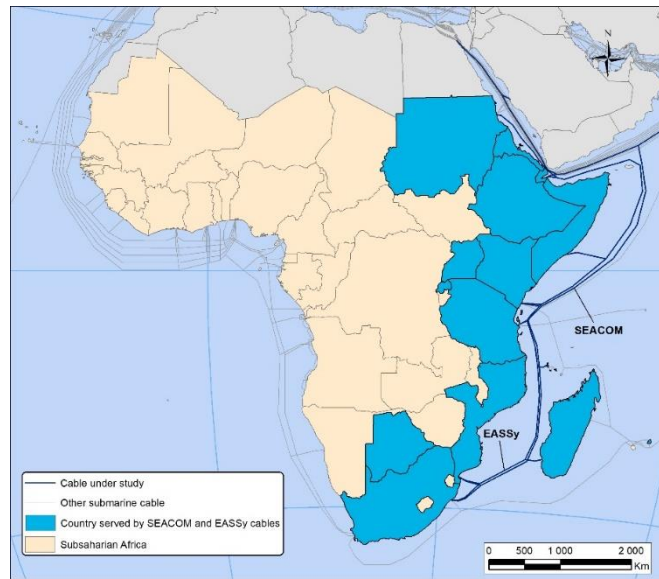
Then, two reasons leads us to believe that the SEACOM/EASSy cable deployment has yielded an exogenous increase in recipient countries' connectivity. First, Figure 3 shows that SEACOM and EASSy have been laid all along East and South-Eastern African littoral, with no exceptions among coastal countries, and has therefore considerably densified the network of interconnected countries in this region. Second, Graph 3 indicates that the average Internet penetration rate's evolution has accelerated in the wake of SEACOM and EASSy laying (Graph 3(a)), and that this acceleration coincides with an unprecedented shift in the cable's capacity to carry international telecommunications, as reflected by the jump in average Internet bandwidth per user in 2008 (Graph 3 (b)). In fact, the end of the 2000s is associated with the first rollouts of cables bringing broadband Internet to the subcontinent (Weller & Woodcock, 2013).

Therefore, the SEACOM/EASSy cable wave is associated with a dramatic technological upgrade in SMC carrying capacity, and has indiscriminately benefitted countries situated along Southern and Eastern African coasts. These features suggest that this SMC wave could act as an exogenous treatment for recipient countries. To challenge these assertions, we test the hypothesis of parallel trends in Internet and mobile penetration evolution prior to SEACOM/EASSy arrival in the next sub-section.

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<sup>7</sup> We consider Mauritius as connected to the SEACOM/EASSy cable wave because it had a direct cable connection to South Africa and Madagascar in 2009.

**Figure 3. SEACOM/EASSy rollout in SSA.**

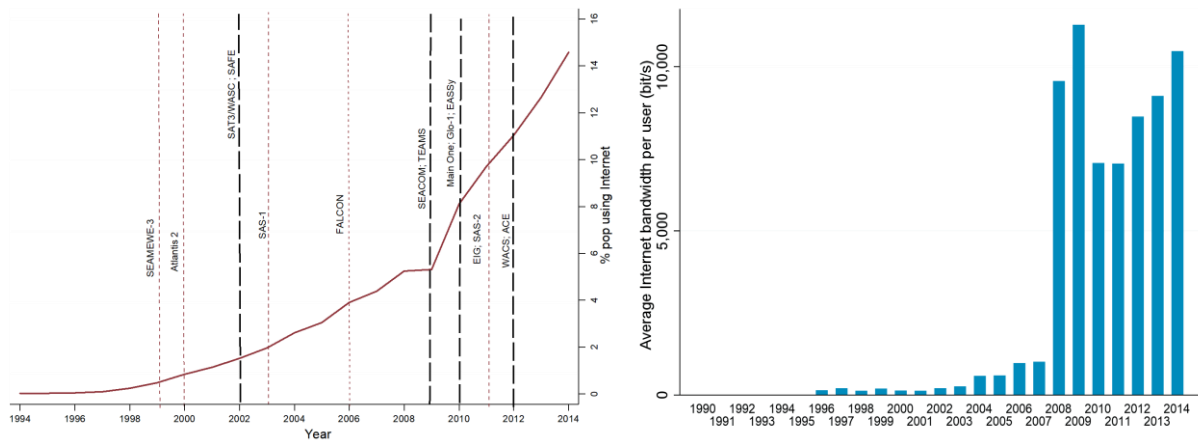


Sources: author, data from ITU (2019) and Telegeography’s [submarine cable map](#).

**Graph 3. SMC arrivals and Internet access in SSA.**

(a) Internet penetration

(b) Internet bandwidth per user



**Source:** author, data from ITU (2019) Telegeography’s [submarine cable map](#). Sample: 49 African countries. Long-dashed vertical lines: arrival of a transcontinental regional SMC, connecting at least four African countries. Short-dashed vertical lines: arrival of a transcontinental local SMC, connecting fewer than four African countries.

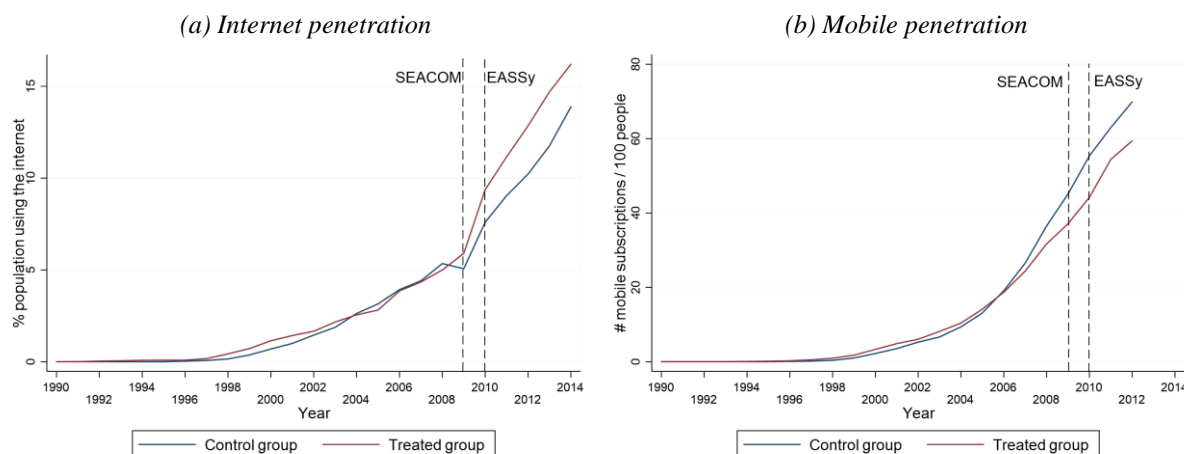
#### 4.2. Parallel trend analysis

Without information on what would have happened without treatment, one common practice is to ensure that outcome variables in treatment and control groups follow parallel trends prior to treatment assignment – in our case, SEACOM/EASSy arrival. This parallel trend hypothesis is a critical assumption of the DID estimator. This subsection shows that treated and untreated countries present an identical long-term evolution of Internet penetration and international telecommunications capacity before the treatment.

First, Graph 4 plots the co-evolution of these outcomes for the treatment and control groups related to SEACOM and EASSy cable rollout in 2009 and 2010. These cables were indeed associated with an apparent change in Internet penetration growth rates, as shown previously in Graph 3. We consider the deployment of SEACOM and the EASSy as one single treatment, since both cables served the same region from one year to another and may have a confounding effect on the evolution of ICT penetration.<sup>8</sup> A visual inspection of Graph 4(a) supports that SEACOM/EASSy deployment seems to be a relevant experiment for a DID analysis. In fact, Internet penetration rates of treated and non-treated groups exhibit quasi-identical pre-treatment trends over 1990–2008, while these trends markedly diverge after the treatment in 2009. By contrast, SEACOM and EASSy do not seem to have affected the penetration of mobile phones (Graph 4(b)).

To further understand the SMCs’ particular contribution to Internet access, Graph 5 plots the evolution of the international Internet bandwidth per user in treated and non-treated countries by SEACOM/EASSy, and shows again parallel and same-level trends prior to the laying of these cables, with a remarkable divergence at the time of the treatment.<sup>9</sup> This suggests that improved bandwidth capacity could explain this shift in Internet penetration. This parallel trend analysis therefore reinforces previous assertions on the treatment’s exogeneity and suggest a possible positive impact on Internet adoption. This is why the following DID analysis is focused on estimating the impact of SEACOM/EASSy cables on Internet penetration rates only, as mobile penetration does not appear to be responsive to these cables’ deployment.<sup>10</sup>

**Graph 4. Trend comparison of ICT penetration before and after SEACOM/EASSy laying.**



**Source:** author; raw data from ITU database.

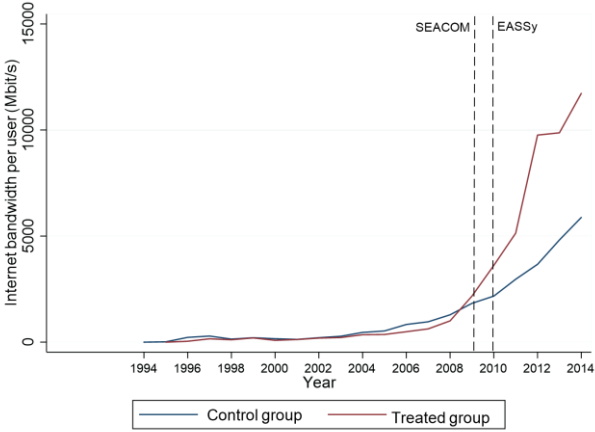
<sup>8</sup> Parallel trend examination considering the SEACOM cable as one single treatment in Appendix B.1 also supports a strong divergence of Internet penetration rates between treated and untreated countries after its laying, and does not provide any evidence for divergence of mobile penetration rates.

<sup>9</sup> Djibouti and South Africa are excluded from the treated group because both countries are continental hubs for SMCs hubs, hosting various cables deployed in countries from the control group, which have experienced an important increase in Internet bandwidth in 2008. These countries are also excluded from the estimation sample in robustness analysis to avoid sample selection bias. Moreover DID estimations of equation (2) using the Internet bandwidth per user as dependent variable stress that SEACOM/EASSy cable had a positive and robust impact on Internet bandwidth (see Appendix D).

<sup>10</sup> The co-evolutions of Internet and mobile penetration rates related to the SAT3/WASC/SAFE wave in 2002, and to the WACS/ACE wave in 2012, also reported in Appendix B.2 and B.3, do not support the parallel trend assumption, suggesting they would not represent a relevant experiment for a DID analysis.



**Graph 5. Trend comparison of Internet bandwidth per user before and after SEACOM/EASSy laying.**



**Source:** author; raw data from ITU database.

**4.3. DID estimation framework**

The SEACOM/EASSy cable wave is the treatment variable (*SMC*), included in the following equation to be estimated:

$$ICT_{i,t} = \beta_0 + \beta_1 SMC_{i,t}^D + \beta_2 W_{i,t} + d_i + d_t + \omega_{i,t} \quad (2)$$

$SMC_{i,t}^D$  is the treatment dummy variable indicating whether country *i* is connected to the global telecommunication network by the SEACOM/EASSy wave at time *t* and after. Country ( $d_i$ ) and time dummies ( $d_t$ ) respectively control for unobserved time-invariant country characteristics and common time-variant unobserved characteristics. These include the period following the laying of SMCs (through time dummies) and time invariant characteristics of the treatment group, i.e. countries hosting SMCs (through country dummies).  $W_{i,t}$  is a set of control variables, adding to the previous set of controls ( $X_{i,t}$  and  $TI_{it}$ ) a variable equal to the number of other SMCs hosted in countries of the control group, and zero otherwise.<sup>11</sup> Assuming that the error term  $\omega_{it}$  is independent from the treatment, that is,  $E(\omega_{i,t} | SMC_{it}) = 0$ , the parameter  $\beta_1$  is the coefficient identifying the causal effect of the treatment on ICT variables. This causal effect is estimated by calculating the DID equal to the change in mean ICT penetration rates for the treatment group minus the change in mean ICT penetration rates for the control group.

**4.4. Main results**

Within fixed-effect estimations of equation (2) are run using an original sample of 45 SSA countries (sample A), over different periods:

- 2002-2012: the baseline period, corresponding to the time-span between SAT3/SAFE laying in 2002 and WACS/ACE cable laying in 2012 (see Graph 3).

<sup>11</sup> In fact, it is necessary to control for the telecommunication infrastructure existing in the control in order to properly estimating the impact of this specific SMC wave.

- 2007-2012: corresponding to the time-span between 2007, identified in Graph 3 as a turning point in SMC capacity for international telecommunications, and WACS/ACE cable laying in 2012.
- 1990-2014: to check the sensitivity of estimates to an extended estimation period, marked by other SMC laying in both control and treatment groups.

Estimates of equation (2), alternatively including  $X_{it}$  and  $W_{it}$  as control variables, are reported in Table 2. They support that the SEACOM/EASSy cables have had a strong, positive, and significant impact on Internet penetration rates. First, estimations conducted over the 2002–2012 period (columns (1) and (2)) stress that the SEACOM/EASSy deployment led to a 1%-significant 5-6 percentage point increase in the share of the population using the Internet. Estimated coefficients lie within the same range whether the estimation period is restricted to 2007–2012 (columns (3) and (4)) or extended to the 1990–2014 period (columns (5) and (6)). They are also robust when we control for the number of SMCs hosted in countries from the control groups. These baseline results support that the arrival of SEACOM/EASSy SMCs has increased the penetration of Internet by around five percentage points in cable-recipient countries compared to non-recipient ones. However, estimated standard errors remain possibly subject to bias induced by autocorrelation (Bertrand et al., 2014). That is why in Table 3, we report Inoue and Solon (2006) tests for auto-correlated disturbances, suggesting the existence of third-order serial correlation.

We therefore re-estimate equation (2) computing Driscoll-Kraay (DK) standard errors (Driscoll & Kraay, 1998), robust to 3-order auto-correlation, to heteroscedasticity, and to cross-sectional correlation.<sup>12</sup> Results are presented in Table 4 and confirm the significance of the estimated relationships. However, they remain subject to a possible sample selection bias that we try to address in the next section. In the following robustness analysis, we conduct estimations with alternatively White-cluster-robust and DK standard errors. In fact, the Pesaran's test of cross-sectional dependence indicating a possible spatial dependence, both estimators are necessary to ensure that standard errors are robust to cross-sectional and temporal dependence (Hoechle, 2007).<sup>13</sup>

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<sup>12</sup> Estimations with standard errors corrected for first, second, and fourth-order auto-correlation are reported in Appendix C.

<sup>13</sup> The test conducted over 1990-2014 rejects the hypothesis of cross-sectional dependence in a mere 12% confidence-level. In presence in cross-sectional dependence, DK standard errors are superior to cluster-robust ones, while in absence of it, the latter are superior to the former (Hoechle, 2007).

**Table 2. DID estimations.**

<b>Dep var: % pop using Internet</b>	(1)	(2)	(3)	(4)	(5)	(6)
Sample A:	2002-2012		2007-2012		1990-2014	
<b>SEACOM/EASSy cable</b>	<b>4.891**</b> <b>(2.149)</b>	<b>5.636***</b> <b>(2.047)</b>	4.767*** (1.761)	<b>4.876***</b> <b>(1.752)</b>	3.326 (2.594)	<b>4.548*</b> <b>(2.391)</b>
# cables, control group		3.601** (1.460)		2.353* (1.328)		2.894** (1.117)
# IXPs	4.226* (2.373)	3.264* (1.694)	4.699 (3.874)	3.952 (3.477)	2.969** (1.329)	2.634** (1.004)
Ln GDP/cap	1.149 (4.839)	-1.335 (4.799)	-7.798 (9.566)	-10.93 (9.271)	2.453* (1.458)	2.051 (1.351)
Public Expenditures (% GDP)	-0.0112 (0.008)	-0.0115 (0.008)	-0.0151 (0.0116)	-0.0152 (0.0116)	-0.0022 (0.005)	-0.0024 (0.006)
Ln population size	16.69 (11.85)	9.512 (10.84)	28.29* (15.29)	19.05 (14.16)	6.915 (5.193)	1.672 (4.485)
% of 15–64yrs	1.708* (0.958)	1.962** (0.929)	1.675 (1.778)	2.063 (1.629)	1.338** (0.520)	1.430*** (0.506)
% urban pop	0.798 (0.499)	0.448 (0.513)	1.530* (0.890)	0.872 (0.911)	0.127 (0.277)	-0.0655 (0.277)
Democracy	0.402 (0.653)	0.319 (0.657)	1.786* (1.008)	1.609 (0.979)	-0.0608 (0.272)	-0.0461 (0.266)
2 <sup>ary</sup> Education	-0.0739 (0.139)	-0.125 (0.124)	-0.0141 (0.174)	-0.0717 (0.153)	-0.109 (0.113)	-0.122 (0.110)
Electricity access (%)	-0.0458 (0.110)	-0.0564 (0.108)	- -	- -	-0.101 (0.126)	-0.162 (0.127)
Country fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
<i>N</i>	349	349	177	177	694	694
# Countries	45	45	43	43	45	45
Within <i>R</i> <sup>2</sup>	0.598	0.634	0.568	0.625	0.601	0.629

Clustered standard errors in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The access to electricity variable is dropped in columns (2) and (4) probably because of collinearity with country fixed effects.

**Table 3. Inoue and Solon (2006) LM test on residuals.**

	H0: No auto-correlation of any order.			
	IS-stat	p-value	N	Max T
Ha: Auto-correlation up to order 1.	20.64	0.004	45	9
Ha: Auto-correlation up to order 2	22.83	0.044	45	9
Ha: Auto-correlation up to order 3	30.85	0.030	45	9
Ha: Auto-correlation up to order 4	31.57	0.109	45	9
Ha: Auto-correlation up to order 5	34.46	0.153	45	9

**Table 4. DID estimations, DK autocorrelation-robust standard errors.**

Dep var: % pop using Internet	(1)	(2)	(3)
	2002-2012	2007-2012	1990-2014
Sample A:			
<b>SEACOM/EASSy cable</b>	5.636*** (1.254)	4.876*** (0.840)	4.548*** (1.081)
# cables, control group	3.601*** (0.611)	2.353*** (0.674)	2.894*** (0.690)
# IXPs	3.264*** (0.927)	3.952*** (0.271)	2.634*** (0.781)
Ln GDP/cap	-1.335 (1.475)	-10.93*** (1.176)	2.051** (0.869)
Public Exp. (% GDP)	-0.0115 (0.00717)	-0.0152*** (0.00334)	-0.00245 (0.00485)
Ln population size	9.512*** (2.486)	19.05*** (3.130)	1.672 (2.061)
% of 15–64yrs	1.962*** (0.0683)	2.063*** (0.363)	1.430*** (0.210)
% urban pop	0.448*** (0.122)	0.872*** (0.145)	-0.0655 (0.0864)
Democracy	0.319 (0.410)	1.609*** (0.258)	-0.0461 (0.162)
2 <sup>ary</sup> Education	-0.125*** (0.0203)	-0.0717** (0.0275)	-0.122** (0.0461)
Electricity access (%)	-0.0564** (0.0279)	- -	-0.162*** (0.0485)
Country fixed-effect	Yes	Yes	Yes
Time fixed-effect	Yes	Yes	Yes
<i>N</i>	349	177	694
# Countries	45	43	45
Within R <sup>2</sup>	0.634	0.596	0.629

Driscoll-Kraay standard errors robust to heteroscedasticity, cross-sectional correlation, and order-3 autocorrelation are in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The access to electricity variable is dropped in column (2) probably because of collinearity with country fixed-effects.

#### 4.5. Robustness analysis

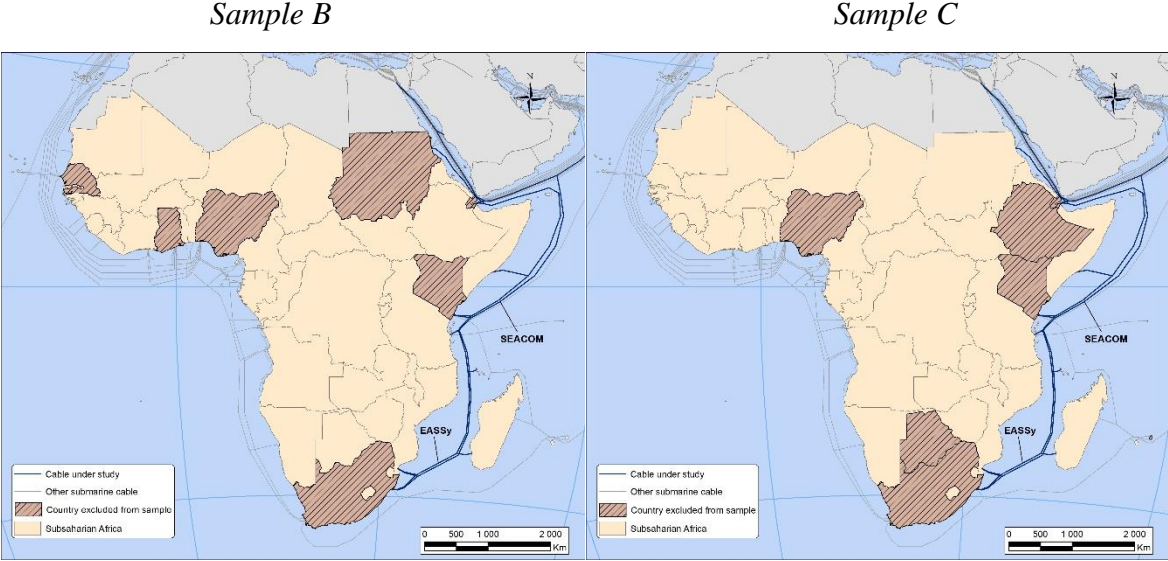
If the treatment's exogeneity is supported by the parallel trend analysis (Graphs 4, 5, and 6), we nevertheless proceed to a range of sample restrictions meant to address a possible sample selection bias caused by policy-related factors. A first way to address this bias is to exclude from the sample all coastal African countries that have been, maybe for some geopolitical or policy matters, the recipient of at least one non-regional SMC, that is, a SMC serving fewer than four countries. This restriction leads to the exclusion of South Africa, Djibouti, Senegal,

Ghana, Nigeria, Sudan, and Kenya from the sample which hosted SEAMEWE-Atlantis-SAS1-SAS2-2-EIG-FALCON-Glo1-Maineone cables (see Figure 4, sample B).

A second source of sample selection is the emerging nature of some African telecom markets, which may influence telecommunications operators’ decision to deploy SMC in specific countries rather than others. To address this possibility, we excluded emerging telecommunications markets, identified as countries with a large a population, and/or where the middle class was representing more than 25% of the population in 2010 (AfdB, 2011)<sup>14</sup> (Figure 4, sample C). The excluded telecom markets are Kenya, South Africa, Ethiopia, Eritrea, Nigeria, and Botswana. Mauritius is also excluded from sample C because its low tax system may make this country attractive for telecommunications infrastructure investments.

Third, landlocked countries’ international connectivity depends on cross-border connections with neighbouring coastal countries hosting SMCs. As a result, the non-treatment might act in a different way in these countries, compared to their coastal counterpart. In addition, the SEACOM/EASSy deployment map (Figure 3) shows that some landlocked countries, like Uganda, Botswana, and Rwanda, have been connected to these cables, while others like Zimbabwe, South-Sudan, Zambia and Malawi have not. This difference in treatment assignment could be related to policy matters, so we re-run estimations excluding landlocked countries (Sample D).

**Figure 4. Sample restrictions.**



Estimations of equation (2) are run on these subsamples over the 2002–2012 period, using  $W_{it}$  as control variables, with alternatively cluster-robust and DK standard errors. Results are reported in Table 5. First, estimated effects from sample B are softer but remain significant at a 10%-confidence level. In fact, estimates from sample B in columns (1) and (2) show that EASSy and SEACOM arrivals have increased Internet penetration rates by 3% in treated countries. Second, estimations conducted excluding emerging markets (sample C, columns (3) and (4)) confirm the positive and 1%-significant effect of SEACOM/EASSy cables on Internet

<sup>14</sup> Deloitte (2014) used this criteria of middle class concentration to identify emerging telecom markets.

penetration. Third, the impact of SMC laying on coastal countries (sample D, columns (5) and (6)) is stronger and significant at a 5%-confidence level. Overall, estimations remain robust to these sample restrictions and support that the arrival of SMCs in 2009–2010 has increased by 3 to 5 percentage points the penetration of the Internet in countries hosting them.

**Table 5. DID estimations with sample restrictions.**

Dep var: % pop using Internet	(1)	(2)	(3)	(4)	(5)	(6)
Sample:	B		C		D	
SEACOM/EASSy cable	3.241*	3.241***	4.360***	4.360***	3.219**	5.237***
	(1.738)	(1.007)	(1.564)	(0.788)	(1.524)	(0.958)
# cables, control group	2.476**	2.476***	1.735	1.735***	-0.937	2.168**
	(1.214)	(0.486)	(1.119)	(0.395)	(0.676)	(1.040)
# IXPs	0.424	0.424	-0.152	-0.152	2.865	5.476***
	(1.420)	(0.551)	(1.191)	(0.565)	(3.586)	(1.773)
Ln GDP/cap	2.235	2.235**	5.558	5.558***	-0.00530	3.164
	(4.190)	(0.924)	(3.648)	(1.374)	(0.0034)	(2.135)
Public Expenditures (% GDP)	-0.00621	-0.0062	-0.0101	-0.0101	18.72**	-0.0367***
	(0.0072)	(0.0063)	(0.0080)	(0.0079)	(7.485)	(0.0114)
Ln population size	15.14	15.14***	9.196	9.196***	-0.609	3.344
	(11.86)	(1.159)	(9.977)	(1.566)	(0.401)	(2.756)
% of 15–64yrs	2.614***	2.614***	2.575***	2.575***	-0.129	2.592***
	(0.768)	(0.146)	(0.761)	(0.124)	(0.284)	(0.186)
% urban pop	0.322	0.322**	0.492	0.492***	2.704***	0.378**
	(0.491)	(0.113)	(0.467)	(0.110)	(0.612)	(0.180)
Democracy	0.568	0.568	0.381	0.381	-0.0209	-0.114
	(0.527)	(0.385)	(0.544)	(0.314)	(0.0642)	(0.414)
2 <sup>ary</sup> Education	-0.176*	-0.176***	-0.204**	-0.204***	0.324**	-0.0981*
	(0.100)	(0.0333)	(0.0917)	(0.0211)	(0.120)	(0.0490)
Electricity access (%)	-0.0724	-0.0724*	0.0180	0.0180	-	-0.0218
	(0.129)	(0.0395)	(0.112)	(0.0132)	-	(0.0160)
Country fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes
Driscoll-Kraay AR(3) std errors	No	Yes	No	Yes	No	Yes
<i>N</i>	292	292	290	290	243	243
# Countries	45	45	45	45	32	32
<i>R</i> <sup>2</sup>	0.665	0.665	0.697	0.697	0.689	0.689

Standard errors are in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . In columns (1), (3) and (5), standard errors are robust to heteroscedasticity and clustered by country. In columns (2), (4), and (6), Driscoll-Kraay standard errors are robust to heteroscedasticity, cross-sectional correlation, and order-3 autocorrelation. The access to electricity variable is dropped in column (3) probably because of collinearity with country fixed-effects.

## 5. Discussion and concluding remarks

In Sub-Saharan Africa, expectations placed on the digital economy take-off, and on its capacity to create jobs and to offer satisfying living conditions to the populations are particularly important. However, the strong digital divide, reflected by the low penetration of ICTs in various African countries, represents a critical impediment for digital technologies to diffuse and fuel an endogenous development dynamic. This inequality in ICT access is explained by demand-side factors, related to populations' characteristics, influencing digital technologies adoption and diffusion, but also by supply-side factors, such as the Internet infrastructure coverage. This paper questions whether and to what extent the laying of telecommunications SMCs, the keystone infrastructure for international connectivity, has reduced the digital divide in sub-Saharan Africa, by presenting novel evidence on their positive effect on African countries' Internet penetration rates.

The examination of changes in Internet penetration and bandwidth capacity before and after different waves of submarine-cable laying over time, suggests that the successive deployment of the SEACOM cable in 2009 and the EASSy cables in 2010 constitutes a relevant experiment for a causal analysis. Diff-in-Diff analysis using these specific cables as treatment stresses that their arrival has yielded a 3–5 percentage point increase in Internet penetration rates in cable-recipient countries compared to non-recipient ones. This is a remarkable advancement, since this difference represents approximately the average rate of Internet penetration in the subcontinent prior to these SMC laying (Graphs 3(a) and 4(a)).

Africa's international connectivity is now established, and is improving at a steady pace thanks to the continuous laying of new cables, with increasing carrying capacity. However, this dynamic hides profound disparities among population's sub-groups: between the richer and the poorer, urban and rural dwellers, men and women, and educated and less-educated individuals. A study of the consequences of this multidimensional divide on socio-economic outcomes in Africa represents burgeoning but yet promising avenue for future research.

From a policy perspective, the digitization of African economies, in particular, the penetration of the Internet and related technologies, could be accelerated by more vigorous policies and regulations that can be implemented at national and supra-national levels. At the national level, the poor competition environment between backbone operators and internet services providers often leads to tariff levels that are unaffordable for most of the population, especially the poorest. The unaffordability of Internet access may result from strong barriers to telecommunications market entry, such as high license prices or arbitrary license attribution process, translating into monopoly or oligopoly positions that are unfavourable to tariff reductions (Schuman & Kende, 2013; OECD, 2014). High Internet tariffs may also result from the high tax burden incurred by telecommunications operators (Matheson & Petit, 2017). To increase Internet diffusion and telecommunications network externalities, governments could instead focus on taxing the rents resulting from the limited competition environment that prevail in the subcontinent (Matheson & Petit, 2017).

Other key challenges that national governments have to face are related to the poor terrestrial infrastructure deployment and maintenance, which substantially narrow the benefits of

improved international connectivity brought about by submarine cables. Backbone backhaul and last-mile mobile networks, as well as Internet exchange points and data centres, are indeed strongly missing in the subcontinent. African countries' connectivity indeed suffers from low exchange point's rollout, whereas this connectivity infrastructure has a proven positive impact on the telecommunications network capacity, cost-efficiency, and redundancy (Kende & Urphy, 2012; OECD, 2014; Internet Society, 2015). Moreover, countries that do not have the local capacity to host Internet content will not be able to make Internet exchange points function properly. In this regard, Sub-Saharan Africa lacks its own network of data centres, as most African websites are hosted in European or North-American data centres, which is a cause of the telecommunication network's poor performance and undermines African sovereignty in telecommunications matters (OECD, 2014). Lastly, the population's access to an affordable and stable source of power supply is the other missing piece of the connectivity puzzle (OECD, 2014). In fact, low energy infrastructure coverage and power outages represent a critical obstacle for the private sector (Cole et al., 2018) and for ICT uptake (Houngbonon & Le Quentrec, 2019).

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## Appendixes

### Appendix A. Variable sources, definition, and descriptive statistics.

#### A.1. Table 1 sample composition (45 countries)

Country Code	Freq. obs	%	Country Code	Freq. obs	%
AGO	18	2.46	MDG	17	2.32
BDI	23	3.14	MLI	17	2.32
BEN	16	2.18	MOZ	17	2.32
BFA	12	1.64	MRT	16	2.18
BWA	18	2.46	MUS	18	2.46
CAF	18	2.46	MWI	17	2.32
CIV	19	2.59	NAM	16	2.18
CMR	15	2.05	NER	16	2.18
COG	13	1.77	NGA	18	2.46
COM	17	2.32	RWA	17	2.32
CPV	17	2.32	SDN	11	1.50
DJI	18	2.46	SEN	19	2.59
ERI	5	0.68	SLE	21	2.86
ETH	18	2.46	STP	13	1.77
GAB	12	1.64	SWZ	17	2.32
GHA	18	2.46	SYC	17	2.32
GIN	16	2.18	TCD	15	2.05
GMB	11	1.50	TGO	23	3.14
GNB	16	2.18	TZA	16	2.18
GNQ	11	1.50	UGA	19	2.59
KEN	19	2.59	ZAF	22	3.00
LBR	10	1.36	ZMB	13	1.77
LSO	18	2.46			
<b>Total</b>			<b>733</b>	<b>100</b>	

#### A.2. Summary statistics

Variable	Mean	Std. Dev.	Min	Max	Obs.
% pop using the Internet	4.236034	7.92738	0	54.26	982
# mobile subscriptions / 100 people	15.23162	26.7871	0	179.4714	1,091
# SMCs	.3795918	0.91488	0	6	1,225
# IXPs	.2016327	0.55365	0	7	1,225
Ln GDP/cap	6.544436	1.09313	3.9129	9.563518	1,092
Public expenditures (%)	15.40793	7.57971	2.0471	69.5428	970
Ln population size	15.93586	2.52285	10.1270	21.57977	1,217
% of 15–64yrs	53.54829	4.16669	47.4030	71.45077	1,099
% urban pop	36.01146	15.8848	5.416	86.4576	1,099

Democracy	4.817755	2.60842	0.31971	10	1,099
2 <sup>ary</sup> Education index	26.80076	23.3858	0	100	1,200
Electricity access (% pop)	31.86537	24.9205	0	100	1,225
International Internet bandwidth / user	4174.124	23790.09	0	392381.4	742
# faults / fixed phone-line	76.16236	117.6383	.03	1500	520
Ln fixed broadband monthly subscription charge	4.196258	1.294018	0	12.14203	303
Annual investment in the mobile network (USD)	6.31e+08	5.67e+09	0	7.75e+10	190
Electric power consumption (kWh per capita)	538.6034	984.6735	22.8250	5061.2	460

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### A.3 Variables definition and sources

Variable	Source	Definition
% pop using Internet	ITU	Internet users are individuals who have used the Internet (from any location) in the last 3 months. The Internet can be used via a computer, mobile phone, personal digital assistant, games machine, digital TV, etc.
# mobile subscript / 100 people	ITU/World Bank	Mobile cellular telephone subscriptions are subscriptions to a public mobile telephone service that provides access to the PSTN using cellular technology. The indicator includes (and is split into) the number of postpaid subscriptions, and the number of active prepaid accounts (i.e. that have been used during the last three months). The indicator applies to all mobile cellular subscriptions that offer voice communications. It excludes subscriptions via data cards or USB modems, subscriptions to public mobile data services, private trunked mobile radio, telepoint, radio paging, and telemetry services.
International Internet bandwidth per user	ITU	Total capacity of international Internet bandwidth in mega bits per second (Mbit/s) per user. If capacity is asymmetric (i.e. more incoming than outgoing), the incoming capacity should be provided. This is measured as the sum of capacity of all Internet exchanges offering international bandwidth.
Ln GDP/cap	World Bank	GDP per capita in 2005 constant USD
Population size	World Bank	Logarithm of total population
% of 15–64yrs	World Bank	Population ages 15–64 (% of total)
% urban pop	World Bank	Urban population (% of total)
Electricity access (%)	World bank, author	Percentage of population with access to electricity. Electrification data are collected from industry, national surveys, and international sources. Missing data have been inter- and extrapolated using five-year moving average.
Government expenditures	Quality of Governance Database <sup>15</sup> 2015, drawn from World Economic Outlook database (IMF)	Share of public expenditures in GDP
Democracy (imputed version)	Quality of Governance Database <sup>16</sup> 2015, constructed from Freedom House and Polity IV dataset	Scale ranges from 0-10, where 0 is least democratic and 10 most democratic. The average of Freedom House political rights and civil liberties variables is transformed to a scale 0-10, and Polity from the Polity IV database is transformed to a scale 0-10. These variables are then averaged. The imputed version has imputed values for countries where data on Polity is missing by regressing Polity on the average Freedom House measure.
2 <sup>ary</sup> Education index	Ferdi/UNDP	Gross secondary school enrolment ratio. According to the UNDP, this indicator measures the number of pupils enrolled in secondary schools, regardless of age, expressed as a percentage of the population in the theoretical age group for the same level of education. Missing raw data have been filled through linear interpolation and extrapolation, and transformed into an index normalized between 0 and 1 <sup>17</sup> .
# SMCs	Telegeography database	Number of active submarine cables
# IXPs	Telegeography, Author, Packet Clearing House and Peering DB databases	Number of active Internet exchange points

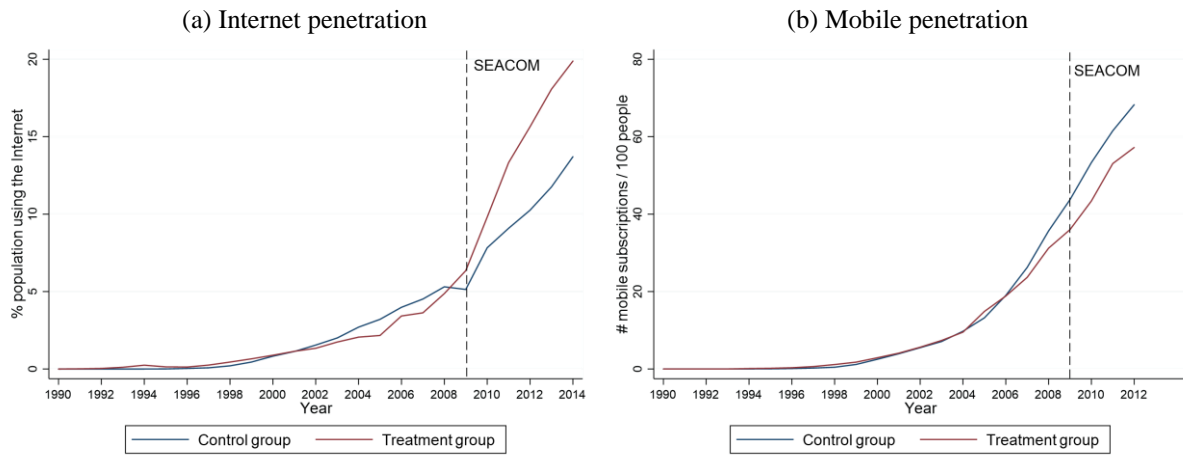
<sup>15</sup> <https://qog.pol.gu.se/data>

<sup>16</sup> *Ibid.*

<sup>17</sup> See Feindouno, S. and Goujon, M. "Human Assets Index retrospective series: 2016 update", Ferdi Working paper P179, décembre 2016. <https://ferdi.fr/en/indicators/human-assets-index-hai>

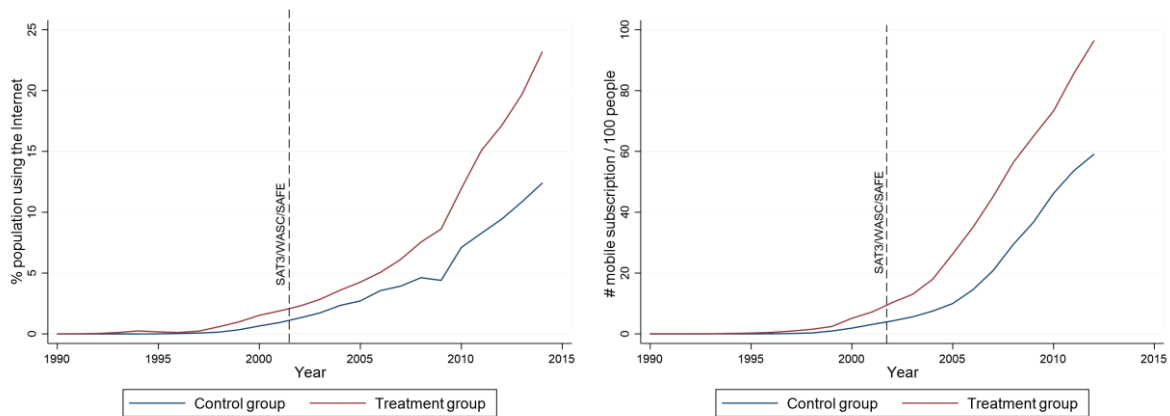
## Appendix B. Parallel trend analysis: other waves of regional SMCs

### B.1. SEACOM (2009).



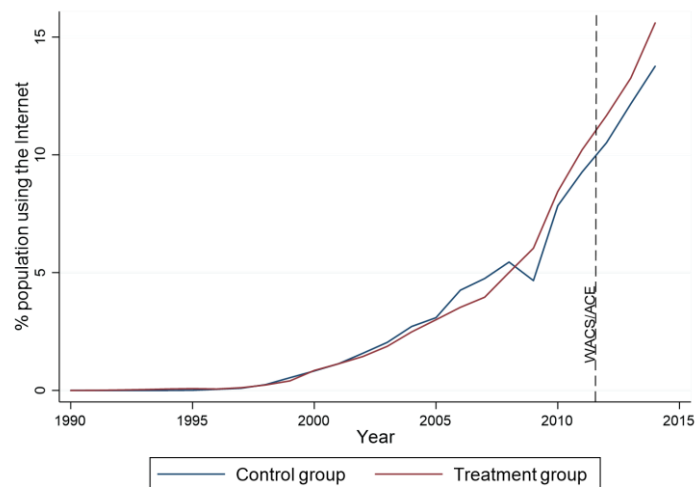
Source: author; raw data from ITU database.

### B.2. SAT3/WASC/SAFE (2002)



Note: Because of missing data, the evolution of other ICT variables in treated and non-treated groups is not reported.

### B.3. WACS/ACE (2012)\*



\*Data on mobile penetration missing after 2012 for many countries.



### Appendix C. DID estimations, correcting for one-order, two-order, and four-order auto-correlated disturbances

Dep var: % pop using Internet Sample A:	(1)	(2)	(3)	(4)	(5)	(6)			
	2002-2012			2007-2012			1990-2014		
SEACOM/EASSy cable	5.636*** (1.630)	5.636*** (1.439)	5.636*** (1.082)	4.876*** (1.415)	4.876*** (1.030)	4.876*** (0.751)	4.548*** (1.418)	4.548*** (1.220)	4.548*** (0.976)
# cables, control group	3.601*** (0.520)	3.601*** (0.575)	3.601*** (0.610)	2.353*** (0.708)	2.353*** (0.683)	2.353*** (0.603)	2.894*** (0.603)	2.894*** (0.663)	2.894*** (0.716)
# IXPs	3.264*** (0.859)	3.264*** (0.918)	3.264*** (0.924)	3.952*** (0.281)	3.952*** (0.324)	3.952*** (0.242)	2.634*** (0.720)	2.634*** (0.768)	2.634*** (0.777)
Ln GDP/cap	-1.335 (1.725)	-1.335 (1.558)	-1.335 (1.437)	-10.93*** (1.378)	-10.93*** (1.243)	-10.93*** (1.052)	2.051** (0.834)	2.051** (0.872)	2.051** (0.845)
Public Exp. (% GDP)	-0.0115 (0.00723)	-0.0115 (0.00723)	-0.0115 (0.00713)	-0.0152*** (0.00533)	-0.0152*** (0.00360)	-0.0152*** (0.00299)	-0.00245 (0.00523)	-0.00245 (0.00513)	-0.00245 (0.00458)
Ln population size	9.512** (4.230)	9.512** (3.229)	9.512** (2.185)	19.05*** (4.697)	19.05*** (3.629)	19.05*** (2.799)	1.672 (2.029)	1.672 (2.029)	1.672 (2.098)
% of 15–24yrs	1.962*** (0.0932)	1.962*** (0.0818)	1.962*** (0.0657)	2.063*** (0.369)	2.063*** (0.378)	2.063*** (0.324)	1.430*** (0.181)	1.430*** (0.201)	1.430*** (0.213)
% urban pop	0.448*** (0.143)	0.448*** (0.133)	0.448*** (0.119)	0.872*** (0.214)	0.872*** (0.167)	0.872*** (0.130)	-0.0655 (0.0808)	-0.0655 (0.0846)	-0.0655 (0.0879)
Democracy	0.319 (0.422)	0.319 (0.415)	0.319 (0.407)	1.609*** (0.319)	1.609*** (0.336)	1.609*** (0.231)	-0.0461 (0.148)	-0.0461 (0.159)	-0.0461 (0.160)
2 <sup>ary</sup> Education	-0.125*** (0.0261)	-0.125*** (0.0231)	-0.125*** (0.0195)	-0.0717** (0.0278)	-0.0717** (0.0354)	-0.0717*** (0.0246)	-0.122*** (0.0415)	-0.122*** (0.0450)	-0.122*** (0.0457)
Electricity access (%)	-0.0564* (0.0302)	-0.0564* (0.0294)	-0.0564** (0.0274)	- -	- -	-10.08*** (1.041)	-0.162*** (0.0461)	4.548*** (1.220)	-0.162*** (0.0492)
Country fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed-effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Std error Auto-correlation order	1	2	4	1	2	4	1	2	4

Driscoll-Kraay standard errors, robust to heteroscedasticity, cross-sectional correlation, and autocorrelation are in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . The access to electricity and the constant variable are dropped because of collinearity.

**Appendix D. Diff-in-Diff analysis of the SEACOM/EASSy impact on international internet bandwidth, 2002-2012.**

Dep var: international Internet bandwidth	(1)	(2)	(3)	(4)
2002-2012. Samples:	A	B	C	D
SEACOM/EASSy cable	11677.9** (5272.5)	2742.9*** (311.0)	440.9** (183.7)	15424.6** (7026.5)
# cables, control group	1928.3 (1354.7)	999.7*** (362.4)	57.76 (285.3)	-4324.5 (3976.5)
# IXPs	6078.2* (3400.2)	68.57 (242.8)	-880.8** (366.6)	10028.3 (6761.0)
Ln GDP/cap	-23810.8*** (7358.2)	-2656.5** (1036.7)	-2603.8* (1400.5)	-1718.9 (13305.2)
Public Expenditures (% GDP)	-4.326 (7.759)	-5.264 (4.279)	-9.064 (5.550)	66.43* (38.69)
Ln population size	-102088.8*** (24623.4)	-846.8 (1178.0)	6946.5*** (918.9)	-131354.3*** (40542.6)
% of 15–64yrs	-25.63 (604.6)	391.1*** (65.85)	-53.35** (21.08)	-426.2 (1106.3)
% urban pop	1569.0*** (445.7)	50.63 (76.39)	320.0*** (57.39)	3327.2*** (1078.2)
Democracy	-3014.0** (1271.6)	454.8* (264.5)	514.7** (230.3)	-3727.0* (2117.8)
2 <sup>ary</sup> Education	-1081.0*** (243.4)	-92.74*** (13.02)	-5.794 (11.99)	-1340.7*** (249.5)
Electricity access (%)	949.7* (502.6)	-16.98 (23.09)	12.15 (8.015)	1314.4* (653.3)
Country fixed-effect	Yes	Yes	Yes	Yes
Time fixed-effect	Yes	Yes	Yes	Yes
<i>N</i>	327	274	268	218
# Countries	45	38	38	31
<i>R</i> <sup>2</sup>	0.130	0.575	0.596	0.176

Driscoll-Kraay standard errors, robust to heteroscedasticity, cross-sectional correlation, and three-order autocorrelation are in parentheses. \*  $p < 0.1$ , \*\*  $p < 0.05$ , \*\*\*  $p < 0.01$ . Sample A includes the whole sample without restriction. Sample B exclude countries hosting non-regional SMCs (i.e. serving less than four African countries). Sample C excludes emerging telecommunications markets. Sample D excludes landlocked countries.

*“Sur quoi la fondera-t-il l'économie du monde qu'il veut gouverner? Sera-ce sur le caprice de chaque particulier? Quelle confusion! Sera-ce sur la justice? Il l'ignore.”*

Pascal



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