The Impact of Digital Infrastructure on African Development

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Abstract

This paper estimates the impact of digital infrastructure on economic growth and its sources. The analysis uses system generalized method of moments and finds evidence of a causal impact from the digital infrastructure variables to economic growth, its sources, income inequality, and poverty. The findings show that mobile connections have an impact on economic growth through the total factor productivity growth channel, while internet users drive it by the capital accumulation channel. Connections have a negative effect on the Gini coefficient, and internet users have a negative effect on the poverty headcount. The analysis also finds that human capital and access to electricity are important complementarities for digital infrastructure to reap benefits. There would be large economic gains if Africa were to close the digital infrastructure gap relative to other regions, yet there are some issues of affordability and skills that need to be addressed to reduce the usage gap and the digital divide across gender, rural-urban, and firm size.
The Impact of Digital Infrastructure on African Development

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1. Introduction

Africa houses 1.3 billion people, including the world’s largest share of youth. Before 2020, Africa’s demography trends projected that by 2030 the continent would account for more than one-third of the world’s poor. However, COVID-19 has taken an important toll on those numbers. For the first time since 1998, global poverty will accelerate considerably. Specifically, recent estimations predict that 32 million of the 119 million people pushed into poverty will reside in Sub-Saharan Africa.\(^2\) In this context, the large proportion of young and poor will have an adverse impact on global productivity. Parallelly, inequality could increase by 1 percentage point in the Africa region, as proxied by the Gini Index, discrediting the last three years of progress.\(^3\)

Considering the global broad agenda of priorities (health, labor, trade, infrastructure, etc.) to combat the negative externalities from COVID-19, policy makers need to provide solutions that can be built upon. Digital technologies (DT) have proven to have an important impact on development (Aker and Blumenstock 2015). During the year 2020, it was mostly digital technologies that helped the world maintain connectivity and productivity. With DT’s, some sectors and factors have increased their efficiency - particularly, healthcare, smart offices, remote assets, location services, and networking technologies. In fact, digital technology adoption reduces a series of economic costs; namely, search costs, replication costs, transportation costs, tracking costs, and verification costs (Goldfarb and Tucker 2019).

First of all, DT’s contribute to the alleviation of information asymmetry problems and communication improvement. By enhancing real-time information input —and, thus, transparency— market efficiency increases (Stahl 1989). The speed at which mobile phones spread information can reduce informational barriers for all agents in economic transactions, such as trade or investment (Aker and Mbiti 2010). As information becomes available, demand uncertainty decreases, and the flow of information will also reduce coordination costs i.e. individuals or firms would have a better chance of identifying a market for their products in an expanded area. This is particularly important for those transactions that occur in rural areas (Aker 2011; Debo and Van Ryzin 2013). Studies have shown that some pilot programs have increased access to export markets with technologies such as blockchains. Particularly, by increasing data transparency across the supply chain and using automatic digital verifications relative to time-consuming paperwork (World Bank 2018).

A second channel through which DTs improve development is by reducing transaction costs (Deichmann et al. 2016). Relative to traditional methods, DTs can be a factor of cost reduction for public and private parties in transfers and payments. Platforms created on handheld devices ease the dynamics and number of intermediate parties involved, thus, the transactions decrease some of the externalities of sending and receiving money and

\(^2\) These figures are based on the baseline GDP growth forecasts from the January 2021 Global Economic Prospects—see Lakner et al. (2021).

\(^3\) See Mahler et al. (2020).
increase the efficiency of public transfer programs (Jack and Suri 2014; Aker et al. 2013). Households are especially benefited due to targeting women in places where there is still an important economic gap (Duflo and Urty 2004; Aker et al 2013).

Third, the application of digital solutions to finance (say, mobile money, fintech companies) has contributed to grant access to finance for low-income individuals, especially those living in rural areas or the unbanked that have no access to formal institutions, such as commercial banks (Mbiti and Weil 2006). Without financial inclusion, they tend to rely on self-mechanisms that share high risks. Mobile money is a safe option for individuals to deposit savings (Aker and Wilson 2013; Ky, Rugemintwari and Sauviat 2018). In 2018, SSA has around 135 mobile money implementers and 338 million users.4

Fourth, the use of digital technologies in education can boost human capital by enhancing the provision of content and fostering the acquisition of skills. Individuals can use messaging, or applications to practice reading and writing (Aker, Ksoll, and Lybbert 2002). They can also be used in classrooms as a teaching tool or as substitute teachers.

Finally, DTs create opportunities to attract new entrepreneurs and investors in the market, without discriminating income. Creating and adopting tools that need digital performance can remain relevant when combining the efforts of digital literacy. Specifically, low skilled informal workers can perform better or higher skilled tasks and learn as they work. Without collateral, such workers can increase savings to access credit and insurance products based on recorded savings and purchase histories. Over time, the records can allow them to be matched with better jobs. Under these circumstances, financial inclusion may help boost productivity growth and reduce poverty. In fragile countries, DTs can be used to manage cross-border movements of displaced people, through digital identities, conduct cash transfers (blockchain) and purchase food from supermarkets (biometric information). Digital psychometric tests can also increase access to loans by eliminating the need for collateral (Alibhai et al. 2018).

The goal of this paper is to statistically evaluate whether digital technologies (DTs) are an important tool for development. More specifically, we examine the impact digital technologies on economic growth, poverty, and income inequality—particularly for the Africa region. To start with, measuring digital technologies is not trivial. It is hard to define because of its multidimensionality.5 For this paper, we proxied digital technologies with GSMA indicators of digital infrastructure —namely, mobile subscriptions, broadband-capable mobile connections (that is, 3G and 4G connections) and the number of internet users. We estimate the impact of the digital infrastructure on the different developmental dimensions (growth, inequality and poverty) for a panel data of 156 countries with non-overlapping five-year period observations from 1990 to 2019. To address the likely issues of unobserved effects

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4 See more information on mobile money and SSA: https://www.povertyactionlab.org/blog/10-22-20/rise-mobile-money-sub-saharan-africa-has-digital-technology-lived-its-promises

5 The different dimensions that define digital technologies are summarized in Section 2.
and weak endogeneity, we use the GMM-IV system estimator for dynamic panel data models (Arellano and Bover 1995, Blundell and Bond) adjusted for small-sample bias (Windmeijer 2005) and overfitting problems due to a large set of instruments (Roodman 2009). Our estimates find that digital infrastructure can foster inclusive growth: it increases economic growth (either through a faster accumulation of physical capital or boosting productivity growth) and it reduces both inequality and poverty.

The paper is divided into 7 sections. Section 1 is the introduction. Section 2 explains the logic behind the driver of growth of the Digital Economy. Section 3 looks at digital infrastructure trends in the Africa region by geography (East and South, West and Central, North Africa, and Fragile, conflict and violent countries). Section 4 empirically estimates the impact of digital infrastructure on economic output, the channels of growth, inequality, and poverty. Section 5 estimates the potential growth benefits of closing the gap with other benchmark regions. Section 6 is a policy discussion of the digital infrastructure coverage versus the connections. Finally, Section 7 concludes.

2. The Digital Economy’s Drive to Connectivity and Inclusiveness

Harnessing the digital economy requires policies that support a long-term vision to transform Africa’s economies, societies, and governments, and unlock new drivers of economic growth, job creation, and poverty reduction. In this context, African governments, development partners, and the private sector must collaborate and commit to policies and programs that stimulate the digital transformation of the continent and allocate resources to building the foundations of a prosperous digital economy. The foundations that would enable African countries to build a dynamic, inclusive, and digitally safe economy comprise: (1) digital infrastructure, (2) digital skills, (3) digital platforms, (4) digital financial services, and (5) digital entrepreneurship. These foundations, in turn, should be supported by a legal and regulatory framework that ensures effective competition, reduces the digital divide, promotes data privacy, and protects against the risks of cybercrime and digital exploitation (World Bank 2019).

The first pillar of the digital economy, digital infrastructure, refers to the network services that are necessary for individuals, businesses, and governments to get online and link with local and global digital services; thus, connecting them to the global digital economy. It includes the spectrum of network, computation and storage functions to successfully operate a connected economy. Digital infrastructure comprises connectivity (through high-speed internet and internet exchange points), the internet of things (mobile devices, computers, sensors, voice-activated devices, geospatial instruments, machine-to-machine communications, and vehicle-to-vehicle communications), and data repositories (data centers and clouds).

The second pillar, digital skills, are defined as: (a) the ability to enhance the adoption and/or use of digital products and services (digital literacy), (b) the ability to create local content, and (c) the ability to build or run a start-up or enterprise. Digital skills need to be accumulated to drive made-in-Africa solutions needed to ensure an inclusive digital economy, where the region is not only on the consumer side of the digital revolution, but also plays an
important role in producing technology. Digital skills have been categorized as operational, formal, informational, communicational, and content creation. Within this classification, one can find abilities such as fluency in inputting information digitally, manipulating data into more understandable forms, confidence in moving between devices and platforms, understanding the effective use of information, engaging in social networks, and ethically and using digital channels for transactions while being aware of the limitations, among others. Digital skills are often linked to better opportunities, and yet they are not exploited. Few adults (only 4 percent) can successfully perform the task of “copy/pasting” documents (UNESCO 2017). Ensuring inclusiveness in the provision of digital skills—at different levels—will be key to prevent the exclusion of already marginalized segments of the population from the benefits of mobile connectivity—thus, deepening existing inequalities.

The third pillar, digital platforms, offers products and services that are accessible through digital channels, such as mobile devices, computers, and the internet, for all aspects of life. The expansion of activity in digital platforms requires the build-up and consolidation of digital ID systems and trust services. Digital ID systems (e.g. electronic signatures) underpin trust in online transactions and create innovation opportunities in the delivery of products and services. Digital platforms can bring together producers and end-users to create value by interacting with each other, with network effects provided by users generating content, data, and larger pools of buyers and sellers. Commercial firms also operate digital platforms to offer a growing array of products and services (social media, digital mapping, data analytics, digital commerce, digital education, digital health, streaming services, gamification, augmented virtual reality, ride-sharing applications, and others). Global connectivity provides users access to information and services regardless of geographic location, leading to global services, such as Google Search, Facebook, or Amazon Web Services. Several types of digital platforms can be identified such as subscriptions models (e.g. Spotify, Netflix), information models (e.g. Glassdoor, Yelp), advertising models (Google, Facebook, LinkedIn, Zillow), e-commerce models (Amazon, Ebay), and pay-per-service models (Uber, AirBnB).7 Finally, digital platforms can connect governments and individuals to provide people-facing-government services (online facilities to pay taxes, driver’s license renewal, digital identity validation, and so forth), share information (open data or reusable public sector data), and run back-office systems (digitally managing the government’s accounting information, human resource information, and so forth). Governments can stimulate the use of digital platforms by digitizing some of their operations or processes, such as procurement, invoicing, or communications. Governments are actively playing a role in designing and implementing policy measures that enable private sector platforms to thrive and that mitigate the market distortions that platforms can bring to the economy given their network effects. These would include robust data policy frameworks (that is, protection and localization), competition policy, antitrust policies, and labor protection, among others.

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6 See Van Deursen, Helsper and Eynon (2014).
7 This classification follows the evolution of business models in Hardin (2018).
The fourth pillar, digital financial services, can enable people who are not formally connected to the banking sector to save, make payments, receive remittances, and have access to credit and insurance. Access to financial services can help individuals/households find new ways to make a living, plan for the future, or recover from economic shocks that could affect their incomes (Buckley and Malady 2015). Access to affordable and appropriate digital financial services is critical for the participation of individuals and businesses in the digital economy. Transaction accounts enable people and firms to conduct transactions electronically or online and open a pathway to a variety of digital financial services in addition to digital payments, including credit, savings, and insurance. Firms can leverage digital financial services to transact more easily with their customers and suppliers, as well as to build digital credit histories and seek financing. Governments can use digital financial services to increase efficiency and accountability in different payment streams, including for the disbursement of social transfers and receipt of tax payments. Digital payments are often the entry point for digital financial services and provide the infrastructure through which additional products can be developed, as shown by the evolution of M-PESA in Kenya. A digital financial services ecosystem requires forward-looking and proportionate legal and regulatory frameworks (for example, to allow market entry and innovation), robust financial infrastructures (for example, national payment systems and credit reporting systems), and development and deployment of low-cost delivery channels (agents, point of sale devices, automated teller machines, and mobile phones).

The final pillar, digital entrepreneurship, can help create an ecosystem that brings the digital economy to life. Innovative digital entrepreneurs can either transform existing businesses or create new growth-oriented ventures that contribute to net employment growth and boost productivity and competitiveness. They offer new products and services that leverage new technologies and business models, and open new markets. A vibrant ecosystem of digital entrepreneurs encompasses skill development (via business mentoring networks), ecosystem-support infrastructure (accelerators, incubators, innovation hubs, and co-working spaces), and access to markets and early-stage financing (seed financing and venture capital). These ecosystems require a conducive and enabling business environment that motivates the creation and use of new digital technologies.

Overall, the digital economy is a multi-dimensional concept. Harnessing the digital revolution implies making sustained investments in the aforementioned five dimensions and putting in place the complementary policies and enabling environment that maximizes the development impact of these investments. For instance, reaping the growth benefits of the digital economy involves the enactment of regulatory frameworks that support digital ecosystems fostering innovation and competition. The goal of this paper is not as ambitious and complex as the concept of the digital economy and does not intend to evaluate the impact of all the different pillars of the digital economy on development. Our approach rather focuses on assessing the impact of the digital infrastructure — that is, the first foundational pillar that also has a larger availability across countries and over time relative to the other pillars.
3. **Benchmarking SSA’s Digital Economy in Terms of Infrastructure**

This section investigates the trends in digital infrastructure for a sample of 48 Sub-Saharan African countries. It compares the evolution of digital infrastructure indicators in Sub-Saharan Africa (SSA) vis-à-vis other group comparators such as industrial countries and non-SSA developing countries (which we will call henceforth ‘developing countries’). Furthermore, it looks at the evolution of the digital infrastructure across country groups in Africa by geographical location —namely, North Africa (AFN), East and Southern Africa (AFE), and Central and West Africa (AFW)— and the group of fragility, conflict, and violence (FCV) affected SSA countries.8

Assessing the trends in digital infrastructure across countries in the Sub-Saharan Africa region implies examining the evolution of the following indicators over time:

   a. Total number of connections, excluding licensed cellular internet of things (IoT), as defined by the number of unique SIM cards (or phone numbers, where SIM cards are not used) excluding cellular M2M registered on the mobile network at the end of the period.9

   b. The number of connections by generation, where we distinguish among the spectrum of mobile broadband connections. More specifically, it distinguishes the 2G mobile network coverage (the first-generation offering data services and SMS text messaging) from 3G (first to enable video calls and faster data transfer), and 4G (providing ultra-broadband internet access).

   c. Individuals using the internet (as percentage of the population), as defined by the people using the internet (from any location) in the last 3 months. The internet can be used via a computer, mobile phone, personal digital assistant, game console, digital TV, among others.

The data on the number of connections (total and by generation) and percentage of individuals using the internet was collected for a wide array of countries worldwide during the period 1990-2020 (where available). The sources are GSMA Intelligence and the World Development Indicators for connections and internet users, respectively.

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8 Central and West Africa include Benin, Burkina Faso, Cabo Verde, Cameroon, the Central African Republic, Chad, the Republic of Congo, Côte d’Ivoire, Equatorial Guinea, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. East and South Africa include Angola, Botswana, Burundi, the Comoros, the Democratic Republic of Congo, Eritrea, Eswatini, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mozambique, Namibia, Rwanda, São Tomé and Príncipe, the Seychelles, Mauritius, Somalia, South Africa, South Sudan, Sudan, Tanzania, Uganda, Zambia, and Zimbabwe. The group of countries in fragile, conflict and violence (FCV) situation includes Burundi, the Central African Republic, Chad, the Democratic Republic of Congo, The Republic of Congo, Côte d’Ivoire, Eritrea, Guinea-Bissau, Liberia, Madagascar, Malawi, Mali, Sierra Leone, Somalia, South Sudan, Sudan, Togo, and Zimbabwe.

9 The source of data, GSMA Intelligence also estimates the number of unique users that have subscribed to mobile services (excluding M2M). Subscribers differ from connections such that a unique user can have multiple connections. This paper uses connections as a better proxy for the supply of digital infrastructure —as unique subscribers may be a better proxy for demand.
**Total Connections**

**Figure 1A** depicts the medians for total connections (excluding licensed cellular IoT) as a percentage of market population by world region. The number of connections has increased in all regions (industrial countries, developing countries, and Sub-Saharan Africa) although at different speeds over the past two decades. The number of connections in industrial countries (INDUS) doubled during the period 2000-20: it jumped from 63 percent in 2000 to 128 percent in 2020. The surge is even steeper for developing countries (DEVEL) and Sub-Saharan African (SSA) countries. The penetration of mobile connections in developing countries increased from 5 percent in 2000 to 115 percent in 2020 while that of Sub-Saharan Africa grew from 0.5 percent in 2000 to 92 percent in 2020. Although Sub-Saharan Africa registers the lowest penetration of mobile connections over the past two decades, it has the fastest pace of progress with an annual average growth rate of 33 percent. Finally, the number of connections per capita across all regions grew at a faster pace in the period 2000-10 than in 2011-20. For instance, the annual average growth of the penetration of connections in the population decelerated from 33 percent in 2000-10 to 4 percent in 2008-20.

**Figure 1. Mobile connections in Sub-Saharan Africa and the World, 2000-20 (percentage of the population)**

| A. Sub-Saharan Africa vis-à-vis the World | B. Sub-Saharan African country groups |
|------------------------------------------|-------------------------------------|
| ![Graph A. Sub-Saharan Africa vis-à-vis the World](image) | ![Graph B. Sub-Saharan African country groups](image) |

*Note. These figures report the medians across country groups for each corresponding year. Source: GSMA Intelligence*

**Figure 1B** depicts the evolution over time of the penetration of mobile connections across country groups in Sub-Saharan Africa during the period 2000-20. Over this period, there is a notorious surge in mobile connections in the Central and West Africa (AFW) region as well as the East and Southern Africa (AFE) region. Yet, the penetration of mobile connections in North Africa is significantly higher than in other SSA country groups. The rate of progress

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10: Note that the number of connections used in this paper excludes the licensed cellular internet of things (IoT). Licensed cellular IoT enables mobile data transmission between two or more machines and excludes computing devices in consumer electronics such as e-readers, smartphones, dongles and tablets.
is heterogeneous across groups and over time. The penetration of mobile connections in the AFW region grew from 0.6 percent in 2000 to 90 percent in 2020 while that of AFE region increased from 0.5 percent in 2000 to 81 percent in 2020. North Africa’s penetration of mobile connections grew from 0.3 percent to 62 percent in 2020. The rising trend in the mobile connection penetration stopped gaining momentum in all groups since 2015, except North Africa, the latter’s growth rate in connections started slowing down in 2011. The annual average growth mobile connections in both the AFW and AFE regions was about 42 percent during the period 2000-15. After the year 2015, the annual average growth rate decelerated sharply; to 3.1 percent in AFW and 4.1 percent in AFE. For North Africa, the average for 2000-11 was 54 percent and from 2012-2020, the pace slowed down to 1.2 percent. Finally, the growth of mobile penetration among FCV-affected countries (which we will call fragile countries henceforth) also experienced a surge over the past two decades. In fact, it grew from 0.3 percent in 2000 to 62 percent in 2020 (at an annual average rate of 33 percent). The expansion of the mobile network in fragile countries of the region also markedly slow down and grew at an average annual rate of 3 percent since 2015 compared to 46 percent from 2000-2015.

There is a great deal of heterogeneity in the penetration of mobile connections across countries in Sub-Saharan Africa. By the end of 2020, 20 of 48 countries have a rate of mobile penetration that exceeds 100 percent (that is, more than one connection per person). The highest rate of penetration is registered by the Seychelles (177 percent of population with connections) followed by South Africa (168 percent) and The Gambia (161 percent). At the other end of the spectrum, four countries fail to reach a penetration rate of 40 percent of the population. These countries are Madagascar (34 percent), the Central African Republic (31 percent), South Sudan (25 percent), and Eritrea (21 percent). Finally, the median rate of penetration of the region is 92 percent, and this rate broadly compares to that of Nigeria, Zambia, and Togo. Similarly, 4 of 6 North African countries registered penetration rates that exceed 100 percent—namely, Algeria (104 percent), Morocco (120 percent), Tunisia (148 percent), and Libya (168 percent) by the end of 2020.

Connections by Generation of Mobile Network

Figure 2A depicts the evolution of mobile connections by network generation across industrial countries, developing countries, and Sub-Saharan Africa over the past two decades. More specifically, it shows the trends of 2G, 3G and 4G digital mobile network coverage. The figure shows the differences in the time and pace of adoption and replacement of the different technologies across country groups. For instance, industrial countries had almost universal 2G network coverage in 2006, and that coverage gradually declined as the service was replaced by the superior 3G network. The 3G network penetration across industrial countries increased from 20 percent in 2007 to

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11 The fourteen countries with a rate of mobile penetration that exceeds 100 percent are the Seychelles, South Africa, Mauritius, The Gambia, Gabon, Botswana, Ghana, Côte d’Ivoire, Cabo Verde, Mauritania, São Tomé and Príncipe, Namibia, Senegal and Burkina Faso.
a peak of 72 percent in 2014. As the coverage of the 3G network than tripled during this period, the emergence of
the 4G network led to a gradual decline in the penetration of 3G mobile connections (it covers only 21 percent of
the population by 2020). Finally, the coverage of the 4G network still shows a steep increase across industrial
countries from 22 percent in 2014 to 94 percent in 2020.

In the case of Sub-Saharan Africa, the continent typically lags the other regions in the adoption and the replacement
of the different generations of mobile network over the past two decades. For instance, the expansion of the 2G
network coverage plateaued at 60 percent of the population in 2013 and started declining in 2016 (as opposed to
2007 among industrial countries and 2012 among developing countries). During the time that 2G was slowly being
replaced in the region, the 3G network coverage was rapidly expanding among developing countries and had already
peaked among industrial countries. The coverage of 4G mobile network in Sub-Saharan Africa has not only emerged
slowly but also remains at very low levels (below 10 percent of the population) by the end of 2020. This penetration
rate is considerably low compared to that of developing countries (40 percent) and industrial countries (94 percent).

Figure 2B plots the evolution of the coverage of the different mobile network generations (2G, 3G, and 4G) across
country groups in the Africa continent. The behavior of the different country groups mimics that of the Africa region
as a whole but there are differences in the pace of growth and the attained levels. For instance, the turning point in
the expansion of the 2G network takes place earlier in North Africa (between the period 2011-13) than in AFE and
AFW. As the penetration of 2G connections decelerates or start declining, we observe the emergence of new
technologies—as reflected by the surge in subsequent network technologies such as 3G and 4G. The figure shows
3G and 4G connections surged earlier and faster in North Africa than in Sub-Saharan Africa. By the end of 2020,
the coverage of the 3G network was more than 4.9-fold that of 2014 in the AFW region, more than 3.4-fold in the
AFE region and more than 8-fold among SSA fragile countries. Although the AFE region had a head start and
seemed to have the lead on 3G coverage, by the end of 2020, the coverage of the 3G mobile network for the AFW
catch up with the AFE region in 2020 at 37 percent. Fragile countries lagged with a coverage of about 27 percent.
Finally, the G4 mobile network emerged later across the different African regions (by the second half of the 2010s),
and its rate of penetration is still very low. By end of 2020, the coverage of the G4 mobile network is about 10
percent of the population in the AFE region, followed by fragile countries (8 percent), and then the AFW region (7
percent).
Finally, there is a greater variation across countries in the coverage of mobile network spectrums across countries in Sub-Saharan Africa. By end of 2020, the average coverage of the 2G network across countries in the region is 37 percent of the population while the coverage of 3G and 4G is equal to 42 and 12 percent of the population. In the case of the coverage of the G2 mobile network, 9 out of 48 countries still have a penetration rate that exceeds half the population, while 6 countries have a rate below 20 percent. There is also a great deal of cross-country variation in the coverage of the 3G mobile network in 2020: 17 countries in the region have a rate of coverage that exceeds 50 percent and 7 countries have a rate of coverage below 15 percent. By end-2020, there were still four countries with no coverage of the 4G mobile network (including Eritrea, South Sudan, among others). In contrast, only six countries in the ratio have a coverage rate of the G4 network that exceeds 15 percent; namely, the Seychelles (57 percent), South Africa (56 percent), Namibia (36 percent), Mauritius (30 percent), Côte d’Ivoire (20 percent), and Botswana (18 percent).

Internet Penetration

Figure 3A depicts the (median) percentage of the population using internet across industrial countries, developing countries and Sub-Saharan Africa from 1990 to 2017. There is a steep increase in the percentage of internet users in industrial countries at the beginning of the sample. This expansion then decelerates and plateaus during the period.

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Note. These figures report the medians across country groups for each corresponding year. INDC=Industrial Countries, DEVC= Developing Countries, SSA= Sub-Saharan Africa. Source: GSMA Intelligence.
2015-17 (where it grows at an annual average rate of 0.6 percent). Still, 88 percent of individuals in industrial countries had access to internet services by the end of 2017. Developing countries as well as Sub-Saharan African ones exhibit protracted increase in the penetration of internet services across the countries —and, unlike industrial countries, they did not show a deceleration in the expansion of these services. By the end of 2017, the median of internet users as a percentage of population is about 65 percent for developing countries and 20 percent for Sub-Saharan African countries.

**Figure 3B** plots the trend of internet penetration in the population of North Africa, the AFW and AFE regions, as well as among fragile countries in Sub-Saharan Africa. Internet services in fragile countries arrived as early as 2003, but it covers a very low percentage of the population by the end of 2017: internet users represent only 8.7 percent of the population. On the other hand, internet penetration appears to have increased at a faster pace among countries in the AFE group than among those in the AFW group since 2014 (at annual average rates of 25 and 20 percent, respectively). By the end of 2017, 21 percent of the population were using internet services in AFW, and 23 percent in AFE. Finally, internet penetration in North Africa started in 1995, and by the end of 2017, more than half of the population were using the internet (52 percent).

In spite of the small differences in the levels and trajectory of internet penetration for the AFW and AFE subregions, there is great dispersion across countries—with the 2017 rate of internet penetration fluctuating from 1.3 percent (Eritrea) to 62 percent (Gabon). There are six countries with a rate of internet penetration that exceeds 50 percent of the population (Gabon, the Seychelles, Cabo Verde, South Africa, Mauritius, and Namibia) and about 13 countries with internet penetration below 10 percent in 2017 (including Somalia, the Central African Republic, Chad, Congo DR, among others). Finally, the average rate of internet penetration for the region in 2017 is 24 percent—a level that is comparable to that of Cameroon, Uganda, and Tanzania.
4. The Impact of Digital Infrastructure: Empirical Analysis

This paper seeks to estimate the impact of the digital infrastructure on economic growth, income inequality, and poverty. Our empirical analysis is carried along the following dimensions:

a. Assessing the development impact of digital infrastructure involves estimating the impact of the expansion of the mobile network and internet services on: (a) economic growth and its sources (capital accumulation and total factor productivity growth), (b) income inequality (as proxied by the Gini coefficient), and (c) the poverty rate (as measured by the poverty headcount ratio).

b. Digital infrastructure is measured using indicators of the penetration of mobile services (number of connections per capita) – where we distinguish between generation of mobile services (as proxied by the coverage of 3G and 4G mobile networks) - as well as internet services (percentage of internet users in the population).

c. We have collected an unbalanced panel data of non-overlapping 5-year averages from 1990 to 2019 for 177 countries worldwide. Upon data availability for the variables involved in the regression analysis (dependent and explanatory variables), the regression sample includes up to 118 countries —of which 46 are in Sub-Saharan Africa.

d. We use an estimation method that is suited to dynamic panel data specifications, controls for unobserved time- and country-specific effects, and accounts for the likely endogeneity or reverse causality of the explanatory variables. The method used in this paper is the GMM-IV system estimator for dynamic panel
data models developed by Arellano and Bover (1995) and Blundell and Bond (1998). The standard error of GMM-IV system estimated coefficients are adjusted for small-sample bias (Windmeijer 2005) and the proliferation of instruments is also controlled for (Roodman 2009).

Before discussing our empirical analysis, we describe the main features of the estimation method used in this paper. The GMM-IV system estimator deals with unobserved time effects through the inclusion of period-specific intercepts. Dealing with unobserved countries’ effects in dynamic panel data is not trivial (due to the presence of the lagged dependent variable). The method then uses differencing and instrumentation to control for unobserved country-effects and likely endogeneity and reserve causality. Specifically, it allows relaxing the assumption of strong exogeneity of the explanatory variables by allowing the explanatory variables to be correlated with current and previous realizations of the error term. Parameter identification is achieved by assuming that future realizations of the error term do not affect current values of the explanatory variables, that the error term is serially uncorrelated, and that changes in the explanatory variables are uncorrelated with the unobserved country-specific effect. As shown in Arellano and Bond (1991) and Arellano and Bover (1995), this set of assumptions generates moment conditions that allow the estimation of our parameters of interest.

4.1 Digital Infrastructure and Economic Growth

Table 1 reports the GMM-IV system estimation of the rate of output growth per worker on different sets of digital infrastructure indicators. Specifically, we introduce different combination of digital infrastructure indicators different combinations of indicators in differences such as total mobile connections (or subscriptions), digital connection spectrum (3G and/or 4G), and the percentage of internet users. The variable for internet users is expressed in differences of the percentage of users. Note that all digital infrastructure indicators (i.e. connections and internet users) are normalized by population and expressed in log differences given their likely non-stationarity.\footnote{We refer to the growth of the digital infrastructure variables whenever cited in the remainder of this paper, unless stated otherwise.} We regress economic growth, as measured by the annual average growth in real GDP per worker over a non-overlapping 5-year period from 1990 to 2019, on the following sets of digital infrastructure variables: mobile subscriptions per capita (column [1]), total mobile subscriptions and (the combined) 3G plus 4G connections per capita (column [2]), total mobile subscriptions, 3G connections per capita and 4G connections per capita (column [3]), total mobile subscriptions and internet users (column [4]), total mobile subscriptions, internet users, and 3G plus 4G connections per capita (column [5]), and total mobile subscriptions, internet users, 3G connections per capita, and 4G connections per capita (column [6]). Note that the set of growth determinants (other than digital infrastructure indicators) include the initial level of GDP per worker in logs, financial depth (credit to the private sector as a percentage of GDP in logs), government burden (government consumption as % of GDP in logs), government burden (government consumption as % of GDP in logs), government burden (government consumption as % of GDP in logs).
education (secondary school enrollment in logs), and a synthetic indicator of governance (using the Worldwide Governance Indicators).

### Table 1. Digital Infrastructure and Output Growth

**Dependent Variable: Output growth per worker (dypw) GMM estimation, with 5-year averages from 1990 - 2019**

|                        | (1)         | (2)         | (3)         | (4)         | (5)         | (6)         |
|------------------------|-------------|-------------|-------------|-------------|-------------|-------------|
| Convergence            | -3.393***   | -3.447***   | -2.884**    | -3.050**    | -3.270***   | -2.734**    |
|                        | (0.000)     | (0.000)     | (0.002)     | (0.001)     | (0.001)     | (0.004)     |
| Financial depth (logs) | 0.203       | -0.0651     | 0.171    | 0.130       | -0.145      | 0.0108      |
|                        | (0.554)     | (0.864)     | (0.681)    | (0.708)     | (0.751)     | (0.980)     |
| Government Burden (logs) | -2.093*    | -3.029**   | -3.598*    | -1.610      | -2.678*     | -3.075*     |
|                        | (0.020)     | (0.006)     | (0.011)    | (0.084)     | (0.023)     | (0.034)     |
| Secondary enrolment (logs) | 7.005*** | 7.661***  | 7.494***   | 6.430***    | 6.717***    | 6.346***    |
|                        | (0.000)     | (0.000)     | (0.000)    | (0.000)     | (0.000)     | (0.000)     |
| Governance             | 0.0970      | 0.176       | 0.0435     | 0.0108      | 0.0467      |
|                        | (0.858)     | (0.755)     | (0.942)    | (0.824)     | (0.939)     |
| Mobile subscriptions   | 0.987***    | 1.291***   | 2.409***   | 0.959***    | 1.469***    | 2.646***    |
|                        | (0.000)     | (0.000)     | (0.000)    | (0.000)     | (0.000)     | (0.000)     |
| 3G + 4G connections    | 2.261**     | 0.186***   | 0.0637**   | 0.0608**    |
|                        | (0.001)     | (0.000)     | (0.003)    | (0.007)     |
| 3G connections         |             |             | 0.0239     | 0.0637**    |
|                        |             |             | (0.099)    | (0.004)     |
| 4G connections         |             |             | 0.364***   |             |
|                        |             |             | (0.000)    |             |
| Internet users (% of population) |       |             | 0.0239     | 0.0637**    |
|                        |             |             | (0.099)    | (0.004)     |
| Constant               | 10.09       | 10.59       | 3.377      | 7.750       |
|                        | (0.258)     | (0.261)     | (0.731)    | (0.395)     |
| Observations           | 462         | 455         | 455        | 457        |
| Groups                 | 136         | 134         | 134        | 135        |
| Instruments            | 40          | 40          | 40         | 40         |
| AR(1)                  | 0.052       | 0.048       | 0.003      | 0.054      |
| AR(2)                  | 0.402       | 0.210       | 0.280      | 0.374      |
| Sargan Test            | 0.0000      | 0.0000      | 0.0000     | 0.0000     |
| Hansen Test            | 0.001       | 0.003       | 0.011      | 0.002      |

*p-values in parentheses * p < 0.05, ** p < 0.01, *** p < 0.001

NOTE: All digital infrastructure variables are expressed in per capita terms and in log differences.

The digital infrastructure variables have a positive and significant effect on economic growth according to the results presented in Table 1. Column [1] shows a positive and significant impact of mobile connections (i.e. total subscriptions) on economic growth. Our estimates reveal that a 10-percentage point acceleration in the mobile network will increase output growth rate by 0.1 percentage point per year. This implies a cumulative growth rate of 0.5 percentage points over the subsequent five years. Column [2] estimates the effect of broadband capable mobile connections (i.e. the combined number of 3G and 4G connections), while Column [3] includes 3G connections and

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14 The indicator is formed by a Principal Component Analysis including control of corruption, government effectiveness, political stability and absence of violence, regulatory quality, rule of law, and voice and accountability from the Worldwide Governance Indicators database.
4G connections separately in the regression specification. Our regression estimates show that the impact in both cases is positive and significant—with the estimated coefficient of the broadband-capable connections is larger. A 10-percentage point increase in the number of broadband-capable connections (3G+4G) would enhance the growth rate of output per worker by 0.23 percentage point per year. Column [3] shows that an analogous increase in the number of connections (included separately) renders a higher growth per worker of 0.02 and 0.03 percentage points per year, for 3G and 4G connections, respectively. Note that in the case of columns [2] and [3], the coefficient estimates of 3G and 4G (either joint or separate) capture the marginal benefits of having broadband-capable connections. Columns [4]-[6] adds the indicator of internet penetration to the specification in columns [1]-[3], respectively. The percentage of internet users has a causal positive impact on growth. When including internet users, our estimates show that 3G plus 4G connections render a greater coefficient estimates than that of each mobile network separately. A 10-percentage point expansion of the 3G plus 4G connections will lead to an acceleration of the economy of 0.41 percentage points (pp), and when estimated separately, 3G connections would render 0.02 and 4G connections would render 0.05 pp. According to the estimates of these specifications, internet penetration increases growth per worker by 0.6 pp per year.

4.2 Digital Infrastructure and the Sources of Economic Growth

Table 2 examines the effect of digital infrastructure on economic growth and its sources; namely, the rate of growth of physical capital accumulation per worker, and the rate of growth of total factor productivity (TFP). Column [1] of Table 2 replicates the estimates of column [4] of Table 1 where economic growth is regressed on mobile subscriptions and internet penetration. Columns [2] and [3] use the same specification of the regression from column [1] but uses physical capital accumulation and TFP growth as dependent variables, respectively. Column [4] of Table 2 follows the specification of column [1] but adds (the combined) 3G plus 4G connections. Columns [5] and [6] estimates the impact of the specification in column [4] on capital accumulation and TFP growth, respectively. Finally, column [7] includes 3G and 4G connections separately to gauge their individual effects. The same specification from column [7] is used to estimate the impact of the digital infrastructure variables on capital accumulation and TFP growth in columns [8] and [9].

Now, we discuss the estimates on the other determinants other than the digital infrastructure variables that explain economic growth and its sources. First, we find robust evidence of conditional convergence in GDP per worker. Countries with lower initial levels of labor productivity tend to exhibit higher growth per worker —and these countries also tend to display greater growth in physical capital per worker and faster TFP growth. Second, growth is fostered by an expansion of education, and this impact is explained by a positive effect on both sources of growth (capital and TFP growth)—although the impact is quantitatively greater on the acceleration of capital accumulation. Third, government burden has a negative impact on economic growth —and the impact is driven by the acceleration of capital accumulation. Financial depth and governance appear to have an impact of growth that is statistically not
Table 2. Digital Infrastructure and the Sources of Growth
Dependent variables: Growth per worker (Y), Growth of capital per worker (K), TFP growth (TFP); GMM estimation, with 5-year averages from 1990 - 2019

|                      | (1)    | (2)    | (3)    | (4)    | (5)    | (6)    | (7)    | (8)    | (9)    |
|----------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Convergence          | -3.050* | -2.785*** | -1.794** | -3.270*** | -2.765*** | -1.996* | -2.734* | -2.548*** | -1.908*** |
|                      | (0.001) | (0.000) | (0.004) | (0.001) | (0.000) | (0.001) | (0.004) | (0.000) | (0.006) |
| Financial depth (logs)| 0.130   | 0.774** | -0.723  | -0.145  | 0.448   | -1.238** | 0.0108  | 0.607*   | -0.718  |
|                      | (0.708) | (0.008) | (0.072) | (0.751) | (0.088) | (0.007) | (0.980) | (0.022) | (0.085) |
| Government Burden (logs)| -1.610  | -1.464  | -0.565  | -2.678* | -2.034  | -1.512  | -3.075* | -1.857   | -1.134  |
|                      | (0.084) | (0.150) | (0.421) | (0.023) | (0.110) | (0.056) | (0.034) | (0.123) | (0.172) |
| Secondary enrolment (logs) | 6.430*** | 4.256*** | 3.022*** | 6.371*** | 4.581*** | 3.091*** | 6.346*** | 5.011*** | 2.848*** |
|                      | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Governance           | -0.125  | -0.258  | 0.512   | 0.0813  | -0.315  | 0.804*  | 0.0467  | -0.357   | 0.836*  |
|                      | (0.824) | (0.454) | (0.084) | (0.892) | (0.386) | (0.009) | (0.939) | (0.358) | (0.011) |
| Mobile subscriptions | 0.959*** | 0.219   | 0.537*** | 1.460*** | 0.562**  | 0.982*** | 2.646*** | 1.516*** | 1.792*** |
|                      | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| 3G + 4G connections  | 4.078*** | 2.573**  | 3.185*** | 6.346*** | 5.011*** | 2.848*** | 0.198*** | 0.204***  | 0.0952** |
|                      | (0.000) | (0.004) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| 3G connections       | 0.0239  | 0.0741*** | -0.00639 | 0.0637*** | 0.106*** | 0.0287  | 0.0608*  | 0.0860*** | 0.0257  |
|                      | (0.099) | (0.000) | (0.549) | (0.004) | (0.000) | (0.062) | (0.007) | (0.000) | (0.078) |
| 4G connections       | 0.470*** | 0.319*** | 0.318*** | 0.470*** | 0.319*** | 0.318*** | 0.470*** | 0.319*** | 0.318*** |
|                      | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Internet users (% of population) | 0.0239  | 0.0741*** | -0.00639 | 0.0637*** | 0.106*** | 0.0287  | 0.0608*  | 0.0860*** | 0.0257  |
|                      | (0.099) | (0.000) | (0.549) | (0.004) | (0.000) | (0.062) | (0.007) | (0.000) | (0.078) |
| Constant             | 7.750   | 11.95   | 9.119   | 12.24   | 11.80   | 13.74*  | 4.387   | 4.508   | 9.363   |
|                      | (0.395) | (0.068) | (0.094) | (0.216) | (0.092) | (0.012) | (0.657) | (0.547) | (0.114) |

*p-values in parentheses. **p < 0.05, ***p < 0.01, ****p < 0.001

NOTE: All digital infrastructure variables are expressed in per capita terms and in log differences.

In terms of digital infrastructure variables, the findings of columns [1] through [3] of Table 2 display the results of the impact of mobile subscriptions and internet users on economic growth, capital accumulation and TFP growth. The growth impact of mobile subscription on growth per worker is transmitted through enhanced TFP acceleration while impact is transmitted through capital per worker growth. Columns [4] through [6] include the impact of 3G plus 4G connections, which have a positive impact on growth. The impact is driven by both, capital and TFP growth, but primarily through an enhancement of TFP. In this context, a 10-percentage point acceleration in the expansion of the growth of 3G plus 4G connections would raise the rate of economic growth by 0.41 percentage points (or a cumulative increase of 2.1 percentage point over the next five years). The growth effect of a faster increase in the different from zero. However, financial depth has a positive impact on physical capital accumulation while governance tends to boost TFP growth.
digital connections is transmitted primarily through the TFP growth channel (Column [5] of Table 2). A 10- percentage point acceleration in the expansion of the connections would accelerate the accumulation of TFP by 0.32 percentage points (or a cumulative increase of 1.6 percentage points over the next five years). Finally, Columns [7] – [9] split the connections of 3G and 4G to show individual effects. The results contrast to that found in columns [4] – [6] in which the impact of the connections on growth is driven by capital growth.

The main takeaways from these regressions are: first, digital infrastructure growth has a positive impact on output growth, and it is transmitted through faster accumulation of physical capital per worker and enhanced TFP growth. Second, the growth returns of an expansion of digital infrastructure are larger in countries that expand broadband-capable mobile connections (3G and 4G networks) simultaneously. Third, the expansion of mobile connections has a higher impact on economic growth than an increase in the percentage of internet users. Finally, the transmission mechanism for mobile connections and internet penetration is different. The growth effects of expanding connections are transmitted through both faster capital accumulation and enhanced TFP growth, while that of internet penetration is driven only by faster accumulation of physical capital.

So far, we have found that digital infrastructure has a positive and significant causal impact on economic growth, but it is likely that the impact on growth is not homogeneous across countries. This heterogeneity might be the outcome of potential synergies between digital infrastructure and analog complements (such as human capital, and access to electricity) in spurring growth. Table 3 and 4 explore these relationships with the digital infrastructure growth variables. Table 3 follows the specifications from Table 2 but for every column, includes interactions for the respective digital infrastructure variables with human capital.\(^\text{15}\)

Columns [1] – [3] of Table 3 include the interactions of the digital infrastructure indicators (i.e. mobile subscriptions and internet users) with human capital (as measured by the Human Capital Index in Penn World Tables 9.0). The findings in column [1] show that mobile subscriptions do not have a significant impact on economic growth — either alone or interacted with human capital. However, internet users would have a positive and significant impact on economic growth beyond certain threshold of human capital—and that threshold of the human capital index is estimated at 3.04.\(^\text{16}\) Looking at the sources of growth (columns [2] and [3] of Table 3), we find that mobile subscriptions have a positive impact on capital accumulation in countries with human capital levels beyond 0.27. Internet penetration does not have a significant relationship (either linear or non-linear) with either capital accumulation or TFP growth.

\(^{15}\) Reminder that human capital is an index that is based on years of schooling and return to education.

\(^{16}\) For this estimation, the first derivative of growth relative to internet users is equal to 0, so -0.39+0.13*HC=0.
Table 3. Digital Infrastructure and Growth: Complementarities with Human Capital

Dependent variables: Growth per worker (Y), Growth of capital per worker (K), TFP growth (TFP)

|                      | (1)  | (2)  | (3)  | (4)  | (5)  | (6)  | (7)  | (8)  | (9)  |
|----------------------|------|------|------|------|------|------|------|------|------|
|                      | Y    | K    | TFP  | Y    | K    | TFP  | Y    | K    | TFP  |
| Convergence          | -4.084*** | -3.758*** | -2.525*** | -4.345*** | -3.478*** | -2.461*** | -5.452*** | -4.277*** | -2.377*** |
|                      | (0.000) | (0.000) | (0.001) | (0.000) | (0.000) | (0.001) | (0.000) | (0.000) | (0.024) |
| Financial depth (logs) | -0.326 | 0.0947 | -0.583* | -0.690* | 0.0697 | -1.137** | -1.113* | -0.673 | -0.632 |
|                      | (0.418) | (0.746) | (0.055) | (0.327) | (0.892) | (0.022) | (0.218) | (0.292) | (0.398) |
| Government Burden (logs) | -1.926 | -1.902 | -0.563* | -2.769* | -3.076 | -0.759 | -4.210* | -3.640* | -1.014 |
|                      | (0.093) | (0.117) | (0.511) | (0.047) | (0.075) | (0.372) | (0.018) | (0.049) | (0.348) |
| Secondary enrolment (logs) | 5.599*** | 4.706*** | 3.229*** | 5.303*** | 3.249*** | 3.360*** | 5.682*** | 4.608*** | 2.679*** |
|                      | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.006) |
| Governance           | 0.526 | 0.180 | 0.547 | 0.579 | 0.636 | 0.362 | 1.006 | 0.289 | 0.568 |
|                      | (0.297) | (0.645) | (0.106) | (0.337) | (0.163) | (0.351) | (0.149) | (0.505) | (0.230) |
| Mobile subscriptions per capita | 0.352* | -0.425* | 0.447 | 1.102*** | 0.274 | 0.909*** | 2.520*** | 1.922*** | 2.076*** |
|                      | (0.160) | (0.041) | (0.057) | (0.001) | (0.384) | (0.000) | (0.000) | (0.001) | (0.000) |
| 3G + 4G connections per capita | 2.856 | 25.97* | -15.12* | 2.951 | 25.97* | -15.12* | 2.951 | 25.97* | -15.12* |
|                      | (0.773) | (0.012) | (0.033) | (0.001) | (0.012) | (0.033) | (0.001) | (0.012) | (0.033) |
| 3G connections per capita |                   |                   |                  |                   |                   |
| 4G connections per capita |                   |                   |                  |                   |                   |
|                      |                   |                   |                  |                   |                   |
| Internet users (% of population) | -0.386* | -0.264 | -0.290 | -0.457* | -0.475 | -0.0108 | -0.184 | 0.0922 | -0.252 |
|                      | (0.019) | (0.107) | (0.116) | (0.049) | (0.073) | (0.954) | (0.473) | (0.704) | (0.138) |
| Mobile subscriptions * human capital | 0.382 | 1.575*** | -0.421 | 1.317** | 3.169*** | -0.560 | 1.781*** | 2.129*** | 0.0988 |
|                      | (0.267) | (0.000) | (0.161) | (0.024) | (0.007) | (0.016) | (0.019) | (0.013) | (0.872) |
| 3G+4G connections per capita * human capital | 1.332 | -6.783 | 6.203** | 1.332 | -6.783 | 6.203** | 1.332 | -6.783 | 6.203** |
|                      | (0.684) | (0.050) | (0.007) | (0.684) | (0.050) | (0.007) | (0.684) | (0.050) | (0.007) |
| 3G connections per capita * human capital |                   |                   |                  |                   |                   |
| 4G connections per capita * human capital |                   |                   |                  |                   |                   |
| Internet users (% of population) * human capital | 0.127* | 0.0811 | 0.104 | 0.163* | 0.127 | 0.0399 | 0.107 | 0.0118 | 0.111* |
|                      | (0.014) | (0.116) | (0.074) | (0.019) | (0.110) | (0.481) | (0.180) | (0.879) | (0.027) |
| Constant             | 25.37** | 24.55*** | 15.63* | 29.76** | 28.66*** | 14.85** | 38.95** | 29.22*** | 12.74 |
|                      | (0.003) | (0.001) | (0.023) | (0.006) | (0.001) | (0.031) | (0.004) | (0.004) | (0.185) |

Observations: 436
Groups: 127
Instruments: 40
AR(1): 0.056
AR(2): 0.151
Sargan Test: 0.000
Hansen Test: 0.027

*p-values in parentheses  
**p < 0.05,  ***p < 0.01,  ****p < 0.001

NOTE: All digital infrastructure variables are expressed in per capita terms and in log differences.

Columns [4] – [6] replicate the specifications from columns [4] – [6] of Table 2, and include mobile subscriptions, internet users, and the aggregate penetration of broadband-capable mobile connection (3G plus 4G connections).

The results from column [4] indicate that mobile subscriptions will have an impact on economic growth beyond certain threshold of human capital (0.84) while the marginal growth returns from 3G plus 4G connections is not
significant—even if interacted with human capital. For internet penetration, we also find that the growth returns are reaped in countries with levels of human capital that are greater than 2.8. Under this specification, all three digital indicators have a negligible impact on capital accumulation, and only the broadband-capable connections (i.e. 3G plus 4G connections) have an effect on TFP growth—especially in countries with a level of human capital that exceeds 2.4.

The last three columns of Table 3 follow the specification of column [4] of table 3 but includes 3G connections and 4G connections in the regression specification. Column [7] shows results that indicate that mobile subscriptions have a positive impact on output growth once human capital index surpasses the 1.41 threshold. The human capital threshold to reap positive growth returns from 3G connections is smaller (0.05). Internet users and 4G connections do not have a significant impact on economic growth. Both variables may have an indirect impact on output per worker through capital accumulation and it accelerates growth in capital per worker for mobile subscriptions and 3G connections when human capital exceeds certain threshold (1.41 and 0.05, respectively). None of the digital variables have a direct relationship with TFP when interacting with human capital.

Table 4 follows the specification from Table 3 but estimates the impact of digital infrastructure variables conditional on the levels of access to electricity. Column [1] shows that the interaction of mobile subscriptions and electrical access is not statistically significant. On the other hand, the estimated coefficient of the interaction of electricity access with internet users is positive and significant. However, the positive growth returns take place at very high rates of electricity access (i.e. 98 percent of the population). In columns [2]–[3], only mobile subscriptions has an effect on the accumulation of capital, but not on TFP growth and that internet has no significant relationship with capital accumulation or TFP growth when considering the interaction with electricity access.

Column [4] from Table 4 shows that mobile subscriptions has a positive impact on economic growth when electricity access exceeds the threshold of 40% of population. The effect of mobile subscription on output is mainly channeled through capital accumulation, yet when looking at the 3G and 4G connections, growth is transmitted through TFP growth. Under this specification, internet users had no effect on growth through any of its sources. Column [7] which states that mobile subscriptions have an impact on economic growth when electric access is above 65% and the impact is driven primarily through capital accumulation. 4G connections have a significant impact on growth and, analogously to 3G connections, is transmitted through faster capital accumulation. The findings from the last three columns of Table 4 shows that the effect from internet users is transmitted through enhanced TFP growth.
Table 4. Digital Infrastructure and Growth: Complementarities with Access to Electricity

Dependent variables: Growth per worker (Y), Growth of capital per worker (K), TFP growth (TFP)

|                          | (1) Y | (2) K | (3) TFP | (4) Y | (5) K | (6) TFP | (7) Y | (8) K | (9) TFP |
|--------------------------|-------|-------|---------|-------|-------|---------|-------|-------|---------|
| Convergence              | -3.831*** | -2.957*** | -2.288** | -4.395*** | -3.261*** | -2.868*** | -4.379*** | -2.466*** | -2.242*** |
|                          | (0.000) | (0.000) | (0.003) | (0.000) | (0.000) | (0.000) | (0.004) | (0.002) | (0.027) |
| Financial depth (logs)   | 0.185  | 0.377  | -0.513  | -0.0943 | 0.486  | -0.862  | -0.235 | -0.323 | 0.0104  |
|                          | (0.633) | (0.093) | (0.203) | (0.861) | (0.203) | (0.110) | (0.731) | (0.542) | (0.986) |
| Government Burden (logs) | -2.564* | -1.647 | -0.884  | -4.423*** | -2.227 | -1.519  | -5.706** | -5.237*** | -0.987  |
|                          | (0.012) | (0.105) | (0.238) | (0.000) | (0.078) | (0.059) | (0.002) | (0.001) | (0.346) |
| Secondary enrolment (logs) | 7.719*** | 5.810*** | 3.395*** | 7.352*** | 5.134*** | 3.598*** | 6.786*** | 3.771*** | 2.988*** |
|                          | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.001) | (0.005) |
| Governance               | -0.234 | -0.556 | 0.551   | 0.163   | -0.430 | 0.891** | 0.222  | -0.116 | 0.321   |
|                          | (0.695) | (0.169) | (0.096) | (0.801) | (0.311) | (0.010) | (0.781) | (0.798) | (0.508) |
| Mobile subscriptions per capita | 0.655*** | -0.182 | 0.563*** | 1.295*** | 0.476  | 0.893*** | 3.179*** | 2.433*** | 2.167*** |
|                          | (0.003) | (0.342) | (0.001) | (0.000) | (0.088) | (0.000) | (0.000) | (0.000) | (0.000) |
| 3G + 4G connections per capita | 2.220  | 7.639  | -23.73** | (0.891) | (0.515) | (0.009) |
| 3G connections per capita | 0.272** | 0.259** | 0.170*** | (0.001) | (0.001) | (0.001) |
| 4G connections per capita | 0.385  | 0.0437 | 0.487*** | (0.060) | (0.789) | (0.000) |
| Internet users (% of population) | -0.593*** | -0.316* | -0.110  | -0.459 | -0.228 | 0.338  | -0.453 | 0.412  | -0.491* |
|                          | (0.002) | (0.045) | (0.406) | (0.200) | (0.510) | (0.105) | (0.256) | (0.198) | (0.046) |
| Mobile subscriptions per capita * electricity access | 0.0104 | 0.0500*** | -0.0116 | 0.0326** | 0.0694*** | -0.00818 | 0.0491* | 0.0609** | -0.00163 |
|                          | (0.214) | (0.000) | (0.103) | (0.009) | (0.000) | (0.356) | (0.040) | (0.001) | (0.913) |
| 3G+4G connections per capita * electricity access | 0.0382 | -0.0272 | 0.272** | (0.819) | (0.829) | (0.003) |
| 3G connections per capita * electricity access | 0.0560 | 0.110*** | -0.0191 | (0.153) | (0.000) | (0.467) |
| 4G connections per capita * electricity access | 0.136** | 0.185*** | 0.00757 | (0.009) | (0.000) | (0.830) |
| Internet users (% of population) * electricity access | 0.00603** | 0.00300 | 0.00129 | 0.00491 | 0.00224 | -0.00289 | 0.00570 | -0.00280 | 0.00555* |
|                          | (0.002) | (0.057) | (0.339) | (0.164) | (0.511) | (0.166) | (0.142) | (0.361) | (0.019) |
| Constant                 | 13.21  | 9.528  | 12.70  | 23.58* | 14.21  | 19.07** | 23.32  | 16.24  | 8.099   |
|                          | (0.201) | (0.215) | (0.057) | (0.048) | (0.062) | (0.003) | (0.120) | (0.074) | (0.353) |

Observations: 451
Groups: 135
AR(1): 0.021
AR(2): 0.292
Sargan Test: 0.000
Hansen Test: 0.003

*p-values in parentheses: *p < 0.05, **p < 0.01, ***p < 0.001

NOTE: All digital infrastructure variables are expressed in per capita terms and in log differences.
4.3 The Inclusive Effects of Digital Infrastructure: Impact on Income Inequality and Poverty

In Tables 1-4 we have found that there are growth benefits from expanding the digital infrastructure. However, it is warranted to ask whether these growth benefits are distributed fairly across the members of society. Do they create opportunities for all? This section evaluates whether the pattern of growth resulting from expanding the digital infrastructure is inclusive by testing its impact on income distribution and poverty.

Table 5 presents the regression estimates of the impact of the digital infrastructure on income inequality and poverty—as measured by the Gini coefficient and the poverty headcount, respectively.\(^{17}\) The first three columns of Table 5 present the estimates of the impact of digital infrastructure on income inequality (as proxied by the Gini coefficient) while the last three columns show the regression estimates for the poverty headcount equations. For each dependent variable, we introduce the digital infrastructure variables in three different ways: (a) mobile subscriptions per capita and internet users, (b) those in (a) and the broadband-capable mobile connections (i.e. the aggregate of 3G plus 4G connections) per capita, and (c) those in (a) with the 3G and 4G connections per capita introduced separately in the regression specification.\(^{18}\)

We first discuss the estimates in columns [1] through [3]. Before discussing the findings for our variable of interest (digital infrastructure), it is important to point out that income inequality tends to be lower in countries with higher economic growth, greater rates of secondary enrollment and stronger governance. There is also evidence of a non-monotonic relationship between the Gini coefficient and the (log) level of income per capita that is consistent with the Kuznets curve hypothesis; that is, income inequality rises and subsequently declines as an economy develops. On the other hand, our evidence tends to say that greater financial development and urbanization may not have a positive effect on the distribution of income. The effects of the sectoral value added growth on the Gini coefficient differs according to the type of economic activity. Agriculture has no significant relationship with income inequality. In contrast, industrial activity has a positive effect on income inequality while services have a negative impact.

The acceleration of the penetration of mobile subscribers and internet users do not have a significant relationship with the Gini coefficient. However, either 3G or 4G connections have a negative and significant impact on inequality. Column [2] shows that the impact of these broadband-capable mobile connections (3G and 4G together) on inequality is negative and significant, and this impact is higher (in absolute terms) than the separate effect of these as portrayed by column [3]. An increase of 10 percentage points in the expansion of 3G plus 4G connections

\(^{17}\) The poverty headcount ratio is defined as the percentage of the population living on less than US$ 1.90 a day at 2011 international prices. We have also conducted our regression analysis with the poverty gap index. Although those regressions are not reported, they are available from the authors upon request.

\(^{18}\) Again, all digital infrastructure indicators (i.e. connections and internet users) are normalized by population and expressed in log differences given their likely non-stationarity.
per capita would lead to a decline in the Gini coefficient of 1.35 percent. Column [3] shows that the impact of 4G connections is more than double than that of 3G connections. The results show that a 10-percentage point increase in 3G and 4G connections would lead to a decrease in the Gini coefficient by 0.04 and 0.09 percent, respectively. This implies that an expansion of the mobile network has a more egalitarian impact on the distribution of income—and this impact is even greater with the arrival of newer technologies.

Next, we discuss the regression estimates in columns [4] to [6] of Table 5. These regressions estimate the effects of digital infrastructure on poverty, as measured by the poverty headcount. Compared to the inequality specifications, these replace the growth rate of agriculture, industry, and services for inflation and the share of agriculture in total value added. We include a set of poverty determinants other than digital infrastructure and we find the following: first, countries with higher labor productivity tend to have lower poverty rates. Second, economic growth is good for accelerating poverty reduction. Third, poverty appears to be higher in countries with a larger agriculture sector (as measured by its share in total value added)—although the effect is not statistically significant. Fourth, financial depth will help reduce the poverty headcount; however, the impact is not robust. Fifth, inflation and urbanization have no robust relationship with poverty. Finally, governance has an unexpected positive coefficient. However, it might be the case that the relationship between poverty and governance is non-monotonic.

In a similar fashion that we present our results for economic growth (and its sources) and income inequality, we regress poverty gap on the combinations of the digital infrastructure indicators. Column [4] of Table 5 shows all mobile subscriptions and internet penetration having a negative and significant impact on the poverty headcount ratio. This implies that a faster expansion of the mobile network and an increase in the penetration of internet services can play a crucial role in accelerating poverty reduction. Column [5] and [6] regress poverty gap on mobile subscriptions, internet penetration plus the 3G and 4G spectrums, jointly and separately, respectively. Both columns [5] and [6] show that the mobile-broadband connections technology have no marginal effect on poverty reduction.
Table 5 - Digital infrastructure, Inequality, and Poverty

Dependent variables: Gini Index (logs) 1-3, Poverty headcount 4-6

|                          | (1)       | (2)       | (3)       | (4)       | (5)       | (6)       |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Initial GDP per worker   | 0.768     | 0.874     | 1.120*    | -7.266*   | -7.315*   | -8.309*   |
|                          | (0.105)   | (0.051)   | (0.027)   | (0.013)   | (0.026)   | (0.012)   |
| Initial GDP per worker SQUARED | -0.0455   | -0.0504*  | -0.0637*  | -0.619*   | -0.610*   | -0.626*   |
|                          | (0.073)   | (0.035)   | (0.019)   | (0.043)   | (0.047)   |           |
| GDP per worker growth    | -0.0168*  | -0.00546  | -0.0179*  | -0.619*   | -0.610*   | -0.626*   |
|                          | (0.049)   | (0.558)   | (0.034)   | (0.017)   | (0.043)   | (0.047)   |
| Education (logs)         | -0.215*** | -0.221*** | -0.183*** | -11.30*** | -10.86*** | -12.22*** |
|                          | (0.000)   | (0.000)   | (0.000)   | (0.000)   | (0.000)   |           |
| Financial Depth (logs)   | 0.0458**  | 0.0695*** | 0.0475**  | -2.617*   | -1.635    | -1.230    |
|                          | (0.009)   | (0.000)   | (0.004)   | (0.043)   | (0.185)   | (0.333)   |
| Inflation                | 0.348     | 0.324     | 0.222     | (0.088)   | (0.084)   | (0.240)   |
| Agriculture Value added (%) | -0.00734  | -0.00710  | 0.000792  |           |           |           |
|                          | (0.071)   | (0.079)   | (0.858)   |           |           |           |
| Agriculture Value added (%) growth | 0.00904** | 0.00756*  | 0.00509   |           |           |           |
|                          | (0.007)   | (0.022)   | (0.105)   |           |           |           |
| Industrial Value added (%) | -0.00228  | -0.0182** | -0.00279  | -0.212    | -0.248*   | -0.217    |
|                          | (0.589)   | (0.008)   | (0.621)   | (0.065)   | (0.034)   | (0.067)   |
| Services Value added (%) | 0.00716** | 0.00713** | 0.00566*  | -0.212    | -0.248*   | -0.217    |
|                          | (0.005)   | (0.003)   | (0.033)   | (0.065)   | (0.034)   | (0.067)   |
| Urban population         | -0.0245   | -0.0445   | -0.0216   | 2.496**   | 2.564**   | 2.522**   |
|                          | (0.294)   | (0.082)   | (0.435)   | (0.004)   | (0.004)   | (0.005)   |
| Governance Index         | 0.0102    | -0.00954  | -0.0231   | -0.302    | -0.278    | -0.797    |
|                          | (0.343)   | (0.425)   | (0.177)   | (0.497)   | (0.566)   | (0.219)   |
| Mobile subscriptions per capita | -0.135**  |           | -0.854    |           |           |
|                          | (0.006)   |           | (0.447)   |           |           |
| 3G + 4G connections per capita |           |           |           | -0.00413* |           |
|                          |           |           |           | (0.023)   |           |
| 3G connections per capita |           |           |           | -0.00918**|           |
|                          |           |           |           | (0.006)   |           |
| 4G connections per capita |           |           |           |           | -0.162    |
|                          |           |           |           |           | (0.147)   |
| Internet users (% of population) | 0.000664 | -0.000704 | -0.000805 | -0.0990***|
|                          | (0.418)   | (0.474)   | (0.411)   | (0.000)   |
| Constant                 | 0.902     | 0.424     | -0.703    | 155.3***  | 153.1***  | 168.2***  |
|                          | (0.664)   | (0.827)   | (0.745)   | (0.000)   | (0.000)   |           |
| Observations             | 354       | 350       | 350       | 344       | 340       | 340       |
| Groups                   | 120       | 118       | 118       | 120       | 118       | 118       |
| Instruments              | 40        | 40        | 40        | 40        | 40        | 40        |
| AR(1)                    | 0.949     | 0.368     | 0.708     | 0.113     | 0.201     | 0.375     |
| AR(2)                    | 0.055     | 0.085     | 0.163     | 0.840     | 0.910     | 0.234     |
| Sargan Test              | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     | 0.000     |
| Hansen Test              | 0.040     | 0.201     | 0.524     | 0.414     | 0.400     | 0.138     |

* p-values in parentheses *p < 0.05, ** p < 0.01, *** p < 0.001

Note: All digital infrastructure variables are expressed in per capita terms and in log differences.
5. Potential Growth Benefits of Increasing Digital Infrastructure: A Comparative Statistics Analysis

This section provides an estimate of the economic impact of the expansion of the digital infrastructure variables selected in the regression tables for the Africa region. It relies on the econometric analysis carried in Section 4.2 to conduct a series of counterfactual exercises that provide the potential benefits of accelerating the coverage of the digital infrastructure network on economic growth and its sources (capital accumulation and TFP growth).

The comparative statics analysis conducted in this section consist of first, measuring the gap (or distance) of the digital variable (expansion of mobile subscriptions, 3G + 4G connections, and/or internet users) relative to a select benchmark of Sub-Saharan Africa and sub-regions (AFW, AFE, and FCV country groups) as well as North Africa. Second, we use the coefficient estimates for each of the digital variables to calculate the economic impact of closing/narrowing the digital infrastructure gap vis-à-vis the selected benchmarks. Hence, we use the regression estimates in column [4] through [6] of Table 2 to compute the likely economic effects of digital infrastructure on economic growth, physical capital accumulation and TFP growth. Third, the economic impact of development is calculated by multiplying the regression coefficient estimate and the magnitude of the gap of digital infrastructure of the Africa region vis-à-vis a select benchmark. In other words, we compute the development impact of the digital infrastructure of the region reaching the pace of expansion of select benchmarks. The developing impact, in turn, involves calculating the effects on growth and its sources (physical capital accumulation and TFP growth). The calculation of the development impact can be summarized by the following formula:

\[ Y_{dj} = \beta_d (Z_R - Z_j) \]

where \( Y \) represents changes in the development indicator in response to the closing gap in digital infrastructure relative to a determined benchmark, \( Z \) is one of the digital infrastructure indicators used in our regression analysis, the subscript \( R \) denotes the reference or benchmark country, the subscript \( j \) denotes the Sub-Saharan African country, subgroup or region as a whole, and the subscript \( d \) corresponds to the different dimensions of development used in this analysis (that is, economic growth, capital accumulation, and TFP growth). The groups of reference, \( R \), or selected benchmarks for this exercise are: (i) the 95th percentile of the Sub-Saharan Africa region, (ii) the 95th percentile of the group of developing countries excluding SSA, and (iii) the 95th percentile of the East Asia and the Pacific (EAP) region.

It is important to highlight that the counterfactual scenarios presented in this section are illustrative rather than conclusive given that, among other simplifying assumptions, they are based on the implicit hypothesis that the expansion of the individual digital infrastructure variables does not lead to changes in any of the other growth determinants. Furthermore, these counterfactual scenarios make no presumption about the desirability, on welfare grounds, of the assumed expansion of the digital infrastructure. More fundamentally, these comparative statics
exercises focus only on the development benefits of catching up (as measured by the impact on growth) and ignore
the costs it might involve—for instance, the extent of public resources that could be diverted from other uses (say,
health, education) in order to support the enhancement of the digital infrastructure network. Such costs can be quite
significant and, therefore, these illustrative exercises should be viewed with caution.

**Potential Growth Benefits from Digital Infrastructure**

Table 6 reports the potential growth benefits of accelerating the pace of mobile subscriptions in different African
groups (SSA, ESA, CWA, Fragile countries, North Africa, and the whole Africa region) vis-à-vis the
reference/benchmark countries/groups. It also reports the channels of transmission of these likely growth benefits
by calculating the potential effects on the accumulation of physical capital per worker and total factor productivity
(TFP) growth. The reference groups are constituted by the three aforementioned benchmarks—namely, the 95th
percentile for three regions: SSA, the developing world excluding SSA, and EAP.

**Table 6. Effects of the expansion of mobile subscriptions per capita on growth and its sources**

|                | PANEL A                  | PANEL B                  | PANEL C                  |
|----------------|--------------------------|--------------------------|--------------------------|
|                | Economic Growth          | Capital Accumulation     | TFP Growth               |
|                | 95th percentile          | 95th percentile          | 95th percentile          |
| SSA            | Dev. countries excl SSA  |                          |                          |
| SSA median     | 0.48 1.10 0.25           | 0.19 0.44 0.10           | 0.32 0.74 0.17           |
| AFE            | 0.48 1.10 0.25           | 0.19 0.44 0.10           | 0.32 0.73 0.17           |
| AFW            | 0.53 1.15 0.30           | 0.21 0.46 0.12           | 0.35 0.76 0.20           |
| FCV            | 0.54 1.16 0.31           | 0.22 0.47 0.13           | 0.36 0.78 0.21           |
| AFN            | 0.82 1.44 0.59           | 0.33 0.58 0.24           | 0.55 0.96 0.40           |
| Africa Median  | 0.52 1.14 0.29           | 0.21 0.46 0.12           | 0.57 0.76 0.20           |

Note: The values for the 95th percentile for SSA, developing countries excluding SSA and EAP are 0.57, 0.98 and 0.42, respectively. The values for Y, K, and TFP are 1.50, 0.60, and 1.00, respectively.

Panel A of Table 6 shows the potential economic growth benefits of reaching the pace of expansion of mobile
subscriptions of the different comparator benchmarks. Our estimates suggest that if the SSA region (median) were
to catch up the top performers of digital infrastructure in SSA (95th percentile), the rate of output per worker growth
would accelerate by 0.48 percentage points per annum (pppa). The potential growth gains are larger in the AFW
region (0.53 pppa) than in the AFE region (0.48) —as they reflect a larger distance to the SSA benchmark for the
AFW region when compared to the AFE region. SSA fragile countries—the countries with the slowest rate of
expansion of the digital infrastructure—would reap growth benefits of 0.54 pppa. The potential increase of the
growth rate for AFN is 0.82 pppa if the subregion were to catch up with the SSA benchmark.
Similarly, the African groups show similar behavior patterns if they are to reach the 95th percentile performance among the developing countries (excluding SSA) or EAP nations. The potential growth benefits of the SSA median to close the gap with the developing world’s would be 1.10 pppa and 0.25 pppa with EAP. The benefits for the AFW region would be around 0.05 pppa larger than for the AFE region. Specifically, the AFW region would render potential output growth benefits of 1.15 and 0.30 pppa if it were to close the gap with the developing world and EAP, respectively. FCV could potentially grow 1.16 pppa if it were to close the gap with the developing world and 0.31 pppa if it were to close the gap with the EAP benchmark.

Panel B of Table 6 looks at the sources of these likely growth benefits by computing the potential increase in the accumulation of physical capital per worker. Our estimates in Table 2 showed that the impact of mobile subscriptions was primarily driven by a faster accumulation of TFP (0.98) rather than by capital per worker growth (0.56). Both effects are statistically significant and positive. The accumulation of physical capital per worker would accelerate by 0.29 pppa if the SSA median would close the gap with the SSA benchmark. Large gains in terms of capital accumulation are observed in the AFW region (0.20 pppa) than in the AFE region (0.18 pppa), with similar benefits observed among fragile countries (0.21 pppa). In this case, the North Africa region would reap the largest gains of 0.29 pppa, while the whole Africa region would also reap similar benefits of 0.20 pppa in capital accumulation. From these exercises, the largest gains would be from all the African regions to close the gap with the EAP benchmark.

The behavior of the regions duplicate in the results for TFP accumulation in Panel C Table 6 for all the benchmarks, but following the example from the SSA benchmark, the SSA median would gain TFP accumulation of 0.48 ppa if it were to close the gap. The largest benefits would be acquired from closing the gap with the Africa median with the SSA benchmark at a TFP accumulation of 0.56 ppa. The SSA regions: AFE, AFW, and the fragile countries (FCV), would lead to TFP growth gains of 0.31-0.35 pppa whereas the TFP growth of North Africa would increase by 0.48 pppa.

Table 7 reports the potential output growth and the sources of likely growth benefits that can be attained by accelerating the speed of 3G + 4G connections of the region (as well as select groups) vis-à-vis the benchmark groups. Due to reasons of space, we only discuss the results with the SSA comparator thoroughly, however, when salient, we make a few comments on the other benchmarks. Panel A shows the results of closing the growth gap from 3G + 4G connections of the African regions with the benchmarks. If the SSA median were to close the gap with the SSA benchmark (95\textsuperscript{th} percentile), the region would render benefits of 1.34 pppa. Similarly, AFE would reap greater benefits than AFE at 1.40 and 1.33 pppa, respectively. As expected, FCV would attain the greatest benefits at 1.61 pppa. The whole Africa region would attain economic growth benefits of 1.27 pppa, while the north Africa region would reap output growth of 0.15 pppa. The potential growth effects would be similar in reference to
the groups and other benchmarks, yet the largest output gains would be attained if the regions were to close the gap with the EAP 95th percentile.

Table 7. Effects of the expansion of 3G + 4G connections per capita on growth and its sources

|                  | PANEL A |                  | PANEL B |                  | PANEL C |
|------------------|---------|------------------|---------|------------------|---------|
|                  | Economic Growth | Capital Accumulation | TFP Growth |
|                  | 95th percentile | 95th percentile | 95th percentile |
| SSA median       |          |                  |          |                  |         |
| SSA              | 1.34     | 1.98             | 2.41     | 0.85             | 1.26    | 1.53   | 1.05 | 1.55 | 1.88 |
| AFE              | 1.33     | 1.97             | 2.40     | 0.84             | 1.25    | 1.52   | 1.04 | 1.54 | 1.87 |
| AFW              | 1.40     | 2.04             | 2.47     | 0.89             | 1.29    | 1.57   | 1.09 | 1.59 | 1.93 |
| FCV              | 1.61     | 2.25             | 2.68     | 1.02             | 1.42    | 1.70   | 1.25 | 1.75 | 2.09 |
| AFN              | 0.15     | 0.79             | 1.22     | 0.09             | 0.50    | 0.77   | 0.12 | 0.61 | 0.95 |
| Africa Median    | 1.27     | 1.91             | 2.34     | 0.81             | 1.21    | 1.48   | 0.99 | 1.49 | 1.83 |

Note: The values for the 95th percentile for SSA, developing countries excluding SSA and EAP are 0.53, 0.69 and 0.79, respectively. The values for Y, K, and TFP are 4.10, 2.60, and 3.20, respectively.

The results from table 2 column [5] and [6] show that the source of growth for the 3G + 4G connections is driven by TFP accumulation. Panel B and Panel C of Table 7 show in a similar way to Table 2 the potential gain from closing the gap in the region with the selected benchmarks. Following the TFP growth results, the benefits for the SSA median from closing the 3G + 4G connections gap with the SSA 95th percentile, would render growth of 1.05 pppa, and 0.99 for the whole Africa region. The country group with the greatest benefits would be the fragile countries with a TFP growth of 1.25 pppa.

Lastly, Table 8 reports the potential growth output gains that can be reached if the selected country groups were to attain the internet user growth levels by our benchmark groups. Following the same exercise, if the SSA median were to close the gap on internet user growth with SSA, the region would reap the benefits of 1.45 pppa of output growth. Larger gains would be for AFW (1.51 pppa) than for AFE (1.17 pppa). Again, as expected the largest gains would be for FCV with 1.90 pppa. The whole Africa region would attain gains of 1.45 pppa, while North Africa would gain 0.84 pppa.

The coefficients from rows [5] and [6] from Table 2 prove that the sources of growth for internet users would be driven by capital accumulation vis-à-vis TFP growth. Panel B and Panel C from Table 8 show the potential gains of closing the gap with the benchmarks. Panel B shows potential benefits for capital accumulation from closing the internet user gap with the SSA leader that range from 0.84 (AFN) to 1.90 (FCV).
Table 8. Effects of the expansion of internet users on growth and its sources

|                  | PANEL A |                  |                  | PANEL B |                  |                  | PANEL C |                  |
|------------------|---------|------------------|------------------|---------|------------------|------------------|---------|------------------|
|                  | Economic Growth | Capital Accumulation | TFP Growth |
|                  | 95th percentile | 95th percentile | 95th percentile |
| SSA dev. excl SSA | SSA dev. excl SSA | SSA dev. excl SSA | SSA dev. excl SSA |
| SSA Median       | 1.45     | 1.79             | 1.29             | 1.45     | 1.79             | 1.29             | 0.43    | 0.54             | 0.39             |
| AFE              | 1.17     | 1.51             | 1.01             | 1.17     | 1.51             | 1.01             | 0.35    | 0.45             | 0.30             |
| AFW              | 1.51     | 1.85             | 1.35             | 1.51     | 1.85             | 1.35             | 0.45    | 0.56             | 0.41             |
| FCV              | 1.90     | 2.24             | 1.74             | 1.90     | 2.24             | 1.74             | 0.57    | 0.67             | 0.52             |
| AFN              | 0.84     | 1.18             | 0.68             | 0.84     | 1.18             | 0.68             | 0.25    | 0.36             | 0.21             |
| Africa Median    | 1.45     | 1.79             | 1.29             | 1.45     | 1.79             | 1.29             | 0.43    | 0.54             | 0.39             |

Note: The values for the 95th percentile for SSA, developing countries excluding SSA and EAP are 23.07, 26.51, and 21.51, respectively. The values for Y, K, and TFP are 0.10, 0.10, 0.03, respectively.

6. Policy Discussion: Coverage versus Connections

The analysis of this paper has so far documented the importance of mobile internet—and, more broadly, digital infrastructure—in driving economic growth, factor accumulation and total factor productivity growth. Most people access the internet in low- and middle-income countries through broadband-capable mobile devices. For instance, a survey of 15 low- and middle-income countries conducted by GSMA Intelligence Consumers shows that 69 percent of users access the internet exclusively through their mobile devices (GSMA 2020).

In 2019, about 3.8 billion people were connected to the internet in the world. The percentage of people living within the footprint of a mobile broadband network but not using internet services (“usage gap”) is 44 percent (that is, 3.4 billion people) while the proportion of the population that do not live in an area covered by a mobile broadband network (“coverage gap”) is 7 percent (0.57 billion people). The coverage and usage gaps in Sub-Saharan Africa are notably higher than other regions of the world (Figure 4). For instance, 26 percent have access to the internet in Sub-Saharan Africa in 2019; however, one in four people in Sub-Saharan Africa do not live in an area covered by a mobile broadband network. This coverage gap is approximately 6 percent of the population in South Asia and the Middle East and North Africa, and even lower in East Asia and the Pacific (2 percent). On the other hand, 49 percent of the population in Sub-Saharan Africa are covered but not connected—a usage gap that is only higher in South Asia (61 percent).

As documented in this paper, digital technologies can lead to greater aggregate output and productivity growth. At the microeconomic level, the adoption of digital technologies can lead to greater firms’ sales, productivity, and

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19 The discussion draws heavily from World Bank (2020 2021) and background work conducted for the forthcoming “Digital Inclusive Africa” report (Begazo-Gomez, Blimpo, and Dutz 2021).
better jobs for more people. For instance, the use of e-mail to connect with suppliers or clients, or a business website to have/increase online presence can boost the firm’s productivity. On the one hand, these digital solutions expand the group of clients of the firm or increase the number of online transactions of existing clients. On the other hand, businesses with an e-mail account to connect with suppliers expand their potential group of input providers and boost production efficiency (Cusolito, Lederman, and Peña 2020). Finally, greater firm profitability might, in turn, allow firms to invest in innovation, including managerial upgrading, or other types of technology adoption. The empirical evidence points to important benefits from digital technology adoption for firms in Sub-Saharan Africa.²⁰ Still, the use of the internet for business purposes is also very low in Africa: only 7 percent of the informal businesses surveyed prior to the pandemic in nine Sub-Saharan African countries. The penetration of the internet among informal firms is greater than the average for the region in South Africa (24 percent) and Mozambique (20 percent).²¹

**Figure 4. Connections, usage gap and coverage gap across regions in the world, 2019**

![Connections, usage gap and coverage gap across regions in the world, 2019](image)

Source: GSMA Intelligence (2020) The State of Mobile Internet Connectivity 2020.

Several factors explain the low uptake of the internet in Sub-Saharan Africa. Among individuals, Research ICT Africa (RIA) surveys show that the affordability of devices and services, as well as the lack of awareness are the

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²⁰ See volume 22 and 23 of *Africa’s Pulse* and the references therein.

²¹ See Mothobi, Gillwald, and Aguera (2020).
main barriers to internet use among the population surveyed across nine (9) African countries. Lack of affordable internet-enabled devices is the main barrier to access in Mozambique (76 percent of the population), Tanzania (64 percent), Uganda (51 percent), and Rwanda (43 percent). Lack of awareness is the main barrier in Ghana (43 percent of the population surveyed) and Nigeria (40 percent). Unaffordable service costs are a barrier for 15 percent of the population surveyed in South Africa and 33 percent in Rwanda (Research ICT Africa 2019). Among informal businesses in the region, surveyed firms do not have internet-enabled devices. For instance, more than nine in 10 informal businesses did not have a working computer in Ghana, Kenya, Mozambique, Nigeria, Tanzania, Uganda, and Rwanda. Computer ownership among informal businesses is high only in South Africa (20 percent). Also, business owners are not aware of the potential impact of the internet on business, or they consider it expensive. For instance, the majority of informal businesses claimed that access to the internet was too costly in Rwanda, Kenya, and Senegal (Mothobi, Gillwald, and Aguera 2020).

Recent econometric evidence for African countries shows that increases in income and wealth, schooling attainment, having electricity and network effects have an influence on likelihood to adopt of mobile services (including or excluding data). Furthermore, network effects network effects (proxied by the number of friends having a phone and paying for data services) and schooling (rather than income) are essential for the adoption of mobile services including data. For instance, a 10-year increase in schooling (from 5 to 15) will raise the average probability of using mobile services with data from 8 to 18 percent. Having more friends using data (from 0 to 5) increases the average likelihood of using mobile services with data from 3 to 34 percent. Finally, large increases in income (from top to bottom quintile of the distribution) increases the likelihood of using mobile services without data by only 2 percentage points while having on significant effect on the probability of using mobile services with data (Atiyas and Doganoglu 2021).

Across developing countries, the cost of acquiring data and internet-enabled devices has been declining over time —although at a much slower pace for the latter. Still, it is considerably more expensive in Sub-Saharan Africa (6.8 percent of monthly income per capita) than in other world regions. Within Sub-Saharan Africa, more than three-quarters of the countries have affordability levels that exceed the 2 percent target. Developing an inclusive digital economy requires mobile data to be affordable for the poorest. The cost of purchasing mobile data for the poorest segments of the population (say, the bottom 20 percent) is particularly more expensive in Sub-Saharan Africa —at 39 percent of monthly income per capita.

The price of a mobile device as a percentage of personal income is, on average, the highest in Sub-Saharan Africa (69 percent of monthly income per capita) and the lowest in Latin America (16 percent). These prices are even more

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22 The countries included in the 2018 RIA survey on barriers to internet access were Ghana, Kenya, Lesotho, Mozambique, Nigeria, Rwanda, Senegal, South Africa, and Uganda.

23 The Broadband Commission for Digital Development targeted entry-level broadband services to be made affordable in developing countries at less than 2 percent of monthly gross national income per capita by 2025.
prohibitive for the poorest segments of the population. On average, the price of an internet-enabled feature phone for the bottom quintile is approximately 81 percent of monthly income per capita in Latin America and 89 percent in East Asia. In Sub-Saharan Africa, the cost of such device among the poorest segments of the population is 375 percent of their monthly income.

The penetration of internet-enabled devices is hampered not only by their high prices but also the lack of payment plans in most post-paid markets in developing countries—and, notably, in Sub-Saharan Africa. Consumers in the region need significant resources, especially those in lower-income households, for one-off purchases. Fostering an inclusive digital economy includes connecting the unconnected by offering payment plans to acquire internet-enabled devices. For instance, Safaricom launched the Maisha Ni Digital (“Life Is Digital”) campaign in partnership with Google to improve access to smartphones and the internet. In July 2019, Safaricom introduced affordable 4G devices in Kenya (ranging from US$35 to US$55) to provide the digital experience for customers without smartphones. Customers are also offered payment plans for phone upgrades and personalized data plans (GSMA 2019). Furthermore, technological advances are delivering new smartphones at lower prices. For instance, Orange partnered with Itel and KaiOS Technologies to launch a new 4G version of their Sanza phone, “Sanza XL,” in December 2019. It is being offered for US$28 in Botswana, Cameroon, Côte d’Ivoire, the Arab Republic of Egypt, Jordan, Mali, and Senegal.

Mobile markets are developing fast in Sub-Saharan Africa and large investments have been undertaken in international connectivity, national backbones, and access networks. However, the adoption of digital technologies by households, firms, and governments in the region still lags that of other regions in the world; and there are large digital divides by urban-rural, gender, and firm size. Further uptake of digital technologies is hindered by limited affordable and quality internet connectivity as well as a lack of widespread availability of adequate digital services to pull demand for digital technologies, coupled with low levels of digital literacy. Therefore, policies are needed across various areas: digital infrastructure for connectivity, digital business models and digital financial services to provide appropriate digital services across economic sectors, public digital platforms and e-government services to create an enabling environment for business and pull demand for digital technologies, and digital skills, gender inclusivity, and capacity to address digital literacy gaps.

More effective regulation is needed to expand digital infrastructure and make connectivity affordable, reliable, and universal. This entails using regulatory instruments and government interventions to eliminate barriers to entry (such as restrictive licensing and exclusivity rights) and promote competition on a level playing field (such as asymmetric regulation of dominant operators, infrastructure sharing, spectrum policy, and antitrust enforcement). Governments can also implement programs targeted at providing universal access through a combination of various instruments, including universal service funds to partner with the private sector, supply or demand subsidies, and public investments. Government subsidies and other incentives for broadband and mobile providers should be
granted to all providers on equal terms without preferential treatment for state-owned enterprises. At the same time, regulatory frameworks in Sub-Saharan Africa should minimize undue regulatory burden on the sector, such as command and control rules that are not capable of accounting for the complexity of regulation and lack of adequate implementation or enforcement. Broadly, regulatory frameworks in the digital sector also need to shift toward a paradigm of fast adoption of technological change and more competitive market dynamics under an agile regulation approach. Hence, there is a need to address the persistence of dominant positions and onerous barriers to market entry, complex and burdensome tax and parafiscal fee schemes, and gaps in regional harmonization.

7. Conclusions

This paper aims to assess systematically the development impact of one of the pillars of the digital economy—that is, the digital infrastructure. Measuring the size or the capacity of the digital infrastructure network is not trivial. Assuming that digital infrastructure can be approximated by different indicators—say, mobile connections (with or without broadband capacity) and internet users—this paper provides evidence that digital technologies have the potential to provide Africa with opportunities to unlock new pathways for rapid economic growth, a more egalitarian distribution of income, and poverty reduction. Yet the problem is that access to internet remains limited and not affordable in the continent.

Our empirical analysis is conducted on an unbalanced panel data of non-overlapping five-year observations for 177 countries (including 47 Sub-Saharan African countries) during the period 1990-2019. We run a series of regressions that test the causal impact of digital infrastructure on: (a) economic growth and its sources (i.e. capital accumulation and TFP growth), (b) income distribution (as proxied by the Gini coefficient), and (c) poverty (as measured by poverty headcount). To address the issue of likely endogeneity and reverse causality, this paper uses the GMM-IV system estimator (Arellano and Bover 1995, Blundel and Bond 1998, Windmeijer 2005, Roodman 2009). The main findings of this paper can be summarized as follows.

First, we find that digital infrastructure in the Africa region has been steadily growing but at a much slower pace than in other regions. Within Sub-Saharan Africa, countries with fragile contexts (FCV) have the lowest number of mobile connections or internet users. In terms of the mobile network generation, we particularly find that Africa lags all other regions not only in the surge of mobile connections (across different generations), but also in the declining trend towards obsolescence. For instance, when 2G connections per capita started declining among industrial countries, they continued increasing among SSA countries.

Second, we find a causal positive and significant impact of digital infrastructure on economic growth across countries and over time. The growth returns of investing in digital infrastructure appear to be larger when considering the 3G and 4G connections jointly rather than individually. Additionally, there is evidence of complementarities between digital infrastructure and human capital/access to electricity in accelerating growth. In
fact, we find that the growth returns of expanding the digital infrastructure network are higher for countries with greater human capital/electricity access rates.

Third, the impact of an expansion in the digital infrastructure on growth is transmitted through both sources of growth – capital accumulation and TFP growth. Mobile subscriptions, and the combination of 3G and 4G connections per capita have an impact on economic growth primarily through the TFP growth channel, while 3G connections per capita, 4G connections per capita and internet users expand the economy via the capital accumulation channel.

Fourth, there is a causal negative impact of expanding digital infrastructure on the Gini coefficient (our proxy of income inequality) and on poverty (proxied by poverty headcount). In other words, actions that speed up the growth of the digital infrastructure help reduce income inequality and poverty. But the effects are very specific: mobile connections have a significant effect on the Gini coefficient, while that of internet users is not robust, and the effects are the other way around on poverty.

Fifth, the growth benefits of a faster expansion of the infrastructure network are economically significant for African countries. The paper conducts a comparative statics analysis of the growth benefits of accelerating the pace of expansion of the digital infrastructure network of the region relative to different benchmarks. For instance, if the pace of expansion of mobile subscriptions per capita of Africa catches up with the 95th percentile of the developing countries excluding Sub-Saharan Africa (i.e. Chile), the rate of economic growth would increase by 1.14 percentage points per annum (pppa); and most of the impact is transmitted through TFP growth per worker (0.76 percentage points). Similarly, if the gap of 3G and 4G connections per capita of the Africa region were to close with that of the developing world, economic output would grow at 1.91 percentage points per annum, and closing the gap of internet users between both regions would read benefits of 1.79 percentage points per annum.

Finally, we find evidence of a likely causal impact from digital infrastructure to growth, income inequality and poverty. Accelerating the expansion of the digital infrastructure network in African countries significantly fosters economic growth and helps lower income inequality and poverty. It also finds that complementarities between digital infrastructure and human capital / access to electricity can further ignite faster growth. Still, there is a high percentage of the population that do not have access to mobile connections (especially, broadband-capable connections) as the coverage of mobile networks continue expanding. Reducing the usage gap —along with the digital divide across gender, urban-rural and firm size— requires policies to foster the accumulation of digital skills and greater access to reliable electricity provision. Regulatory frameworks that promote competition and innovation in the telecommunications market can also help address the affordability problems. Overall, reaping the full potential of the digital economy would require the investment in the aforementioned analog complements (skills, electricity, regulation).
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