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DIGITALIZATION AND DIGITAL SKILLS GAPS IN AFRICA | AN EMPIRICAL PROFILE

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Introduction

Digital technologies launched, in many ways, by the microelectronics revolution and the Information and Communication Technology (ICT) advances which ensued in the 1970s—have had a profound impact on economies around the world. Ranging from frontier technologies such as Artificial Intelligence (AI), the Internet of Things, big data, blockchain, 5G, 3D printing, robotics, drones, gene editing, nanotechnology, and solar photovoltaic—these new technologies have significantly affected the sectors and workplaces of domestic economies around the world. In particular, increased digitalization has resulted in shifts in the nature and functionality of labor markets on both the demand and supply sides. Much of the focus on the relationship between digital technologies and the labour market, however, has been on the developed world. In a world in which digitalization—and the skills associated with digitalization—are becoming increasingly important in the structural transformation of economies, there is limited research aimed at measuring and understanding the nature and extent of digitalization and digital skills gaps in Africa particularly.

Many of the studies to date have focused on advanced economies, primarily investigating the potential effects of digital adoption on labor market disruptions, specifically automation and unemployment concerns. Theoretical and empirical work is much more limited for developing and emerging economies despite having distinct labor market characteristics, as well as being major contributors to the future workforce demographically. Developing and emerging economies overall have higher rates of self-employment and informal employment compared to advanced economies which presents a unique labor market to be affected by digitalization. The African continent in particular should be a key region of study when it comes to labor market disruptions or future of work discussions more broadly (International Labour Organization, 2019). As the world's youngest continent, Africa will make up one-fifth of the total workforce and one-third of the total youth workforce in the world by 2030, adding 10 to 12 million young people to the workforce each year (Munyati, 2020). With mobile phone subscriptions, internet availability, and innovations in mobile banking increasing in the region, digitalization will play a key role in how labor markets and ultimately economies will function within the region and globally.

The paper has three core components. Firstly, through the proposition that digitalization can be measured in five dimensions ranging from digital finance and digital platforms to digital skills and digital infrastructure, we provide empirical evidence on the changing dynamics since 2007 in Africa across these various dimensions relative to a sample of developed and emerging markets. Secondly, following this descriptive overview of digitalization trends in Africa, we apply the Alkire-Foster measure of multi-dimensional poverty widely in use in poverty analysis to the notion of digitalization in an economy and region. In so doing, we hope to deliver a Digitalization Gap Index and by extension a Digital Skills Gap Index for Africa and for a series of African countries in our sample. Such a Digitalization Gap Index will hopefully empirically anchor our understanding of the digital economy progress with respect to digitalization—and within it, digital skills—in Africa. The final component of the paper serves to develop a richer, unit record-based measure of digital skills combining country-level labor force survey data with a task-based coding system drawn from the U.S. Department of Labor. The paper focuses on the following key questions:

1. What is the level of digitization in Africa?
2. To what extent is the level of digitization in Africa ahead or behind that of other regions?
3. How can we measure digital skills' demand, supply, and the skills gap?

To consider these questions, we proceed in Section II to provide a brief analytical background locating the notion of digitalization within the broader parameters of structural transformation. Section III provides the methodological and data overview utilized in order to build our Digitalization Gap Index. Section IV provides a descriptive overview of changes in digital infrastructure, digital finance, digital entrepreneurship, digital skills, and digital public sector engagement across the individual indicators informing these dimensions. Section V provides our results for the A-F Digitalization Gap Index. In Section VI we use a case study to introduce an empirical task-based approach to measuring digital skills. Using South Africa as an example, we demonstrate that it is possible to measure the demand and supply of digital skills as well as the digital skills gap, if the relevant data is available. Section VII provides brief policy reflections whilst Section VIII concludes.

Digitalization and digital skills gaps: Background

The digital economy is a concept that has come to the fore with the rise of the use of computers and digital technologies in the world. Around the 1960s, digitalization initially involved automation of existing technologies and business processes (Lowry, 2020). Beginning from the mid-1990s however, the rapid growth of internet technologies, social networks, mobile communications, and the rise of smartphones has resulted in the broad use of technology by a broader set of end users (Lowry, 2020). Aligned to this, economies have undergone digital transformations in the presence of these digital innovations (Aptekman et al. 2017; Lowry, 2020). In discussions about digitalization, there is now a focus on how digital technologies, products, services, skills, and techniques are diffusing across economies (UNCTAD, 2019). Computers have become an integral part of our daily lives, and domestic economies are centrally reliant on digital and internet technology in ways that few could have predicted even a few years ago (Barefoot et al, 2018). The impact of these technologies on product and service offerings, as well as businesses and consumers, can be understood within the concept of the "digital economy"—with different countries having reached different levels of digitalization, along a pathway to being fully fledged digital economies.

In Africa, specifically, the concepts of digitalization and digital economies must be understood within the broader concept of structural economic transformation. Historically, many advanced economies have of course followed a similar development path from agriculture to manufacturing-intensive growth through to the final stage of industrialization as services-dominant economies. In this manner, employment generation shifted from being anchored around agriculture to being manufacturing and then services-dominant. However, recent evidence suggests that many countries—especially in Sub-Saharan Africa—are following different development trajectories compared to developed countries. Specifically, peak manufacturing employment in SSA countries are far below that achieved by developed countries and at lower levels of income (Matthess & Kunkel, 2020). This has brought into question the viability of developing countries following a manufacturing-led growth path.

Rodrik (2016) notes the phenomenon of "premature industrialization" in many developing economies and shows that for countries that industrialized before 1990, the average peak manufacturing employment share was 21.5 percent at an average GDP per capita of $11,048 (1990 US dollars). For countries which industrialised after 1990, the average peak employment share was 18.9 percent which was reached at a much lower GDP per capita of $4,273 USD—a decline of over 60 percent. In terms of manufacturing output, the average pre-1990 peak value was 27.9 percent (achieved with an average GDP per capita of $47,099 USD), compared to a post-1990 peak value of 24.1 percent (achieved with an average GDP per capita of $20,537 USD). Atoila et al. (2019) put forward several explanations for this trend including a lack of additional international demand for manufacturing goods, weak infrastructure and institutions, and an inability to compete with countries with established manufacturing bases.

The lack of growth in the manufacturing sector and challenges developing countries continue to face in developing their manufacturing sectors has brought into question the viability of developing countries following a manufacturing-led growth path and forced policymakers to explore alternative avenues for growth and employment. Much of the focus has been on the services sector, which has more than doubled its employment share in Africa from 18.0 percent in 1960 to 37.0 percent in 2010 (Matthess & Kunkel, 2020). Bhorat et al. (2016) also note that the post-2000 growth period in Africa has seen the declining importance of agriculture and a significant increase in the importance of services along with somewhat stagnant performance in manufacturing. However, most of the services sector employment growth has been located in traditional services sectors (e.g. wholesale and retail, accommodation services), which are characterized by low productivity and often informality—and hence being unable to generate high levels of economic growth for an extended period of time (Matthess & Kunkel, 2020; Bhorat, Asmal & Allen, 2020). Digitalization—and digital transformation—thus offers an opportunity for a new form of economic growth for developing countries, with the added possibility of countries being able to 'leap' stages of development—and in so doing to support structural change that provides employment opportunities and rising standards of living.

Within this context, it is important to understand what the term 'digital economy' refers to in order to measure digitalization and digitalization gaps at the country and regional level. The IMF (2018) notes that the "lack of a generally agreed definition of the "digital economy" or "digital sector" and the lack of industry and product classifications for internet platforms and associated services are hurdles to a standardized measure of the digital economy. What is clear, however, is that the term refers to the impact that digital technologies have had and continue to have on economic activity within countries, and across the world. In this regard, the continually changing nature of technology, and its impact on economic activities, contributes to the difficulty of defining the digital economy. Any definition of the term must be able to account for this rapidly evolving nature (Johnson, 2019). Further, given the differing levels of digitalization across different countries, a definition must also be flexible enough to account for the vast gaps in levels of digitalization, and rates of further digitalization, across the world.

Mesenbourg (2001) offered a comprehensive definition which consists of four components of the digital economy: Firstly, e-business infrastructure which is the share of total economic infrastructure used to support electronic business process and conduct electronic commerce. Secondly, electronic business which is any process that a business organization conducts over computer-mediated networks. Thirdly, electronic commerce which is the value of goods and services sold over computer-mediated networks and finally computer-mediated networks which are electronically linked devices that communicate interactively over networks. More recent definitions have been more flexible to encompass the full spectrum of activities that occur digitally that continue to increase over time. For example, Lowry (2020) defines the digital economy as all types of economic activity based on digital technologies, including e-commerce, internet services, electronic banking, entertainment and others. The IMF (2018) narrowly defines the digital economy as online platforms and activities that owe their existence to such platforms. For the purpose of this study, and aligned to the most recent definitions available, we understand the digital economy to refer to any and all economic activities related to, reliant on, or enhanced by, the use of digital technologies. Digital technologies include, but may not be limited to, digital infrastructure, digital services and/or platforms, and digital media. The digital economy includes all producers and consumers of goods and services which are produced and/or consumed with the aid of digital technologies.

A digitalization index: Method and data

The World Bank, through its foundational pillars of the Digital Economy for Africa Initiative—proposes a series of five dimensions of digitalization (Bashir & Miyamoto, 2020): Firstly, *digital infrastructure,* which an individual requires to engage in digital activities through the availability of widespread, high-quality broadband infrastructure. Secondly, *digital entrepreneurship,* which measures the ability of entrepreneurs to easily explore new products and opportunities in the digital space. Thirdly, *digital finance,* which captures the availability to and use of financial services by individuals and households allowing them the opportunity to pay, save, and borrow. Fourthly, the presence of *digital public platforms* through which governments provide public services using digital channels of communication and engagement. Finally, the *digital skills* dimension which measures the skills and education required to actively participate in the digital ecosystem. The proposed Digitalization Gap Index here essentially provides for individual indicators to measure each of these dimensions of digitalization which would then be coalesced using the Akire-Foster measure into a single Digitalization Gap Index at the country or region level.

As Table 1 illustrates, in very simple terms, we are proposing a measure of a region or country's Digitalization Gap Index (DG_i) as being composed effectively of five elements, namely: (i) digital infrastructure (DI_i) reflects the availability and quality of digital technologies; (ii) digital entrepreneurship (DE_i) reflects the environment that enables the creation and growth of digital businesses; (iii) digital finance (DF_i) reflects the use of digital technologies to support financial activities; (iv) digital public participation (DP_i) reflects the use of digital technologies to facilitate governments' digital engagement with citizens, such as the extent of citizens' digital engagement in the governance process; and (iv) digital skills (DS_i) reflects the availability of a skilled workforce to support the development and use of digital technologies. This can be represented simply as:

$$DG_i = f[DI_i, DE_i, DF_i, DP_i, DS_i]$$

Whilst we outline this in greater detail in the appendix below, it is important to note that for each dimension of the digitalization gap we have a series of individual indicators. Ultimately the five dimensions of digitalization would be built up collectively through sixteen individual indicators – which are spread across the five dimensions.[1] These are detailed in Table 1 below and include the following: For DI_i we include measures of fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), secure internet servers (per 1 million people),

[1] The South African, Nigerian and Ghanaian Digital Economy Diagnostic reports used these indicators to proxy for the foundational pillars of the digital economy (World Bank, 2019a, 2019b, 2019c).

and share of population using the internet. These indicators reflect the level of access and usage of the telecommunication services and internet penetration in a particular country.

Table 1. A Digitalization Gap Index: Dimensions and indicators

Dimensions	Indicators
Digital infrastructure (DI)	(i) Fixed telephone subscriptions (per 100 people) (ii) Mobile cellular subscriptions (per 100 people) (iii) Secure internet servers (per 1 million people) (iv) Individuals using the internet (percent of population)
Digital entrepreneurship (DE)	(i) Venture capital availability (ii) Ease of access to loans (iii) ICT services export (percent of exports Balance of Payments (BoP))
Digital finance (DF)	(i) Account ownership at a financial institution or with a mobile money-service provider (percent of population age 15+) (ii) Used the internet to pay bills or to buy something online in the past year (percent of population age 15+) (iii) Made or received digital payments in the past year (percent of population age 15+)
Digital public participation (DP)	(i) Online service index (ii) E-participation index value
Digital skills (DS)	(i) Secondary gross enrollment ratio (percent) (ii) Tertiary gross enrollment ratio (percent) (iii) Mean years of schooling (iv) Internet access in schools

For DE_i we measure venture capital availability, ease of access to loans, and ICT service exports for country i. These indicators are important for digital entrepreneurship as they reflect the availability of funding for digital businesses to develop and grow, and the availability of resources to invest in technology and the engagement in export activities of ICT services. DF_i is measured through account ownership at a financial institution or with a mobile-money-service provider, use of the internet to transact online in the past year, and finally making or receiving digital payments in the past year. High levels of account ownership, internet payment and digital payment usage suggest that the population is actively participating in the digital economy, which can drive financial inclusion, increase access to financial services, and facilitate digital transactions. DP_i is measured by the value of the online services index for the country and secondly its e-participation index value. The online services index indicates the level of governments' effort to provide digital services to citizens and the e-participation index indicates the level of citizens' willingness to participate in the governance process through digital means. Finally, for DS_i our indicators include secondary gross enrollment ratio (percent) and tertiary gross enrollment ratios (percent), mean years of schooling and internet access in schools. A high enrollment ratio indicates a strong investment in education and the development of a knowledgeable workforce. High mean years of schooling and tertiary gross enrollment reflect a well-educated population that will be able to drive innovation and competitiveness and having internet access in schools is important for students to be able to learn about digital technologies and to develop the digital skills necessary for the growth of the digital economy.

Each of these dimensions and their indicators are individually very useful in providing insights into various aspects of an economy or region's progress (or lack thereof) in specific aspects of the digital ecosystem. We thus provide an empirical overview of trends in these indicators in the next section. However, it is important to note that when combined together, these indices could potentially provide powerful summary measures on the nature and extent of progress at the country or regional level in the digital ecosystem. In order to derive such a composite measure of digitalization—or rather a 'Digitalization Gap Index' and within it for example a 'Digital Skills Gap Index'—we lean on the multi-dimensional poverty literature to provide us with a methodologically sound measurement tool.

Hence, given the above composite measure, DG_i, we propose to apply the Alkire-Foster Multi-Dimensional Poverty Index very widely in use in poverty studies (Alkire & Foster, 2011) to construct a measure of Digitalization—our Digitalization Gap Index——at the country and region level. The Alkire-Foster (A-F) Index measure of multi-dimensional poverty is used in the measurement of poverty as it includes a range of non-income variables such as education, housing and health access (Alkire & Foster, 2011). Using the A-F Index method allows us to combine all five dimensions of the digital ecosystem into a unique, single, multi-dimensional measure of a digitalization gap at the country and regional level.

Methodologically, the A-F framework requires the explicit selection of dimensions and indicators, weights, and cut-offs. The dimensions in which we group the indicators focus on key foundations of the digital economy. Whilst detailed in the appendix, it is important to note that standard A-F practice is to assign equal weighting across and within dimensions, unless there are justified normative or empirical reasons not to (Alkire 2016). In this study the index distributes equal weights across the five dimensions (one-fifth each), and the sixteen indicators within each dimension receive equal weights[2]. In addition, the derivation of the Digitalization Gap Index involves setting a threshold 'digital vulnerability line'. We set this as the mean for each indicator—and then estimating the mean normalized gap for each sub-group's deviation from the digital vulnerability line. The study uses the Group of 20 (G20) sample of economies as the country mean for each indicator as the cut-off. This allows for an assessment of the changing nature of digital vulnerability in Africa relative to these G20 countries over time. The

[2] We have applied equal weighting in our analysis. Alkire and Foster's methodology allows for flexibility in the weighting applied and can be adjusted based on the specific requirements. We presented results using different weights in Table A1 in the appendix, and we find that the results remain consistent even when different weighting options are used, compared to the equal weighting scenario. In Table A1, we have combined 2 dimensions: digital entrepreneurship and digital finance.

index is based on the normalized income gap—called the 'poverty gap' in the poverty literature. Given the indicator, $\boldsymbol{x}$, we begin by calculating the normalized gap, given by:

$$Normalized\ Gap = \frac{x_{G20} - x_{Africa}}{x_{G20}}$$

Where x_{G20} and x_{Africa} are the mean values for indicator $\boldsymbol{x}$ in G20 and Africa respectively. The matrix is then censored by replacing all negative elements with a zero. Negative elements are an indication that a country is not vulnerable in that dimension.

To calculate the Digitalization Gap Index, we then calculate the average of the dimensions. For example, digital entrepreneurship (DE) would be estimated as the average of venture capital, ease of access and ICT services and so on, whilst for digital public participation (DP) it would be the average of online services and e-participation and so on. In order to calculate the overall Digitalization Gap Index, we calculate the average of all the dimensions. In poverty literature, this is known as the adjusted poverty gap. The entire process is replicated for each period.

The study utilizes data from different sources, primarily from the World Bank database and the United Nations. The sample consists of 21 African countries[3] and 21 G20 countries (excluding South Africa) covering the period 2011 through 2017[4]. Ultimately then, as detailed in Table 1, the Digitalization Gap Index is constructed based on the five dimensions and is made up of 16 individual indicators. The indicators are then synthesised into a single composite measure of a Digitalization Gap. Importantly, these indicators were selected depending on the data availability for our sample countries. There are two critical concerns to deal with in relation to our data choices. Firstly, using the G20 sample of economies is on the face of it possibly arbitrary and not ideally representative of the world economy. Our choice was driven by three factors. Firstly in terms of the individual indictors' information, it was most often that the G20 sample of economies yielded a full set of data points for the individual indicators. Widening the sample to include all developing countries tended to result in missing data for numerous countries—rendering comparisons across the dimensions and indicators over time unbalanced at the country level. Secondly, the G20 sample of countries has a combination of industrialized economies and a series of emerging markets ranging from India and Indonesia to Argentina and Turkey. As a comparison group for Africa—it represents an important aspirational sample of economies in terms of the region's progress in the digital ecospace. Finally the G20 economies of course are a highly representative group of economies as they account for over 85 percent of global GDP and two-thirds of the world's population (Department of Foreign Affairs and Trade, 2023).

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[3] African countries in the sample include Algeria, Benin, Botswana, Cameroon, Egypt, Arab Rep., Ethiopia, Madagascar, Malawi, Mali, Mauritius, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Tunisia, Zambia, and Zimbabwe

[4] G20 sample countries include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain, Turkey, the UK, and the USA.

Our second and final data caveat relates the very real challenge of missing data for Africa. Whilst micro data for African economies is hard to come by, it remains particularly difficult to access even broad statistical estimates for many African economies on the digitalization index dimensions and indicators. We thus run the risk in many indicator measures of possibly overestimating the extent of progress in the various digitalization dimensions. The fact that we have no digital infrastructure measures for the Burundi or CAR for example, almost certainly means that our estimates of digital infrastructure availability in Africa are upwardly biased. Indeed, this type of missing data problem is pervasive for almost all our indicator measures. As we will show below this can often result in clearly outlier results for Africa, when compared with the G20.

Measuring digitalization in Africa: A descriptive overview

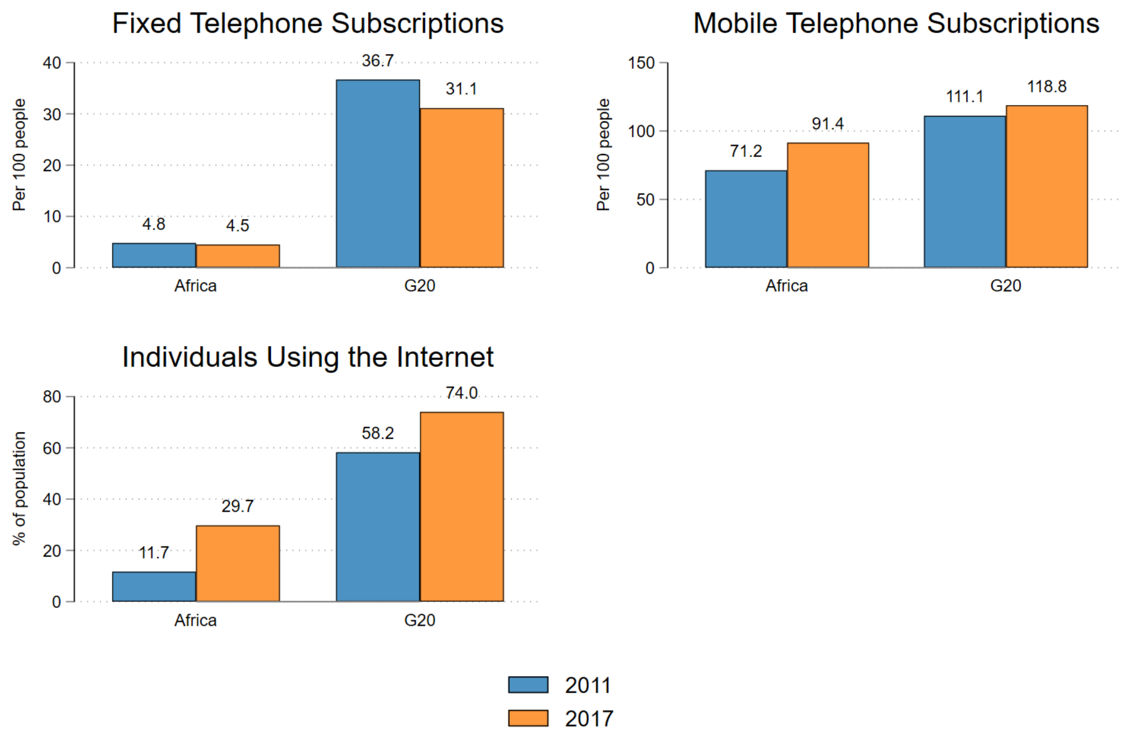
Given the above five dimensions of digitalization, we turn now to a detailed empirical overview of the trends observed over time—in most cases between 2011 and 2017—in each of the sixteen indicators. Our comparison group is the G20 as noted above, and furthermore we attempt to ensure accuracy in our sample specificity for Africa. As is often the cases, large swathes of the continent's economies are excluded due to lack of data. We turn now to each of the individual dimensions of digitalization.

Digital infrastructure

Digital infrastructure is the key to connecting people and businesses globally. High-quality, affordable broadband internet is the key infrastructure requirement of the digital economy. It can boost economic growth, improve productivity, and provide citizens with better access to information. Casual observation would suggest that whilst the overall state of Africa's digital infrastructure is uneven at the country level it has witnessed some progress in some of the individual indicator measures of infrastructure. Fixed-line internet and especially fiber-optic (FTTX) connections to homes and businesses have experienced rapid growth in recent years, showing much promise.

Figure 1 provides then an overview of shifts in digital infrastructure in Africa relative to the G20 for 2011 and 2017—across the three individual indicator measures. Visually, it is very clear firstly that there is a much higher endowment of digital infrastructure in Africa with respect to mobile subscriptions and individual internet usage relative to fixed line infrastructure.

Figure 1. Digital infrastructure in Africa and G20, by type of infrastructure: 2011 and 2017



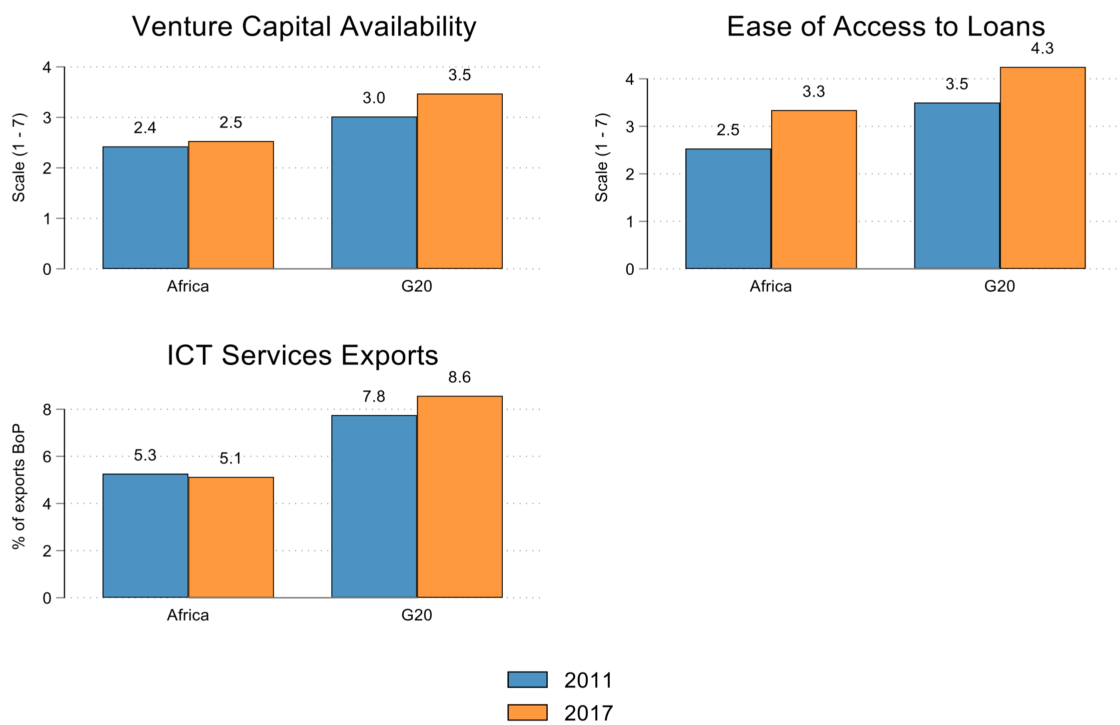
Source: World Bank (2022), authors' calculations.
Notes [1] African sample countries include: Algeria, Benin, Botswana, Cameroon, Egypt, Ethiopia, Madagascar (excluding 2017: Percentage of individuals using the internet), Malawi, Mali, Mauritius, Namibia, Niger, Nigeria (excluding 2011: Fixed broadband subscriptions), Rwanda, Senegal, South Africa, Tanzania, Togo, Tunisia, Zambia (excluding 2017: Percentage of individuals using the internet), and Zimbabwe.
[2] G20 sample countries include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain, Turkey, the UK, and the USA.

Specifically then, for the sample of African economies we find that 91 out of 100 individuals have a mobile phone compared with only 4.5 individuals with a fixed line in 2017. The G20 mobile and fixed line differential—although smaller—is equally stark. However, it is when examining internet usage and fixed telephone subscriptions that the Africa differential relative to the G20 becomes clear. Hence, despite 30 percent of all individuals in the African sample using the internet (up from 12 percent in 2011)—this figure is much lower than the 74 percent for over two-thirds of the world's population. A final point on country heterogeneity: Even within the relatively limited sample of African economies we present here—it is important to note that there are significant country-level differences. Hence for example, whilst South Africa, Tunisia, and Mauritius had more than half of the population using the internet, in contrast Niger, Togo, Benin, Malawi, Mali, Tanzania, and Ethiopia had less than one fifth of the population using the internet. Even in mobile subscriptions, we find that in 2017, South Africa, Botswana, and Mauritius had 155, 147, and 145 mobile subscription per 100 people—whilst Madagascar, Ethiopia, and Niger had 34, 37, and 40 mobile subscriptions per 100 people.

Digital entrepreneurship

Digital entrepreneurship is a key component of a strong digital economy that is capable of creating new products and services, as well as contributing to job creation. Figure 2 shows several indicators of digital entrepreneurship in Africa between 2011 and 2017. Venture capital availability is the ease of access by entrepreneurs with innovative but risky projects to secure venture capital measured here on a scale between one (lowest) and seven (highest). Ease of access to loans—in trying measure liquidity and credit in an economy is also similarly measured. We then have a third indicator for digital entrepreneurship measured by the share of ICT exports in total services exports.

Figure 2. Digital entrepreneurship indicators in Africa, 2011-2017



Source: World Bank (2022), authors' calculations.
Notes: [1] African sample countries include: Algeria, Benin, Botswana, Cameroon, Egypt, Ethiopia, Madagascar, Malawi, Mali, Mauritius, Namibia, Niger (excluding venture capital availability (2011 & 2017) and ease of access to loans (2011 & 2017)) , Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Tunisia (excluding venture capital availability (2011 & 2017) and ease of access to loans (2011 & 2017)), Zambia, and Zimbabwe.
[2] G20 sample countries include: Argentina (excluding ease of access to loans (2011 & 2017)), Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain (excluding ICT services exports (2011), Turkey, the UK, and the USA.

On average for countries sampled here, it would seem that whilst it is easier to access venture capital funding in the G20—it is not chronically impossible in Africa. Access to venture capital is surprisingly close in ranking at 2.5 to that of the G20 countries at 3.5—where it is possible that more mature capital markets, which are more risk averse render it harder to access such capital for digital entrepreneurs.

Relatedly, access to loans has also improved significantly in the region from a rank of 2.5 to 3.3 over the period. This is still below the 4.3 rank score for the G20. Country heterogeneity shows that Mauritius, Rwanda, and South Africa had the highest scores of 4.21, 4.06, and 3.95 for ease of access to loans in 2017, respectively. In contrast, Benin, Nigeria, and Malawi had the lowest scores of 2.32, 2.58, and 2.6 loan access in 2017. Notably, the access to loans score has improved across all the African countries in the sample, except for Benin. ICT services exports—while the data is patchy and relatively unreliable—Africa's share has remained stable at about 5 percent whilst that of the G20 has increased steadily from 7.8 to 8.6 percent as a share of total services exports.

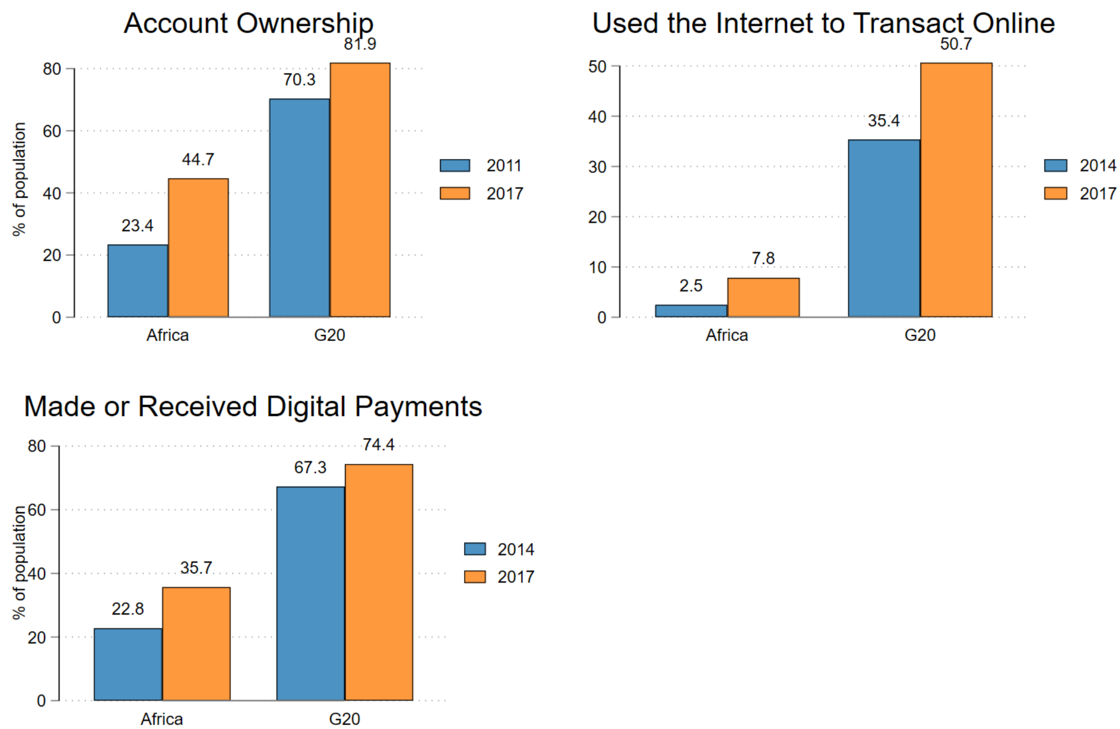
Ultimately though, it is clear that in this digital entrepreneurship dimension, there has been steady progress towards providing enhanced access to entrepreneurs and firms in terms of venture capital financing and more generally access to credit in the African market. It is likely again that the digital infrastructure built through the mobile phone revolution and its neighbor—mobile banking—has fueled at least part of this growth in Africa.

Digital finance

ICT services have improved access to digital financial services and markets, thereby boosting financial inclusion (IMF, 2018). Digital financial services provide individuals and households convenient and affordable ways to pay, save and take out loans. A successful digital financial services ecosystem involves the development of robust and forward-looking regulations and broad types of financial infrastructure that can support the expansion of digital financial services (World Bank, 2020).

Figure 3 thus represents three individual indicator measures of digital finance, namely bank account ownership, usage of the internet to transact online, and the making or receiving of digital payments. Across all three indicators for digital finance there has been a growth in usage rates in Africa, indicating some progress toward enhanced digitalization in the region. In terms of the specific indicators, it is clear that the first step in digital finance inclusion—namely some form of a financial services account—has grown rapidly in Africa. Indeed by 2017 for the sample of economies, 45 percent of all individuals had a financial services account. Notably though, this still lagged behind the G20 where 82 percent of all individuals over 15 report having an account. Across the remaining indicators though, it is clear that the gap between Africa and the G20 economies is substantial.

Figure 3. Digital finance indicators in Africa, 2011-2017



Source: World Bank (2022), authors' calculations.
Notes: [1] African sample countries include: Algeria, Benin (excluding use of a debit/credit card (2011)), Botswana, Cameroon (excluding use of a debit/credit card (2011)), Egypt, Ethiopia (excluding account ownership (2011) and use of a debit/credit card (2011 & 2017)), Madagascar (excluding use of a debit/credit card (2011 & 2017)), Malawi, Mali (excluding use of a debit/credit card (2011)), Mauritius, Namibia (excluding account ownership (2011)), Niger (excluding use of a debit/credit card (2011 & 2017)), Nigeria, Rwanda, Senegal (excluding use of a debit/cred card (2011)), South Africa, Tanzania, Togo (excluding use of a debit/cred card (2011)), Tunisia (excluding account ownership (2011)), Zambia (excluding 2017:Percentage of individuals using the internet), and Zimbabwe.
[2] G20 sample countries include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain, Turkey, the UK, and the USA.

For example, whilst 75 percent of G20 residents made or received digital payments—this figure was only about half of this at 36 percent for Africa. Using the internet for online transactions in Africa is rarity as a mere 8 percent of residents report using the internet for these purposes—while over half of the G20 population report making online transactions.

Again though, the country-level heterogeneity within the African sample provides a reminder of the inequality of digitalization at the country level. For example whilst at least more than half of individuals had an account at a financial institution in Mauritius, Namibia, South Africa, Zimbabwe, Botswana, and Rwanda in 2017,in Niger and Madagascar only 15.5 and 17.9 percent respectively of their populations report having a bank account. Online transaction data at the country level shows that whilst Namibia accounted for the largest share of individuals who used the internet for online transactions at 18.3 percent, followed by Mauritius (16.4 percent), and

South Africa (14.1percent),less than 2 percent of the population in Ethiopia participate in online transactions, whilst in Madagascar this figure is 0.6 percent.

The above data does however suggest more broadly that for the sample of African economies for which we have data there has been a growing digitalization of financial services as individuals have gradually moved away from traditional methods of payment in Africa. The increasing use of mobile telephones in developing countries has no doubt contributed to the emergence of branchless banking services, thereby improving financial inclusion (IMF, 2018). However, in many countries for which we have data it is clear that the levels of digital finance usage remain chronically low—and indeed have not kept pace with the growth rates observed for the majority of the world's population resident in the G20 sample of countries.

Digital public platform participation

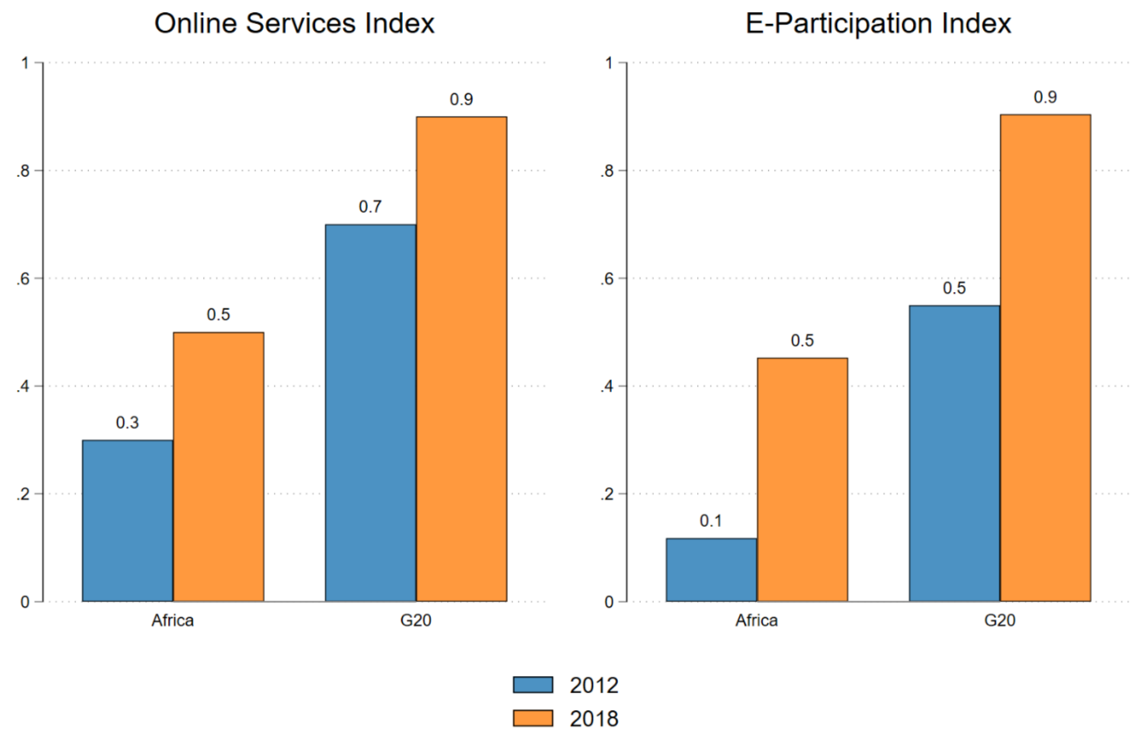
Digital public platforms serve as an important enabler of digital economy, allowing both public and private sector organizations to come up with new or better outcomes for citizens. The discussion of digital public platforms is often equated with the development of e-government or digital government.

E-government development is focused on the comprehensive view of how government can benefit citizens by delivering services and information through the use of technology (UN, 2020). Mathematically, the E-Government Development Index (EGDI) is a weighted average of three normalized scores on three most important dimensions of e-government, namely scope and quality of online services, development status of telecommunication infrastructure, and inherent human capital (UN, 2020). To avoid double counting of the e-government development index and the digital skills indicators, we use Online Services Index (OSI) to proxy for measuring the government's role in providing digital services to its citizens.

In turn, the E-Participation Index (EPI) is defined by the United Nations as "the process of engaging citizens through ICTs in policy and decision making in order to make public administration participatory, inclusive, collaborative and deliberative for intrinsic and instrumental ends" (UN, 2014: 61). According to the United Nations, the E-Participation Index evaluates the quality and usefulness of information and services offered by a country with the objective of engaging its citizens in public policymaking (UN, 2016). The EPI consists of three broad areas: e-information, e-consultation, and e-decisionmaking, where the index is then presented as the normalized score of the three sub-indicators.

Figure 4 shows that for both the OSI and EPI, African governments have lagged behind those of the G20. Hence in 2012, the OSI stood at an average normalised score of 0.3 for Africa, whilst for the G20 it was 0.7. In addition, the EPI was 0.5 for the average African government, but 0.9 for the average G20 government. What is important to note however, is the rapid improvement in EPI in particular for African governments. Hence over the 6-year period we have witnessed a 400 percent increase in the average participation index of African governments—suggesting significant improvements in governments' engagement with their citizens in Africa.

Figure 4. Digital public participation indicators in Africa, 2011-2017



Source: World Bank (2022), authors' calculations.
Notes: [1] African sample countries include: Algeria, Benin, Botswana, Cameroon, Egypt, Ethiopia, Madagascar, Malawi, Mali, Mauritius, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo, Tunisia, Zambia, and Zimbabwe.
[2] G20 sample countries include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain, Turkey, the UK, and the USA.

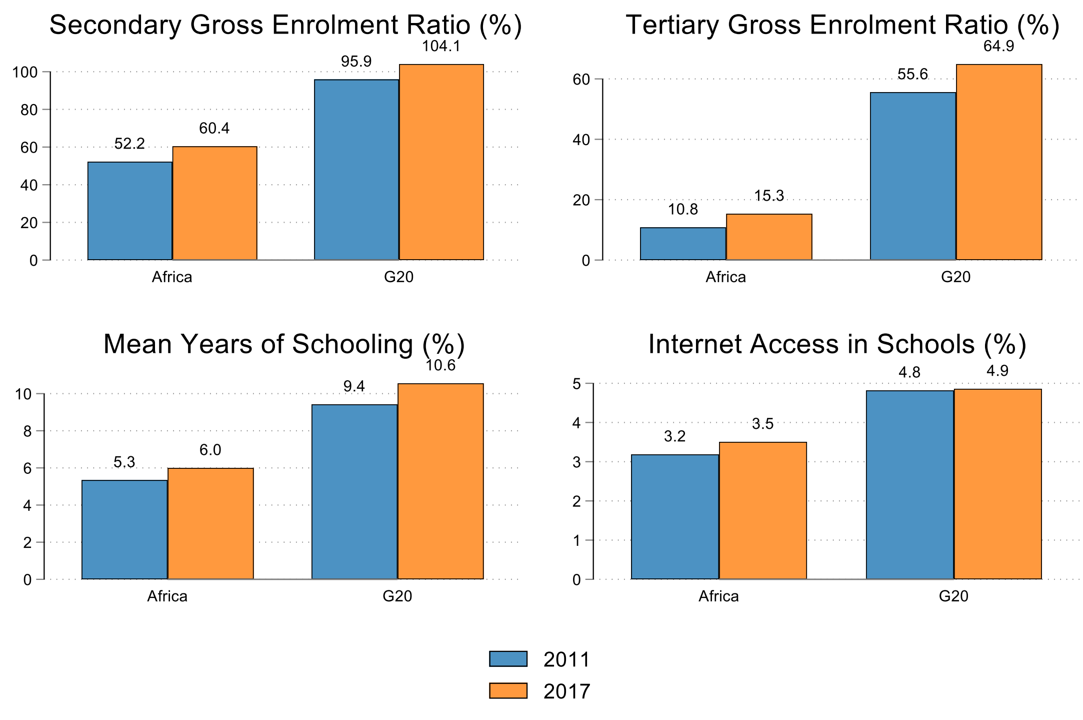
Country-level data shows that both Tunisia and South Africa scored the highest online services index at 0.8 followed by 0.7 in Mauritius and Rwanda. Notably, most African countries saw an increase in their OSI, except for Madagascar, Mali, Malawi, Algeria, Botswana, and Niger. Data for the EPI shows that in South Africa, Tunisia, Rwanda, and Mauritius the index stood at 0.85, 0.8, 0.76 and 0.69 respectively in 2017—with countries such as Algeria, Botswana, and Malawi yielding much lower estimates of the EPI at 0.2.

Digital skills

The final component of the ecosystem is the availability of skills that are required to make use of digital infrastructure and digital platforms. The development of a vibrant, dynamic, and inclusive digital economy requires a deep labor pool (World Bank, 2019). Foundational for a digital economy to flourish, developing a digitally competent workforce and digitally literate citizens is essential (World Bank, 2019). The digital economy requires higher levels of human and capital investment from governments and the private sector to meet current and future digital skills needs. This means that individuals will need to be upskilled along with improvements in digital infrastructure to adapt to the ever-evolving digital market.

The workforce's ability to innovate and utilize digital technology is tied to the overall digital economy. While there is currently no data on the extent of basic digital skill attainment, there are several proxy indicators that can help provide insights. Secondary education is the appropriate place to assess acquisition of functional ICT skills. The secondary Gross Enrollment Ratio (GER) for most African countries is high, indicating that most countries can accommodate all of its school-age population (
Figure **5**). More than 80 percent of the population were participating in secondary schooling in Algeria, Mauritius, South Africa, Tunisia, Egypt, and Botswana. Indeed, these countries are closer to the average of G20 countries (104.1 percent) than the African mean of 60.4 percent. In contrast, Tanzania, Ethiopia, Madagascar, and Rwanda have less than two-fifths of the population who are enrolled in secondary education—so mitigating significantly against the adoption of digital skills.

Figure 5. Digital skills indicators in Africa, 2011-2017



Source: World Bank (2022), authors' calculations.
Notes: [1] African sample countries include: Algeria, Benin, Botswana, Cameroon, Egypt, Ethiopia, Madagascar, Malawi, Mali, Mauritius, Namibia, Niger (excluding secondary gross enrollment ratio (2017), tertiary gross enrollment ratio (2017), mean years of schooling (2017) and internet access in schools (2011 & 2017)), Nigeria, Rwanda, Senegal, South Africa, Tanzania, Togo (excluding internet access in schools (2011 & 2017)), Tunisia, Zambia, and Zimbabwe.
[2] G20 sample countries include: Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, Republic of South Korea, Mexico, Russia, Saudi Arabia, Spain, Turkey, the UK, and the USA.

In turn, we find that whilst mean years of schooling reach well into secondary school—at 10.6 years in the G20—they do not on average exceed six years in Africa. Too many African pupils are not proceeding beyond primary schooling. The consequence then of this poor performing secondary schooling system is that tertiary GERs are exceedingly low in Africa. Hence the GER for Africa stood at 15.3 percent in 2017, compared with 65 percent in the G20. If there was one crucial measure indicating that lack of readiness within the region in terms of producing the necessary quantum of digital skills—it is the extremely low enrollment rates in higher education institutions in Africa. The share of schools with internet access is surprisingly low for both Africa and the G20, although this may be a data coverage issue. Hence we find that whilst 3.5 percent of schools in Africa for which there is data have access to the internet, this number is 4.9 percent in the G20.

One important analytical extension is worth including here, namely the need to ensure not only that accumulation of human capital occurs but that it is both in the correct fields required by firms operating in the digital economy—but is also of a sufficiently high quality. In trying to describe the significant inequality in the distribution of quality of higher education within the STEM fields, we extend the table below from Bhorat et al (forthcoming).

Hence, in Table 2 below we use rankings of universities by field of study and country, from the Quacquarelli Symonds (QS) World University Rankings database. The latter is widely used in annual global rankings analysis of tertiary institutes around the world. Table 2 thus provides data on the top 500 higher education institutions by subject and level of income for regions of the world. The data illustrates a significant maldistribution in the quality of higher education institutions in STEM fields, in the world economy. Hence, over 80 percent of the top 500 ranked universities in STEM fields in the world are in high-income countries, with an additional 16 percent located in upper-middle income countries.

Table 2. Top 500 education institutions by subject and country income classification, 2021

Country group	Eng. & tech.	Share	Natural Sci.	Share	Life Sciences and medicine	Share	TOTAL STEM	Share
High Income	393	75.58	400	79.84	426	84.86	1219	80.04
UMI	96	18.46	81	16.17	64	12.75	241	15.82
UMI (excl. China)	58	11.15	46	9.18	37	7.37	141	9.26
LMI	31	5.96	20	3.99	11	2.19	62	4.07
LI	0	0.00	0	0.00	1	0.20	1	0.07
G20	362	69.62	368	73.45	365	72.71	1095	71.90
Africa	8	1.54	7	1.40	10	1.99	25	1.64
Total	520	100.00	501	100.00	502	100.00	1523	100

Source: QS World University Rankings by Subject, Institution and Country (2022). Adapted from Bhorat et al (forthcoming) Author's calculations.
Note: Total counts G20 countries and upper middle income countries once. i.e. Germany is both a G20 country and a high income country but is only counted once in the total

What is of relevance here is the very poor performance of Africa in these rankings. Specifically for STEM fields as a whole, there are only 25 universities in Africa ranked in the Top 500 globally—constituting less than 2 percent of the total sample. This figure is eight in Engineering, seven in the Natural Sciences and 10 in the Life Sciences. Furthermore—only three countries feature in the Africa rankings: South Africa, Egypt, and Uganda. This data is important albeit too sparse to include into our Digitalization Index measure: They suggest that not only are there too few African universities within the STEM fields—but that where they exist their quality is exceptionally low relative to the rest of the world.

The A-F Digitalization Gap Index for Africa: Results

The above descriptive overview has attempted to provide an empirical snapshot of adoption rates at the regional level in the five different dimensions of digitalization over the 2011 to 2017 period. Whilst it is clear that the gaps between Africa and the G20 remain significant, they are also heterogenous at the indicator level. These indicators and dimensions however can be synthesised into a single composite Digitalization Gap Index using our A-F measure outlined in Section II above and in greater detail in the technical appendix below.

Specifically then, we combine the individual indicators for each of the digital skills, digital entrepreneurship, digital finance, digital public participation, and digital infrastructure into sub-index measures to determine shifts in Africa over time across these dimensions. These are then aggregated into our single Digitalization Gap Index. We provide both the traditional 'headcount' and 'poverty gap' measures of the A-F Index in our estimates in Table 2 below.

The headcount index measures are instructive. Using the G20 mean estimates as the cut-off the figures are startling and worrying for Africa. They suggest firstly that for all sub-measures of the digitalization index—from digital skills through to digital infrastructure—well over 90 percent of all African countries in the sample fall below the G20 mean for the individual or indeed aggregate digitalization measure. For example, the data shows that 100 percent of all African economies in 2017 fell below the mean of digital skills achievement in the G20—recalling that two-thirds of the world's population live in a G20 country. In turn when combining all our individual digitalization dimensions into a composite index, we find that on this Digitalization Gap Index, by 2017 98 percent of all African economies were below the average digitalization competence level existent in the G20. In addition to the extraordinarily high headcount measures of digital vulnerability—what is also clear is that there has been very little, if any, change over time. Apart from the digital infrastructure indicator then, where there has been a marginal decline in the headcount, on all other measures there has been little progress for the sample of African economies relative to the G20 mean performance.

Table 3. Headcount and relative vulnerability measures: Digitalization gap

Dimension	2011	2017	Percent change
Digitalization Gap: Headcount Index *(DG_0)*			
Digital skills	100.00	100.00	0.00
Digital entrepreneurship	89.08	96.30	8.11
Digital finance	98.15	98.41	0.26
Digital public participation	97.62	100.00	2.44
Digital infrastructure	96.43	92.86	-3.70
Headcount Index	***96.26***	***97.51***	***1.30***
Digitalization Gap: Relative vulnerability index *(DG_1)*			
Digital skills	0.51	0.48	-5.88
Digital entrepreneurship	0.31	0.32	3.23
Digital finance	0.76	0.61	-19.74
Digital public participation	0.67	0.49	-26.87
Digital infrastructure	0.76	0.67	-11.84
Relative Vulnerability Index	***0.60***	***0.51***	***-15.00***

Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, TCdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: [1] We look at two time periods: 2011 and 2017 due to data availability, with the exception of made or received digital payments in the past year (percent age 15+) we use 2014; and Online Services Index and E-Participation Index value we use 2012 and 2018 period.
[2] Digital skills consists of: Secondary gross enrollment ratio, tertiary gross enrollment ratio, mean years of schooling, internet access in schools. Digital entrepreneurship consists of venture capital availability, ease of access to loans, ICT service export (percent of exporters BoP). Digital finance consists of account ownership at a financial institution or with a mobile-money-service provider (percent of population ages 15+), used the internet to pay bills or to buy something

online in the past year (percent age 15+), made or received digital payments in the past year (percent age 15+), Digital platforms consists of Online Services Index and E-Participation Index value. Digital infrastructure consists of fixed broadband subscriptions (per 100 people) (21 countries in 2017), fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), secure Internet servers (per 1 million people), individuals using the internet (percent of population).

[3] Data is not available for some countries in our African sample for various indicators: Secondary gross enrollment ratio (20 countries in 2017), tertiary gross enrollment ratio (20 countries in 2017), Mean years of schooling (20 countries in 2017), Internet access in schools (19 countries in 2017), Venture capital availability (20 countries in 2017), ease of access to loans (20 countries in 2017), ICT service export (percent of exporters BoP) (18 countries in 2017), account ownership at a financial institution or with a mobile-money-service provider (percent of population ages 15+) (21 countries in 2017), used the internet to pay bills or to buy something online in the past year (percent age 15+) (21 countries in 2017), made or received digital payments in the past year (percent age 15+) (21 countries in 2017), E-Government Development Index (21 countries in 2017), E-Participation Index value (21 countries in 2017), fixed broadband subscriptions (per 100 people) (21 countries in 2017), fixed telephone subscriptions (per 100 people) (21 countries in 2017), mobile cellular subscriptions (per 100 people) (21 countries in 2017), secure internet servers (per 1 million people) (21 countries in 2017), individuals using the internet (percent of population) (19 countries in 2017).

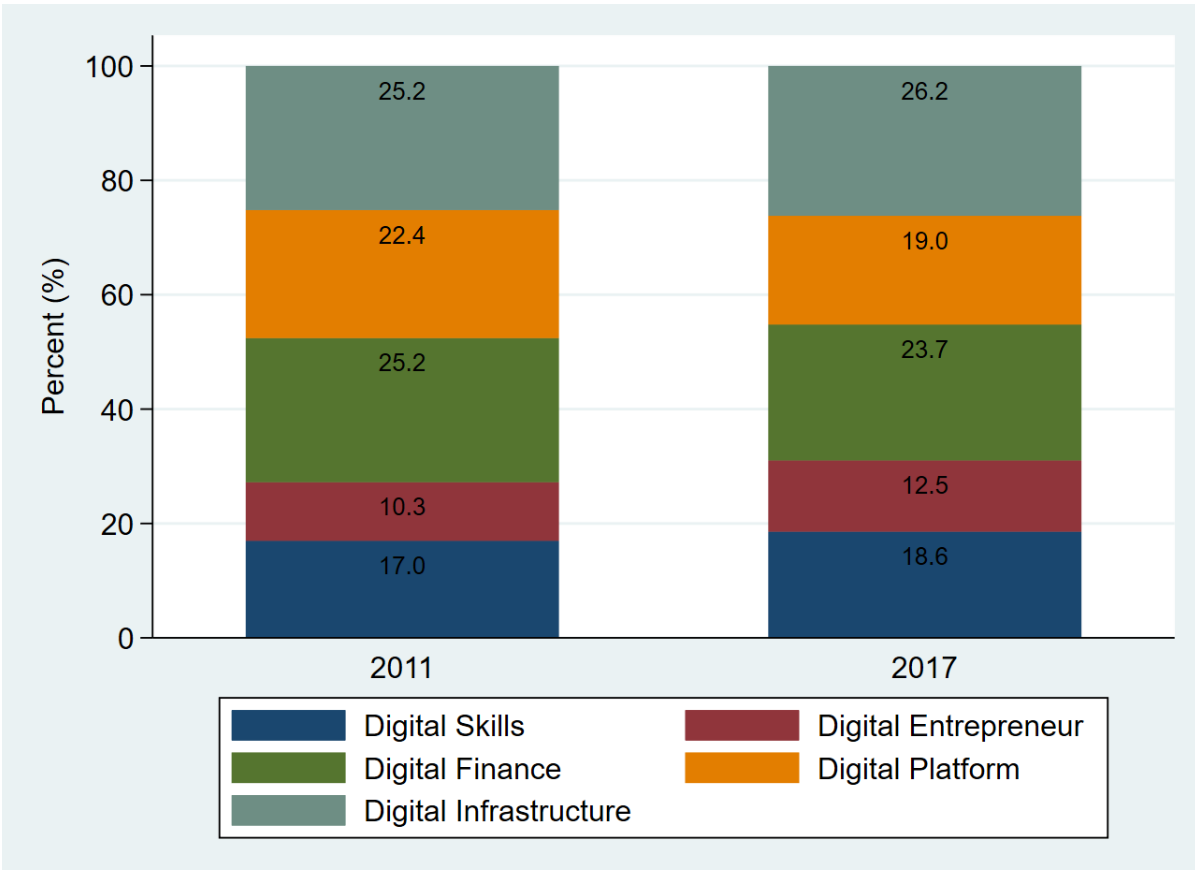
[4] We removed the anomalies in the data for ICT service export (percent of exporters BoP) in Malawi, Mali, and Niger.

Perhaps as a more nuanced measure of relative progress across the digitalization performance space, is to consider whether the relative performance of the African economies below the G20 mean thresholds have improved. Effectively, given our headcount data,this would mean assessing whether there have been improvements for almost all the African economies in the sample—despite them being below the average G20 scores for each of the dimensions. The results are instructive and indeed more encouraging: They suggest that for all dimensions except that of digital entrepreneurship, there has been a decline in relative digital vulnerability. Hence the average digital score for the aggregate digitalization index and for 4 of the 5 indictors has improved despite remaining below the G20 mean. The largest reduction in relative digital deprivation at the indicator level was for digital public participation and digital finance which fell by between 12 and 27 percent over the period. In turn, note that the average African economy improved its relative digitalization score in the aggregate as well—shifting from an AF Index score of 0.60 to 0.51.

Ultimately then, these results show that almost all African countries in the sample lag behind the average G20 country across all dimensions of the index. Digital skills in particular, is the one dimension in which no country in the sample meets the G20 threshold mean for both 2011 and 2017. This indicates that policy interventions to enable digital transformation should prioritize this area in Africa. However the extraordinarily high proportion of countries in the sample that do not meet the G20 cut-off in the other dimensions suggest that is not just the skills dimension that warrants attention. The other dimensions of infrastructure, entrepreneurship, finance, and public platforms will also need to be considered in any strategy that aims to develop digital economies in Africa to standards elsewhere.

Given the above, and noting the weighting structure of the Digitalization Index, it is also important though to assess the percentage contributions of each dimension to the overall Digitalization Gap Index scores noted above. Hence Figure 6 below estimates the percentage share contribution of each dimension in 2011 and 2017 to the aggregate digital gap index. This exercise enables us to identify the relative importance of each dimension in driving the overall digitalization gap over time.

Figure 6. Average contribution by dimension to the digital gap index, 2011-2017



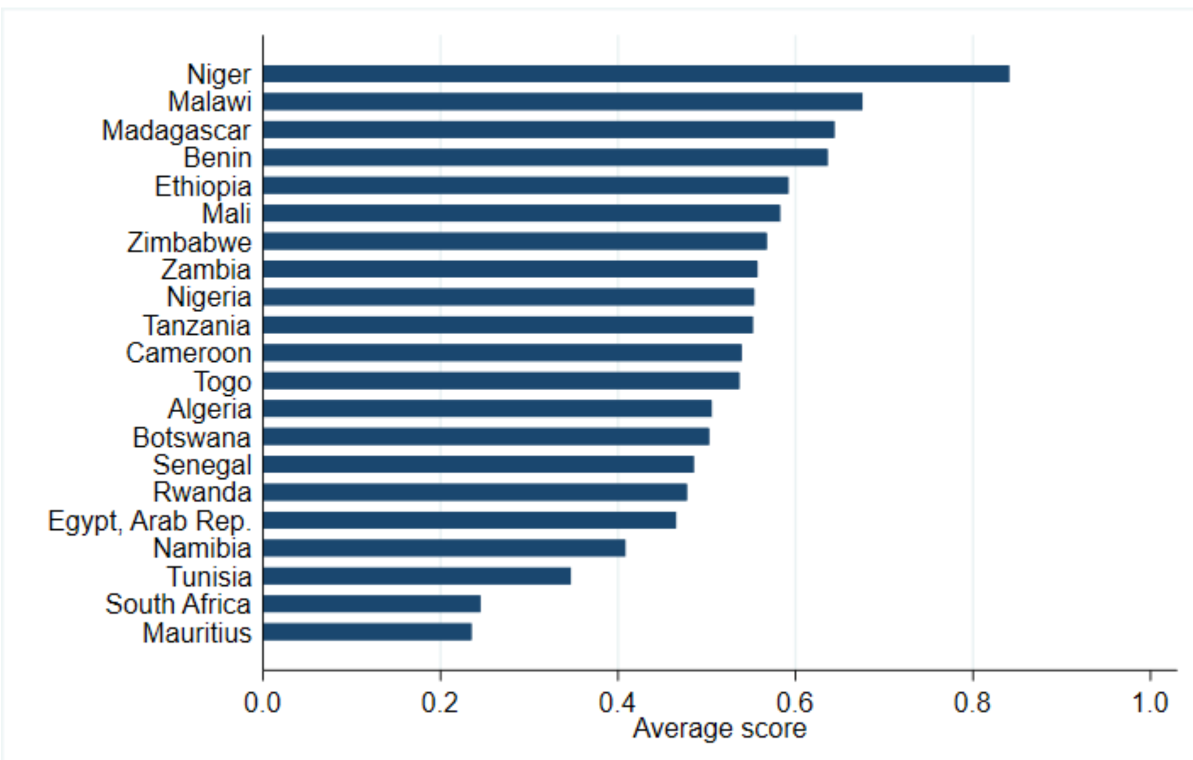
Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, TCdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: Same data caveats as Table 3.

The data shows, for example, that in 2011, digital skills contributed 17 percent to the overall Digitalization Gap Index score for Africa. Hence we note that in both 2011 and 2017 it has been the poor performance of African countries in terms of digital infrastructure which remains the key contributor and driver of the aggregate digitalization gap on the continent. Interestingly, digital public platforms have contributed less over time to this digital vulnerability—driven of course by the observed growth in online services and other public sector digital initiatives in Africa. In turn the contribution of digital skills has increased over time—constituting some 18.6 percent to the overall digitalization gap score for Africa by 2017.

It should be clear, at least from a careful reading of how the A-F Digitalization Gap Index is constructed that the measure is built up from the level of the country. Hence, the measure, for example, of digital infrastructure can be presented also at the country level. The same would be true for the other dimensions and then of course for the individual indicators – where one could examine the country performance by each of these indicators or dimensions. We attempt to do this country-level analysis in the graphs which follow below.

In the first instance then, we turn now to examine digital gap scores by country to see how each country compares with the G20 countries. What becomes clear is that upper-middle income countries are doing better than lower- or lower-middle income countries. Figure 7 presents the average digitalization index score by country in 2017. Note that these scores are deviations from the mean score for the G20 and hence higher scores would indicator poorer performance. Hence, the data indicate, for example, that in our sample of African economies the economies with the poorest overall digitalization performance are Niger, Malawi, and Madagascar. In turn Mauritius, South Africa, and Tunisia would be ranked in the sample as having the lowest digitalization gaps relative to the G20 mean.

Figure 7. Africa Digitalization Index Gap, by country, 2017

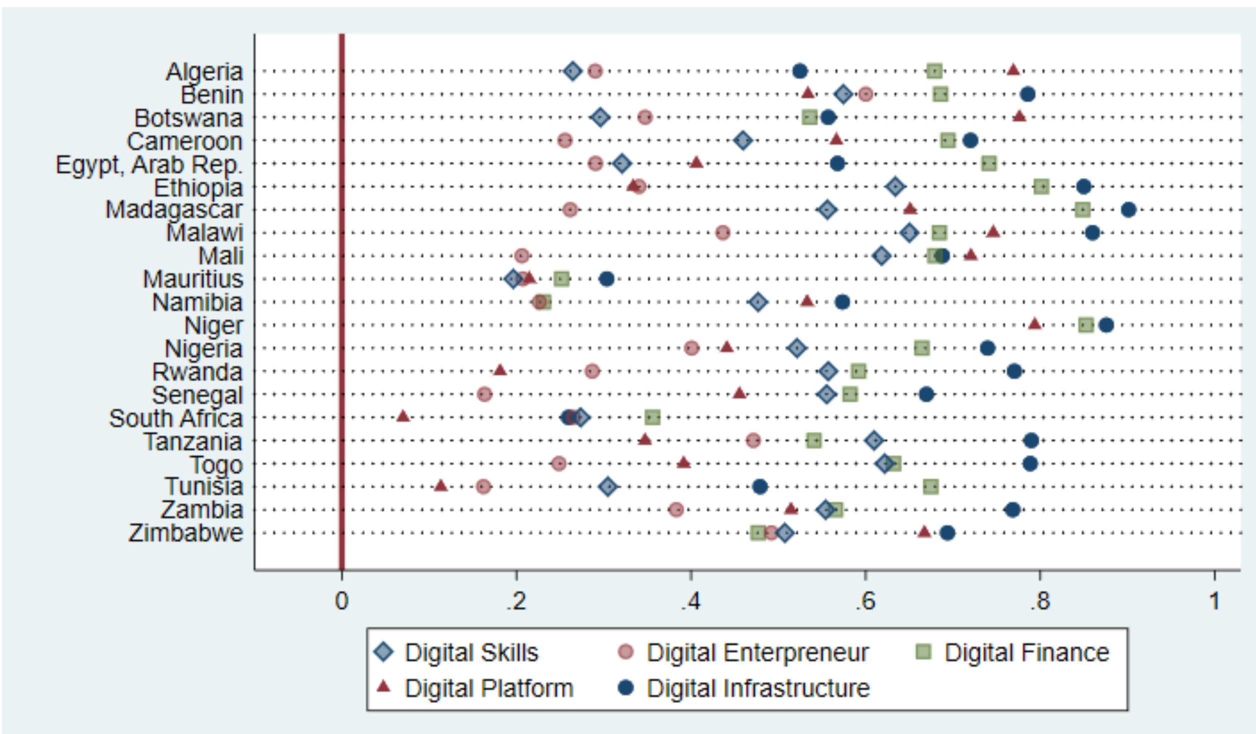


Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, Tcdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: Same data caveats as Table 3.

What would be important then at the country level, and at least within the African context—is to focus on those economies which clearly are lagging significantly in terms of their potential participation in the digital ecospace. Donor-driven and multilateral type support should clearly focus on those economies where the digitalization gaps are both the most inertial over time and the highest.

In trying to further detail the specific indicators which may explain the above aggregate digitalization scores, we present in Figure 8 below digital gap scores for each country and the individual indicators for 2017. At the indicator level, it is evident that the gap is the largest for the digital infrastructure and digital finance dimensions for the most vulnerable countries Benin, Malawi, Madagascar, and Niger—but also clearly the most dominant constraint for all countries in the sample. Hence, any focus on the digitalization gap in Africa—even when focused on country-level concerns—should almost certainly be anchored around digital finance and digital infrastructure.

Figure 8. Digital gap score by dimension and country, 2017

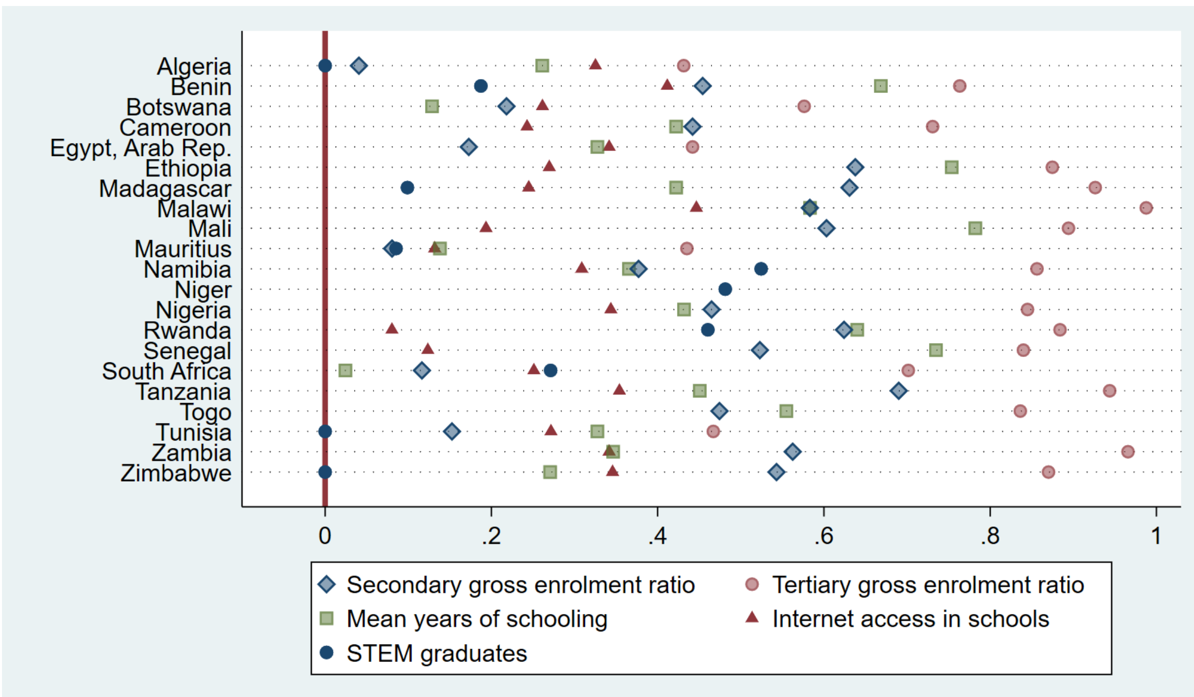


Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, TCdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: Same data caveats as Table 3.

In contrast, it is clear that country-level heterogeneity is important when considering digital platforms. Hence, we see for example that in the case of Niger, Mali, and Malawi—public digital platforms lag behind those found in the G20 by much more than other countries in the sample. Interestingly for the digital entrepreneurship dimension, most African economies in the sample perform relatively well with the exception possibly of Zimbabwe and Benin.

In Figure 9, below, we now provide more detail on one of the dimensions—specifically focusing on the digital skills dimension and the individual indicator scores by country between 2011 and 2017. This allows us to see beyond the dimension-based averages discussed above and examine each individual country digital score. We have also added in the data we have for STEM graduates at the country level—although we did not include it in the construction of the digitalization index, given its very poor coverage in the Africa sample. It is unsurprising given the overall digital skills headcount index that almost all African countries in our sample lag behind G20 countries in terms of all the digital skills indicators.

Figure 9. Digital skills score by country, 2017



Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, TCdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: Same data caveats as Table 3.

The figure shows the digital gap score for African countries compared to the average of G20 countries, where the solid vertical line represents the average for G20 countries. This means that countries on the line are either at the same level or higher than the average for G20 countries for that specific indicator. This holds true for none of the indicators used in the construction of Digitalization Index. What is also visually evident is that tertiary GER is the digital skills indicator which is furthest away from the vertical line for most countries compared to other indicators. The poor performance in secondary school enrollment and possibly a lack of investment in tertiary education, controlling even for the quality concerns noted above, must serve as the key drivers of this very poor performance in African countries in terms of producing a sufficient number of higher-education trained individuals for their domestic economies.

Measuring digital skills gaps with survey data: A case study

In this section, we propose an approach to measuring the demand for digital skills, the supply of digital skills, and the digital skills gap in individual countries using Labor Force Survey (LFS) or equivalent survey data. Based on the method proposed, we apply this to one particular African country for which the required data is available. We thus provide in what follows below—indicators of digital skills demand, digital skills supply, and a digital skills gap for South Africa with the hope that the methodology can be extended to other countries with access to the relevant data.

Demand for digital skills

Through the use of occupation variables often available in labor force survey data, we can obtain a greater understanding of the level of digitalization of an economy through interrogating the country's profile of employment. If workers are employed in jobs that have higher digital content, this implies a higher level of digitalization of a country's economy. We use the U.S. Department of Labor's very detailed Occupation Information Network (O*NET) coding database. O*NET provides detailed occupation-specific information on a worker's education, training, experience, and skill-related requirements, to obtain a digital score for each occupation that individuals are employed in. We then aggregate these digital scores across the employed to obtain an estimate of the demand for digital skills across sectors of the economy.[5]

To calculate a digital score for each O*NET occupation, we follow the methodology of Muro et al. (2017). Muro et al. choose two O*NET task variables, namely: "Knowledge: Computer and Electronics" and "Work Activity: Interacting with Computers". The first variable quantifies the amount of knowledge in computer and electronics that is required to perform the job while the latter variable measures the importance of computers in carrying out the tasks associated with that occupation. For each O*NET variable, the level and importance are provided. The level of a skill refers to how complex the application of the skill is in the occupation's daily course of events. A skill's level was measured on a scale ranging from zero (lowest) to seven (highest). On the other hand, importance of a skill can be thought of as how critical it is that an individual has this skill in order to complete their day-to-day tasks. Importance was also measured on a scale of one (not important) to five (critically important).

As the level and importance scales are different, it was necessary to standardise the scores. We follow the method recommended by O*NET to standardise the scores as follows:

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[5] It must be noted, however, that the O*NET database is based off U.S. occupations and the tasks assigned to each occupation are an inexact match or fit to the tasks for each occupation in the South African (or any other African country's) labor market.

$$S = ((O - L)/(H - L)) * 100 \quad \ldots\ldots(1)$$

Where S = standardised score, O = original rating on either of the two scales, L = lowest possible score on the rating scale and H = highest possible score on the rating scale.

After standardising the scores, we use the following equation to derive a digital score for each O*NET occupation:

$$Digital\ Score = \frac{\sqrt{Knowledge_{level}\ x\ Knowledge_{importance}} + \sqrt{Work\ activity_{level}\ x\ Work\ activity_{importance}}}{2} \quad \ldots\ldots(2)$$

The highest possible score is 100, with a higher score indicating a higher level of digitization of an occupation. For illustrative purposes, we use the computer systems analyst occupation to observe how the digitization score is calculated. This is presented in the box below.

Example: Calculating the digitization score of an occupation

Occupation title: Computer systems analyst

Level and importance	Value
Knowledge level	5.13
Knowledge importance	4.3
Work activity level:	4.84
Work activity importance:	4.62

Source: O*NET (2022)

We then standardise each value as follows:

Standardised knowledge level score = (5.13 – 0)/(7—0)) * 100 = 73.29
Standardised knowledge importance score = (4.3 – 1)/(5 – 1) = 82.50

Standardised work activity level score = (4.84 – 0)/(7 – 0) = 69.14
Standardised work activity knowledge importance score = (4.62 – 1)/(5 – 1) = 90.5

Having calculated the standardised scores, we put these numbers into equation (2) described above to obtain the following digital score for a computer systems analyst:

$$Computer\ systems\ analyst = \frac{\sqrt{73.29\ x\ 82.50} + \sqrt{69.14\ x\ 90.5}}{2} = 78.4$$

We adapt the classification of Muro et al. in determining cutoffs for occupations which low, medium, and high levels of digital skills.[6]

[6] Under the level measure, for occupations exhibiting a 'low' digital skill, we did not specify a condition. In Muro et al., their condition is that the level score is at least a three for both the 'knowledge' and 'work activity'.

Table 4. O*NET digital skill level: Score thresholds

Standardised digital score	Digital skill level
60 and above	High
34 – 60	Medium
33 and below	Low

Once we have calculated the digital score for each O*NET occupation, we are then required through a series of data steps to convert the O*NET occupational codes into South African occupational codes. These sequential steps are provided in Appendix II.

As a result of the crosswalks utilised in our matching process from O*NET to the LFS data, the number of occupational codes changed when transferring occupational codes from one coding system to another. An important caveat is that the numbers represented here show the number of distinct occupations in relation to our data and not necessarily the overall number of distinct occupations per occupational coding system. In addition, because we use two years for analysis—2010 and 2020—we use two distinct O*NET databases—version 25.3 for 2020 and 15.1 for 2010. Our 2010 data has marginally better coverage than 2020, with the final number of occupations (314) representing 36.0 percent of the original number of O*NET occupations compared to 33.1 percent for the 2020 year.

Table 5. No. of distinct occupations by occupational coding system

Year	O*NET	SOC 2010	ISCO-08	ISCO-88	SASCO (2003)
2010	873	618	373	361	314
2020	843	746	436	389	279

As is evident, the number of unique occupational codes decreases for each subsequent occupational coding system. In effect, the number of unique occupational codes acts as a proxy for the level of detail in an occupational system. Given that O*NET seeks to capture a high level of detail by occupation, it is understandable that it can identify many occupations. In contrast to O*NET, the South Africa Standard Classification of Occupations[7] (SASCO) has the fewest number of unique occupational codes in our data.

A final caveat before we present our results relates to the comparability of data between 2010 and 2020. As seen in Table 5, there are 35 more occupations in 2010 than in 2020. This is as a result of a wider variety of occupations from respondents than in 2020. In addition, the type of

[7] SASCO is largest based on the ISCO-88 occupational coding system, however, a number of adaptions have been made to account for occupations that are unique to the South African labor market, such as shebeen owners.

occupations may be different in 2010 and 2020. In other words, the samples are not directly comparable, however, as our comparisons are aggregated at a high level, we believe these differences should not materially affect our results.

Results

We begin our analysis by identifying several representative occupations for each digital skill level. As expected, computer programmers score very highly on digital skills as it is both important to their work and they need to exhibit a high degree of skill in this area. Electrical engineers and geologists/geophysicists are other occupations which require high levels of digital skills. What is particularly noticeable for all three occupations in the high digital skills level is that they emanate from Science, Technology, Engineering and Mathematics (STEM) disciplines.

Table 6. Representative occupations by digital skills intensity, 2020

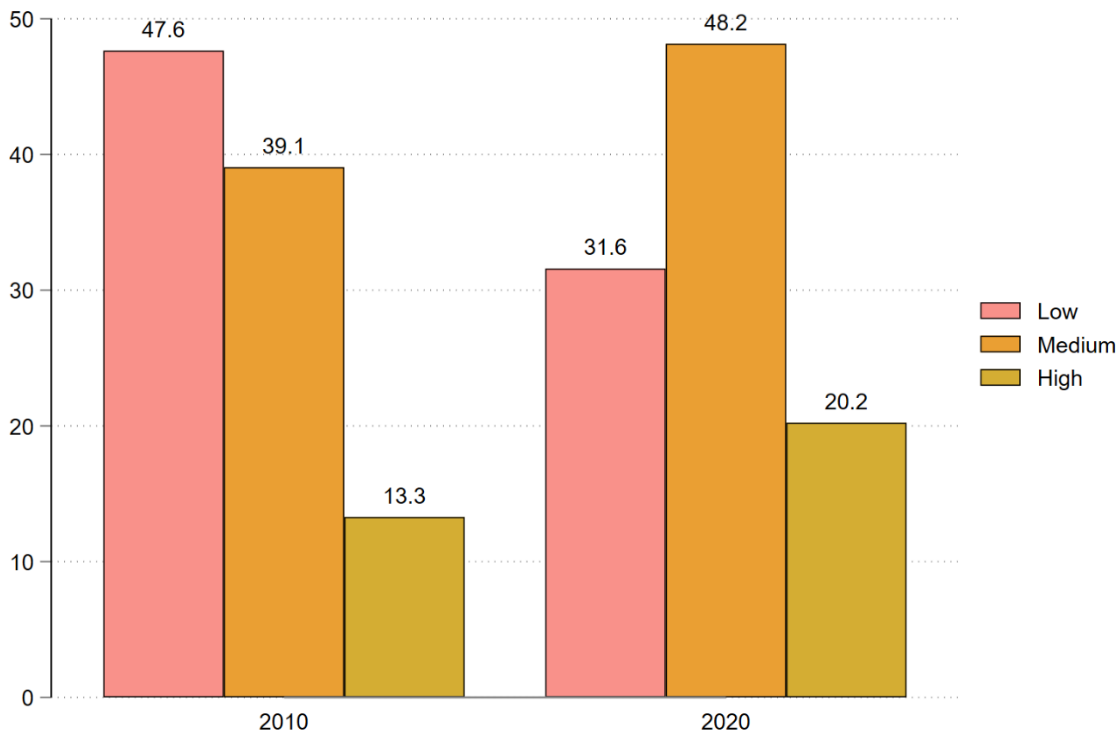
Digital level	Occupation	Digital score
High	Computer programmers	**92.1**
High	Electrical engineers	**76.5**
High	Geologists and geophysicists	**69.0**
Medium	Data entry operators	**58.9**
Medium	Dental assistants	**50.6**
Medium	Firefighters	**46.1**
Low	Plumbers and pipe fitters	**30.2**
Low	Building construction labourers	**16.3**
Low	Shoemakers and related workers	**10.0**

Source: Statistics South Africa, (2010, 2020), authors' calculations.

Our representative occupations which show 'medium' levels of digital skills come from a diverse range of industries—from the medical field (dental assistants) through to hospitality (cooks). Data entry operators can be found across many industries—from politics through to retail and finance. All the representative occupations which exhibit low levels of digital skill are manual occupations which do not require high levels of educational attainment.

We now turn our attention to a closer understanding of how these occupations have changed in terms of employment levels—but now crucially through the O*NET infused digital skills lens. Figure 10 attempts a first cut of this data. It is immediately evident that labor demand patterns reflect a rise in the digital skills intensity of employment over the 2010-2020 decade. Specifically, the proportion of occupations requiring a low level of digital skills declined by 16 percentage points—from 47.6 percent to 31.6 percent.

Figure 10. Employment shares by digital skills intensity, South Africa: 2010-2020.

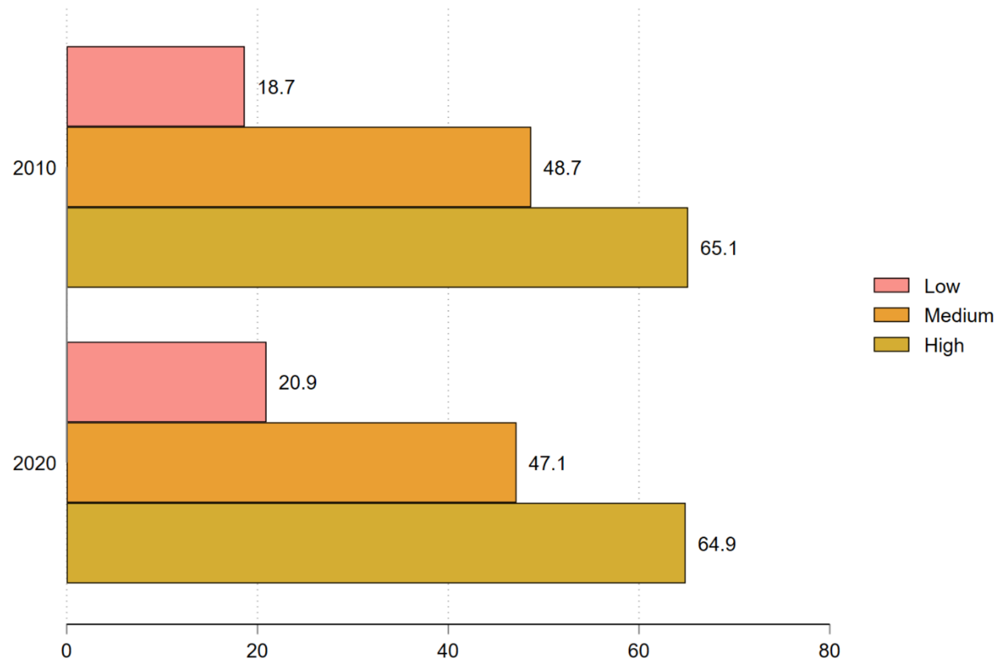


Source: Statistics South Africa, (2010, 2020), authors' calculations.

In contrast, occupations which required a medium or high level of digital skills increased by 9.1 and 6.9 percentage points, respectively. There are two potential explanations for this shift: Either current occupations require more digital skills, or the occupational distribution is shifting towards those jobs requiring a medium or high level of digital skills (Muro et al., 2017). In the US, the first effect is substantially larger than the second effect (Muro et al., 2017) and this is likely to be the case in South Africa as well, which has a far less developed labor market than the US and thus limits the opportunities for new occupations to become dominant.

The results also suggest that digital skills are becoming valuable in the labor market. This trend is likely to continue with the onset of the Fourth Industrial Revolution and related technologies such as robotics, artificial intelligence and cloud computing. To further support the notion of the digitization of the South African labor market, we present the mean digital scores in 2010 and 2020 across the three digital skill tiers (Figure 11). For the low digital skill tier, the mean digital score increased by 2.2 points between 2010 and 2020. On the other hand, the mean scores for the medium and high digital skill tiers decreased by 1.6 and 0.2 points, respectively. The potential explanation for the shift in scores is similar to that of Figure 10—that is, current occupations are requiring more digital skills.

Figure 11. Mean digital skills intensity scores, 2010 and 2020



Source: Statistics South Africa, (2010, 2020), authors' calculations.

We provide a more nuanced picture of how digital skill levels have changed by industry in Table 7. The mean digital score increased from 34.9 points to 39.9 points—an increase of 5.5 points. All industries experienced an increase in their digital score with manufacturing (7.5), transport services (7.0) and construction (7.0) experiencing the largest absolute increases.

Table 7. Industry mean digital skills intensity scores, 2010-2020

Industry	2010	2020	Difference
Agriculture	20.6	23.4	2.8
Mining	32.1	36.9	4.8
Manufacturing	36.8	44.3	7.5
Utilities	46.5	52.8	6.3
Construction	24.4	31.4	7.0
Wholesale and retail	38.5	43.9	5.4
Transport services	43.8	50.8	7.0
Financial services	46.0	49.6	3.6
CSP services	44.0	48.1	4.1
Private households	12.2	18.2	6.0
Average	**34.5**	**39.9**	**5.5**

Source: Statistics South Africa, (2010, 2020), own calculations.

The smallest increases were in agriculture (2.8), financial services (3.6) and community, social, and personal (CSP) services (4.1). However, in the case of the CSP and financial services industries, their mean scores were already high relative to other industries, suggesting that it would be more difficult to increase their level of digitization compared to industries with low levels of digitization.

Supply of digital skills

Obtaining information on the level of digital skills in Africa is challenging. This can be attributed to the lack of a generally-agreed-upon definition of digital skills and the lack of data on digital skills based on a representative sample (Bashir & Miyamoto, 2020). As it currently stands, none of the large labor force surveys carried out in African countries collect information on digital skills (Bashir & Miyamoto, 2020) Where data does exist, it is usually based on self-reporting measures or proxies, such as the possession of certain devices (e.g. computer or cell phone) or tasks performed (e.g. opening a file on a computer) (Bashir & Miyamoto, 2020).

One such survey that has attempted to measure the level of digital skills in Africa is the International Telecommunication Union's (ITU) "Information Society" report. Using a self-reported measure, the ITU classifies the level of digital skills possessed by an individual as either basic, standard or advanced.[8] The sample contains nine African countries (survey year in brackets): Botswana (2014), Cabo Verde (2015), Djibouti (2017), Egypt (2016), Ivory Coast (2017), Morocco (2017), Niger (2017), Sudan (2016), Zimbabwe (2014). The results showed that these countries had significantly lower basic, standard, and advanced digital skills compared to countries in Asia and South America. Within Africa, the northern African countries had the highest level of basic, standard, and advanced digital skills compared to other sampled African countries.

An alternative to using self-reported surveys—and the one which we adopt here—is to use the level of education achieved as a proxy for digital skills. This measure assumes that a level of digital skills is provided to students throughout their educational career, with a higher level of digital skills required with a higher level of educational attainment. Ideally, the curriculum of each country would be measured against a digital skills framework, such as the widely used Digital Competence Framework for Citizens, to understand how the content taught relates to competencies (Bashir & Mayamoto, 2020). However, this would be a resource-intensive exercise requiring input from digital skills subject experts. Instead, we apply an approximation linking the level of education to the level of digital skills expected of an individual. Using the Digital Competence framework developed by UNESCO and the EU, Bashir & Mayamoto (2020) provide a link to educational levels (see Table 8). There are four levels of digital proficiency—foundation, intermediate, advanced, and highly specialized—which can be broadly linked to levels of educational attainment. In the third column, we provide a link to the equivalent South African educational levels, as this is necessary to provide a mapping from the educational profile of South Africa's labor force to digital skills.

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[8] See ITU (2018) for the tasks associated with each level of digital skills.

Before we begin our analysis, it is important to highlight that we are using a different sample to that in the previous section. Instead of only including those who are employed in occupations for which digital scores can be calculated, we include the entire sample of individuals in the labor force, as this provides a more representative picture of the availability of digital skills in South Africa.

Table 8. Digital skills to educational levels mapping

Digital skills—level of proficiency	Level of education	South African equivalent[9]
Foundation	Primary, lower secondary	Grades 0 – 9, National Technical Certificate Levels 1 & 2
Intermediate	Upper secondary, vocational education & training, post-secondary technical (certificates, diplomas or Associate Degrees)	Grades 10 – 12, post-secondary certificate, diploma and associate degree programs, National Technical Certificate Levels 4-6
Advanced	Non-university tertiary (Institutes of Technology, Community Colleges), under-graduate	Bachelor's Degree
Highly Specialized	Post-graduate	Honors, Masters and Ph.D. degree, Bachelor's Degree and Post-graduate Diploma.

Source: Bashir & Mayamoto (2020).

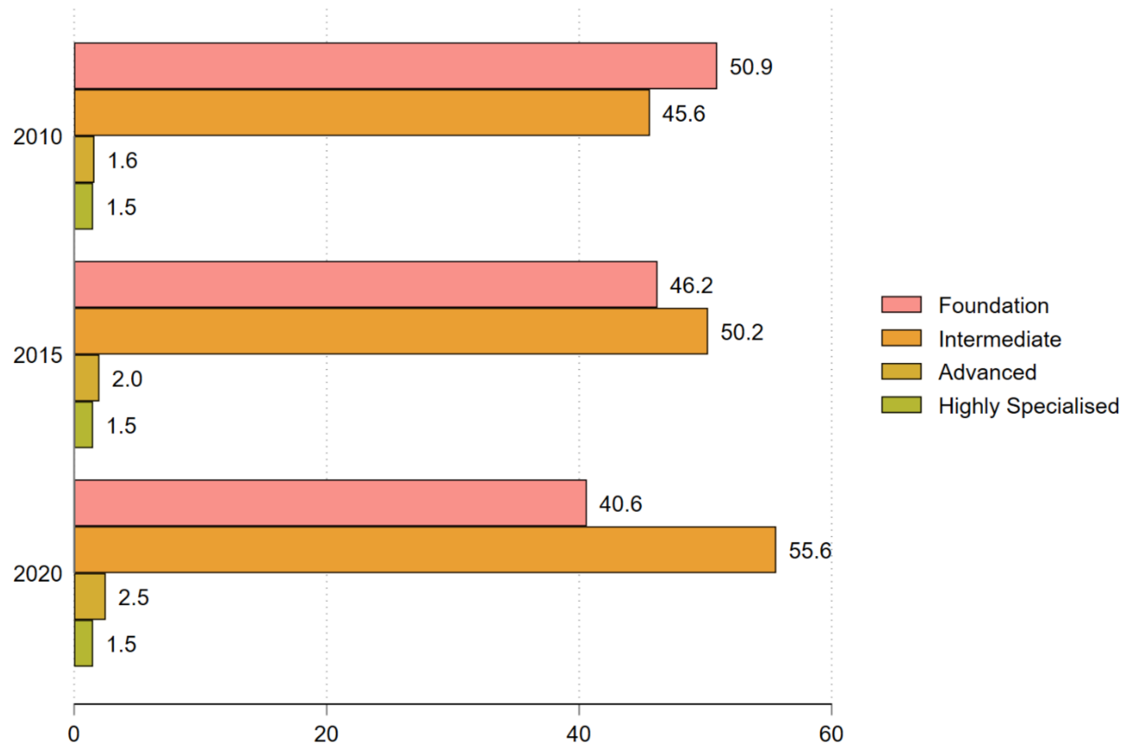
We begin our analysis of the supply of digital skills in South Africa by examining the evolution of digital proficiency levels in South Africa in 2010, 2015, and 2020. From the outset, a clear picture emerges: South Africa's proficiency levels in digital skills are increasing. In 2010, the proportion of the population who had only foundational digital skills was 50.9 percent—this decreased 46.2 percentage points in 2015 and subsequently to 40.6 percentage points by 2020—an overall decrease of 20.2 percent.

On the other hand, those with intermediate digital skills increased from 45.6 percent in 2010 to 55.6 percent in 2020—an increase of 21.9 percent—similar in magnitude to the decrease in the proportion of the population who only had foundational levels of digital proficiency. Although those with advanced digital skills increased by 56.3 percent between 2010 and 2020, this was off a very small base and thus will not be a decisive factor in assessing South Africa's digital

[9] We exclude those with no schooling as there is no provision for this in the Bashir & Mayamoto (2020) taxonomy.

skills stock. 1.5 percent of South Africa's population had highly specialised digital skills, and this figure remained static between 2010 and 2020.

Figure 12. Levels of digital proficiency—2010, 2015, & 2020



Source: Statistics South Africa, (2010, 2020), authors' calculations.

Overall, individuals with basic and intermediate skills comprise over 95.0 percent of the population in 2020. Although this figure is unchanged compared to 2010, the composition has shifted towards those with intermediate skills. This is encouraging as it means a larger proportion of the population exhibit a higher level of digital proficiency, making them well-placed to take advantage of job opportunities which increasingly require a higher level of digital skills. Although the proportion of individuals with advanced and highly specialized digital skills is low, this is not too concerning as most occupations will not require such a high degree of skill. However, these figures do suggest South Africa is unlikely to become a hub of digital innovation related to Fourth Industrial technologies as there are too few people with such skills to make it a reality.

Having provided a broad picture of the overall levels of digital proficiency, we now provide a more nuanced picture of level of proficiency of digital skills by employment status (Table 9). Across all years, a clear picture emerges: the unemployed have a higher proportion of individuals with foundational digital skills, while the employed have a higher proportion of those with advanced and highly specialized digital skills. The proportion of individuals with intermediate digital skills is similar across both groups.

Table 9. Digital skills by employment status, 2010-2020

	Foundation (percent)		Intermediate (percent)		Advanced (percent)		Highly Specialised (percent)	
Year	Employed (E)	Unemployed (U)	E	U	E	U	E	U
2010	26.8	35.1	65.1	64.1	4.0	0.1	4.0	0.3
2015	23.5	29.5	68.0	69.3	4.8	0.8	3.7	0.4
2020	17.7	22.1	72.2	75.9	6.1	1.7	4.0	0.4
Percent change	**-9.1**	**-13.0**	**7.1**	**11.8**	**2.1**	**1.6**	**0.0**	**0.1**

Source: Statistics South Africa (2010, 2015, 2020), authors' calculations

A closer examination of the trends shows that there has been a decline in the proportion of individuals with foundational digital skills across both the employed and unemployed, with the unemployed (-13.0 percentage points) experiencing a greater decrease than the employed (-9.1 percentage points). Both groups also experienced an increase in the proportion of individuals with intermediate digital skills, with the unemployed enjoying a marginally higher increase (11.8 percentage points) than the employed (7.1 percentage points). The proportion of those employed with advanced digital skills increased by 2.1 percentage points compared to the marginally lower increase of 1.6 percentage points for the unemployed.

From the above, we observe that the employed have higher digital skills proficiency than the unemployed, on average. However, for both groups, the average level of digital skills proficiency has increased between 2010 and 2020.

Policy Suggestions

As shown above, many African economies can be said to be lagging in terms of digital development. In the face of a rapidly evolving digital frontier, African economies are currently at risk of falling further behind due to significant gaps in infrastructure, technology, and skills (DSCAP, 2021). There are undoubtedly myriad relevant and appropriate policy interventions which can and should be designed and proffered to aid a country or region's digital development. We begin the section with a discussion about the importance of tailoring policies to the local political and economic context while emphasizing the need for comprehensive national, regional, and continental strategies for digital transformation. While improving all components of the digital ecosystem should be considered as part of a balanced digitalization strategy, we focus our discussion here on three key areas of focus identified as critical needs by the index to encourage digitalization across African economies: (i) Improving access to digital infrastructure and platforms, (ii) Developing digital skills in line with trends in demand for them, and (iii) Promoting digital financial inclusion. We then briefly discuss other considerations including the need for more data to guide policy decisions in the future.

To identify potential synergies and address potential barriers between competing priorities, leadership should develop and continuously update a comprehensive strategy that aligns priorities for a thriving digital economy. In-depth analysis and country-specific insights from the digital skills gap index can help guide priorities, and if data and resources permit, countries could replicate the in-depth skills analysis presented in this report for South Africa. Strategy development at the national, regional, and continental levels should involve multi-stakeholder collaboration and be based on a whole-of-government approach.

There are several existing policy recommendations and examples, many of which are discussed below, for improving digital infrastructure, skills, and finance; however, the key to successful outcomes will rely on strategic prioritization by each individual government focusing on local context. Strategies should focus on opportunities for quick wins (examples: expanding access to mobile telephones, internet, & fintech, reforming tariff structures to support technology imports, and public-private partnerships in education) while also focusing on launching initiatives that will deliver results in the medium term (examples: expansion of energy infrastructure, reforming the education curriculum, etc.) (Fox and Signé, 2022). This index can help guide the priorities for leadership by pointing out specific vulnerabilities and strengths.

Digital infrastructure and digital platforms

Our Digitalization Gap Index confirmed that African countries lag behind G20 countries on indicators related to digital infrastructure, and found that the digital infrastructure dimension is the one that contributes the most to the overall digitalization gap for our sample of African countries. With inadequate digital infrastructure, it will not be possible for African countries to reap the benefits of digital transformation, since access to digital infrastructure is the foundational element upon which the broader digital ecosystem is built. Without the infrastructure, individuals are not able to access digital platforms or make use of any digital skills. Thus, the digital infrastructure divide remains a huge problem in Africa and will continue to constrain economic growth in the future if the gap is not bridged. Policy priorities and strategies will depend greatly on mix of factors unique to each country, especially for countries with limited public funds that are facing competing demands. Where possible, governments should focus on adopting policies that can address broadband affordability and access.

Increasing broadband affordability

The results from the index found that African countries overall are stronger in terms of mobile subscriptions compared to fixed line infrastructure and fixed broadband. While the increase in use of mobile phones is encouraging and the potential for 5G infrastructure exciting, fixed broadband should be a priority to ensure that high-speed internet becomes more accessible and that firms are able to digitize within the country. Reliable and cost-effective electricity and broadband is central to the digital transformation. Unfortunately, for many countries, mobile phone use and internet connectivity remain expensive (Fox and Signé, 2022).

Leaders should consider existing strategies to increase affordability including cross-subsidization by regulating prices for lifeline packages, increasing competition between ICT firms by auctioning spectrum licenses, and aggregating demand from public buyers to encourage network expansion and strategize what could be economically and politically viable (PfPC, 2018). Given constrained public budgets, partnerships with the private sector will also be critical for expanding broadband coverage.

Rwanda’s ICT development serves as an example for other African countries of successful government strategies and policies. Increasing competition for network operators was critical, sparking a positive cycle of more affordable coverage spurring more users and more demand. Rwanda’s success came down to effective planning in five-year stages with significant political will. During the first stage of the National Information Communications Infrastructure (NICI) policy (2000-2005), the country focused on developing institutional, regulatory, and legal frameworks and reducing specific barriers to entry for the telecoms market. The second stage (2005-2010) focused on enhancing that infrastructure by establishing a national data center, finding opportunities for cloud computing, and deploying a national fiber-optic network that connected them to international sea cables. Between 2000 and 2010, the number of fixed-line customers more than doubled, the number of mobile phone customers went from 42,000 to 3.5 million, and the number of internet users went from 1,200 to almost 494,000 (Ben-Ari, 2014). These figures had increased to 10.6 million and 3.1 million, respectively, by 2020 (World Bank, 2022). The third stage (2011-2015) focused on service delivery, which involved distributing laptops to primary school-aged children (Ben-Ari, 2014). In the final stage (2016-2020), the Rwandan government went on to focus on skills, community development, and cybersecurity (Ben-Ari, 2014). In this final phase, Rwanda’s national broadband planning was extremely effective by leaning on public-private partnerships to deliver on ambitious goals including a significant reduction in price per gigabyte (now less than one fifth of the price it was in 2015)

(Vota, 2021). Partnering with one of South Korea's largest telecom providers, KT Corporation, the country achieved 97 percent 4G mobile coverage by 2020 (Munga, 2022). Wherever a country may be when it comes to their broadband affordability, Rwanda serves as a helpful example that national plans can be effective when they are rooted in political and economic realities and build off of existing strengths.

Increasing digital infrastructure accessibility

Increasing access to digital infrastructure will be critical to address gender and regional divides. Governments can play a few roles to prioritize underserved communities. Governments can subsidize the loss of revenue for ICT companies in marginalized or poor communities by requiring the industry to raise the cost of services in cities, or by using Universal Service Funds that derive from ICT industry taxes (as long as management of the funds is more transparent than it has been in the past). Strategies should also be in place to prevent ICT companies from operating as an oligopoly that excludes lower-income users by only providing high-cost bundles (Fox and Signé, 2022). Overall, broadband strategies should promote regional integration that will grow networks and digital hubs to make them available to marginalized communities.

Bridging the digital divide hinges on the affordability of devices and data.
Universal access to digital infrastructure should be prioritized to ensure that Africans can benefit from digital transformation both across the world and within their countries, and any drive to improve digital infrastructure and connectivity within countries must not leave behind those who are currently less likely to have access to digital infrastructure.

Digital skills development

At the core of a competitive digital economy is a strong foundation in digital skills and human capital. According to the Digitalization Gap Index, every African country with sufficient data was lagging behind the G20 mean for each of the digital skills indicators, requiring each country to make difficult but critical decisions about how to upgrade digital skills.

Individual countries may, however, have different digital skills requirements and face different challenges in developing digital skills. To the extent that these are understood, appropriate country-specific interventions that target the development of specific skills should be considered. Any actions taken on the supply side should also be coordinated with interventions to improve access to digital infrastructure and digital platforms, as well as interventions to stimulate demand for the skills that are being developed.

Apart from a few more advanced countries in Southern Africa, primary schools are unlikely to have the minimum infrastructure required to conduct digital skills training specifically. It is thus imperative that digital infrastructure be developed in Africa along with investments in digital skills. Ultimately, any strategies to enhance the digital skills of a country's population should be far-reaching and address all of these challenges to develop digital skills at the basic, intermediate and advanced levels. In terms of policy interventions, given limited resources, it is unrealistic to assume that investing in both basic education and technological postsecondary education to the extent needed is possible, creating a difficult trade-off.

Higher education and high-level skill development

Policy discussions about the future of work and the digital technologies often emphasize that countries need to invest in postsecondary education focused on STEM and on the digital skills specific to emerging technologies in order to meet demand in formal firms. However, our South African case study revealed that with digitalization still not at a high level in the broader economy, at least in the short term, advanced skills are not likely to be in short supply there. But this does not mean that advanced skills gaps do not exist and there is no need to invest in them. These advanced skills will be necessary, although expanding postsecondary education is expensive and would likely leave few resources for other educational investments such as primary and secondary school (Fox and Signé, 2022).

Options for updating higher education curriculum and financing models can be met by partnering with the private sector. For example, South Africa's Ministry of Communications and Digital Technologies partnered with Coursera, a digital learning platform, to offer classes in data science, digital marketing, AI, coding, and app development for free. Kenya has also partnered with Ajira Digital on a digital platform that has expanded access to online jobs to more than 630,000 young people (Fox and Signé, 2022).

Primary and secondary education

Overall investment in upgrading primary and secondary education is important due to its implications for lifelong learning and inclusivity. Lifelong learning and on-the-job training are common recommendations for increasing job mobility (World Bank, 2019d), but lifelong learning will be impossible without students first learning how to learn through basic education—technical, vocational, and other higher-order skills can only be built on a strong foundation of basic cognitive skills (Fox and Signé, 2022). Despite progress, African countries must continue to expand the primary and secondary education infrastructure because of high fertility rates and high participation in the informal sector. Several African countries, including South Africa, Cameroon, and Ghana, have made ICT in the core curriculum compulsory. In doing so, certain barriers arose such as a lack of adequate teacher training and a lack of infrastructure or actual devices that schools could use to access and practice the skills. In response to these challenges, Ghana's government has had to implement other policies to make sure implementation was actually successful including distributing more laptops to teachers and students and installing wireless internet in high schools and training colleges. Similarly, Senegal recently launched a platform SENLYCEE 2Sciences that trained 2,000 teachers on digital tools and platforms endorsed by the Ministry of Education (UNESCO, 2023). Their experiences highlight how strategies will be affected by local contexts.

Digital finance

Digital finance had the second-highest contribution to the digitalization index. As discussed, the first step in digital financial inclusion—ownership and use of a financial service account—has grown rapidly across African countries. This progress is encouraging and likely fueled by the increase in mobile phone use, but there still remains a gap compared to G20 country averages. The gap is even greater among the other digital finance indicators, and on an individual country level, digital finance is one of two factors, along with digital infrastructure, that have the biggest gaps across all countries in the sample. This is especially true for the most vulnerable countries—Benin, Madagascar, Malawi, and Niger.

Governments should enable financial sector deepening by promoting regulation that addresses these barriers and extends the drivers to allow the opportunity for all citizens to benefit from digital finance. Governments can do this by promoting the use of blockchains for financial transactions and establishing a single identity for residents, which currently does not exist for about half of African countries. Magume and Bulime (2022) found that in Kenya and Uganda, a driver for mobile banking adoption was having a SIM card registered in the user's name; this is significantly easier if there is a single identity system. Governments should invest in an efficient national ID system that addresses administrative barriers and can issue IDs in real-time. This will have an effect on gender and urban-rural divides as well, as studies in Kenya and Uganda have found that financial inclusion for rural women increases with both the ownership of a mobile phone (Cheronoh, 2019) and ownership of a national identity card (Tusubira and Mbabazi, 2021).

Governments should also address threats of fraud, cybersecurity, and high transactional costs. Consumer protection policies are critical to instill trust among the general public, without which certain populations will be inclined to stick to traditional forms of banking and cash transactions. Magume and Bulime's study (2022) did not find the effect of trust to be significant in Kenya, which may be explained by Kenya's strong consumer protection framework (Di Castri, 2013), a model that should be implemented across other African countries.

Africa already leads the world in digital financial inclusion, but leadership should continue to use the advantage of the rise in mobile banking to further formalize the informal sector through formal credit access and assessment using tools like AI, blockchain, and record keeping (Signé and Heitzig, 2022).

Other important considerations

While these policy recommendations have focused on the top three contributors to the digital index, other recommendations targeting the other two broad categories—digital platforms and digital entrepreneurship—will be important as well. These will both affect and be affected by developments in the other areas—infrastructure, skills, and financial inclusion—but policy recommendations that promote agile governance and an enabling business environment can help accelerate progress.

Lack of data from several countries hindered the Index's ability to provide insights for all African countries; leadership should emphasize the importance of collecting this type of data so that more tailored analyses and insights can be developed in the future.

Conclusion

The above paper has attempted to describe and better crystallize Africa's participation in the digital revolution sweeping across the world economy today. The empirical results from the descriptive evidence suggest that at least in terms of some digital infrastructure and digital finance indicators—such as mobile phone subscriptions and bank accounts—the sample of African economies observed have shown some steady progress and catch-up with the average G20 economies. However it is also clear that across many, if not the majority of the five dimensions of digitalization—African economies lag behind the G20 significantly. In areas ranging from fixed broadband subscriptions to undertaking online transactions and using debit or credit cards, the African performance is very poor and is suggestive of a significant digital divide. Perhaps the most negative performance lies in digital skills, where Africa's performance in tertiary GER and the quality thereof is so poor that the region can only rely on three countries for quality STEM education at the tertiary level. The notion, however, that digital participation by African governments has improved significantly remains a positive shift worth noting.

Indeed, when moving from the descriptive statistics to those derived from our composite A-F Digitalization Gap Index or its sub-index representations, the results are more stark. They would suggest on the Digitalization Gap Headcount Index measure for example, that over 90 percent of all African economies in the sample remain below the G20 mean in the aggregate—and when considering the individual dimension indices such as digital skills, digital finance and so on. Indeed, it is in digital skills specifically that the African performance is the worst. Our individual digital scores at the country level also confirm this vast gulf in tertiary GER rates relative to the G20 sample mean. One important subtlety is that when we examine the relative digital vulnerability measure, we do find evidence of some progress in areas such as digital public participations and digital finance. Finally the shares analysis, which is standard in the A-F type measures, does show that the largest contributor to the overall Digitalization Gap Index in Africa over time has been digital infrastructure. Hence the provision of digital infrastructure—particularly in terms of fixed broadband and increasing internet usage—would seem key to unlocking the growth potential of greater digitalization in Africa.

The paper concludes with a guide in terms of how digital skills can be more accurately measured using both a country's labour force survey and the code-based task measures of the O*NET listings. It remains a key approach in trying to be more exact in tracking both the demand for and supply of digital skills in the African context.

Limitations

There are several limitations in this study, and we highlight them briefly here. Firstly, the data which we use to construct the A-F Digitalization Gap Index is relatively old and likely outdated. If more recent data were available, we would be able to construct a more relevant index which could tell us about the current level of digitization in Africa. However, while we believe that if more recent data were available, Africa would show improvements on several indicators, particularly digital infrastructure (due to the large number of investments which have occurred recently (de Feydeau, Menski & Perry, 2022), our overall conclusions would remain the same, as significant improvements in these indicators would take an extended period of time.

A second limitation of our study is that the case study on digital skills demand, supply and the skills gap is limited to South Africa, a country which is unrepresentative of Africa, given its level of economic development, which is higher than most other African countries. We did consider including other African countries in our case study, however, there were a number of issues we faced with regards to the labor force survey data of other African countries. The data were either outdated, released in unpredictable intervals, or did not have the level of occupational detail required for the analysis to be carried out.

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Technical Appendix I. Derivation of the A-F Index

The Alkire-Foster (A-F) method is a way of measuring multidimensional poverty. Here, we apply it to measure digital vulnerability. Our Digitalization Gap Index is composed of digital skills (DS), digital entrepreneurship (DE), digital finance (DF), digital public participation (DP), and digital infrastructure (DI). This measure is thus a synthesis of these other measures. If we assume data for DS, DE, DF, DP and DI for country i at time t, then the estimated means for the full sample of countries in the world is measured variously as:

$$DS_{itc}, DE_{itc}, DF_{itc}, DP_{itc} \text{ and } DI_{itc}$$

Where $i \in [1, u]$ denotes indicators within each dimension, where u is the number indicators within each dimension; and $c \in [1,21]$ denotes countries and $t \in [2011,2017]$ denotes year. That is, DS_{1i} is secondary gross enrollment ratio (percent) within the digital skills dimension for country i; DS_{2i} is tertiary gross enrollment ratio (percent) within the digital skills dimension for country i. DE_{1i} is venture capital availability within the digital entrepreneurship dimension for country i; DE_{2i} is ease of access to loans within the digital entrepreneurship dimension for country i; DE_{3i} is ICT service export (percent of exporters BoP) within the digital entrepreneurship dimension for country i. DF_{1i} is account ownership at a financial institution or with a mobile-money-service provider (percent of population ages 15+) within the digital finance dimension for country i; DF_{2i} is used the internet to pay bills or to buy something online in the past year (percent age 15+) within the digital finance dimension for country i, DF_{3i} is made or received digital payments in the past year (percent age 15+) within the digital finance dimension for country i. DP_{1i} is online services index within the digital public participation dimension for country i, DP_{2i} is e-participation index value within the digital public participation dimension for country i. DI_{1i} is fixed telephone subscriptions (per 100 people) within the digital infrastructure dimension for country i, DI_{2i} is mobile cellular subscriptions (per 100 people) within the digital infrastructure dimension for country i, DI_{3i} is secure Internet servers (per 1 million people) within the digital infrastructure dimension for country i, DI_{4i} is individuals using the Internet (percent of population) within the digital infrastructure dimension for country i.

We then require the mean values for each dimension of DS, DE, DF, DP and DI for Africa. For example, $m_{DS,Africa}$ is the mean of Africa's digital skills dimension. For simplicity we store these values in a matrix where the columns are our dimensions, and the countries are our rows. We thus derive the mean for each indicator for African countries for year t.

Using the means, we calculate the normalised gap i.e., the overall mean subtracting the mean for G20 countries, all divided by the mean, to form the normalized gap matrix for year t. This is represented with the following formula:

$$n_{dimension,t} = \frac{x_{G20,t} - x_{Africa,t}}{x_{Africa,t}}$$

Where $dimension = \{DS;\ DE;\ DF;\ DP; DI\}$.

The values are then censored by replacing all negative elements with a zero. Negative elements are an indication that a country is not vulnerable in that dimension. The individual country in Africa's normalized gap can be collected in an n^{th} dimension vector:

$dimension = \{DS;\ DE;\ DF;\ DP; DI\}$.

The censored values are as follows:

Where $k_{dimension} = \begin{cases} n_{dimension,}\ if\ n_{dimension} > 0 \\ 0\ if\ n_{dimension} < 0 \end{cases}$,

In this study we only censor the elements for which there is no vulnerability. This is known as the first cut-off. It is common in Alkire-Foster literature to introduce a second censor, whereby the entire row is set to zero. The second censor is used when there is a threshold for the number of (or particular) vulnerabilities a country needs to be considered vulnerable. This is termed a dual cut-off.

To derive our vulnerability index, we then calculate the average of the dimensions. i.e.

$$\boldsymbol{VI_t} = average(k_{dimension})$$

The index for digital skills ($\boldsymbol{DS_t}$), is calculated as the average of the $\boldsymbol{DS_{1i}}$ **,** $\boldsymbol{DS_{2i}}$**,** $\boldsymbol{DS_{3i}}$ and $\boldsymbol{DS_{4i}}$ values for year t. The index for digital entrepreneurship ($\boldsymbol{DE_t}$), is calculated as the average of the $\boldsymbol{DE_{1i}}$, $\boldsymbol{DE_{2i}}$ and $\boldsymbol{DE_{3i}}$ values. The index for digital finance ($\boldsymbol{DF_t}$), is calculated as the average of the $\boldsymbol{DF_{1i}}$ **,** $\boldsymbol{DF_{2i}}$ and $\boldsymbol{DF_{3i}}$ values. The index for digital public participation ($\boldsymbol{DP_t}$), is calculated as the average of the $\boldsymbol{DP_{1i}}$ and $\boldsymbol{DP_{2i}}$ values. The index for digital infrastructure ($\boldsymbol{DI_t}$), is calculated as the average of the $\boldsymbol{DI_{1i}}$ **,** $\boldsymbol{DI_{2i}}$**,** $\boldsymbol{DI_{3i}}$ and $\boldsymbol{DI_{4i}}$ values for year t. The overall vulnerability index ($\boldsymbol{VI_t}$) (M_1) is calculated from the average of all the dimensions for year t. It is as this step where a weighting scheme can be introduced if one wishes to emphasise/ deemphasise a particular dimension, however we use an equal weighting for each dimension.

A core starting point for the presentation of the A-F measures is to calculate the headcount and the percent contribution of the dimensions. The headcount is simply ratio of the number of countries (or regions) that are vulnerable, over the number of countries in that group. This gives indication of the breadth of vulnerability. The headcount ratio for the n^{th} dimension is calculated as follows:

$$VI_{nt,Africa} = \frac{number\ of\ vulnerable\ countries}{number\ of\ countries\ in\ our\ sample}$$

The percent contribution ($\varphi_{dimension,Africa}$) indicates how much vulnerability came from a particular dimension. To calculate the percent contribution we divide $H_{\ n,Africa}$ by $VI_{o,n,Africa}$. i.e.

$$\varphi_{dimension,Africa} = \frac{VI_{t,n,Africa}}{VI_t}$$

The entire process is replicated for each period.

Table A1. Headcount and relative vulnerability measures: Digitalization Gap with adjusted weights

Dimension	2011	2017	Percent change
Digitalization Gap: Headcount Index (DG0)			
Digital skills	100.00	100.00	0.00
Digital entrepreneurship + digital finance	93.61	97.35	3.99
Digital public participation	97.62	100.00	2.44
Digital infrastructure	96.43	92.86	-2.93
Headcount Index	***96.91***	***97.55***	***0.66***
Digitalization Gap: Relative Vulnerability Index (DG1)			
Digital skills	0.51	0.48	-5.88
Digital entrepreneurship + digital finance	0.54	0.47	12.95
Digital public participation	0.67	0.49	-26.87
Digital infrastructure	0.76	0.67	-8.86
Relative Vulnerability Index	**0.62**	**0.52**	**-15.39**

Source: Authors' calculations, World Bank Group, World Development Indicators, Education Statistics, TCdata260, Global Findex (various years), United Nations E-Government Knowledgebase (2021), UNDP (2012, 2015), International Telecommunication Union (ITU) (various years).
Notes: [1] We look at two time periods: 2011 and 2017 due to data availability, with the exception of made or received digital payments in the past year (percent age 15+) we use 2014; and Online Services Index and E-Participation Index value we use 2012 and 2018 period.
[2] Digital skills consists of: Secondary gross enrollment ratio, tertiary gross enrollment ratio, mean years of schooling, internet access in schools. We combine Digital entrepreneurship + Digital finance dimensions, they are made up of venture capital availability, ease of access to loans, ICT service export (percent of exports BoP), account ownership at a financial institution or with a mobile-money-service provider (percent of population ages 15+), used the internet to pay bills or to buy something online in the past year (percent age 15+), made or received digital payments in the past year (percent age 15+), Digital platforms consists of Online Services Index and E-Participation Index value. Digital infrastructure consists of fixed broadband subscriptions (per 100 people) (21 countries in 2017), fixed telephone subscriptions (per 100 people), mobile cellular subscriptions (per 100 people), secure internet servers (per 1 million people), individuals using the internet (percent of population).
[3] Data is not available for some countries in our African sample for various indicators: Secondary gross enrollment ratio (20 countries in 2017), tertiary gross enrollment ratio (20 countries in 2017), mean years of schooling (20 countries in 2017), internet access in schools (19 countries in 2017), venture capital availability (20 countries in 2017), ease of access to loans (20 countries in 2017), ICT service export (percent of exporters BoP) (18 countries in 2017), account ownership at a financial institution or with a mobile-money-service provider (percent of population ages 15+) (21 countries in 2017), used the internet to pay bills or to buy something online in the past year (percent age 15+) (21 countries in 2017), made or received digital payments in the past year (percent age 15+) (21 countries in 2017), E-Government Development Index (21 countries in 2017), E-Participation Index value (21 countries in 2017), fixed broadband subscriptions (per 100 people) (21 countries in 2017), fixed telephone subscriptions (per 100 people) (21

countries in 2017), mobile cellular subscriptions (per 100 people) (21 countries in 2017), secure internet servers (per 1 million people) (21 countries in 2017), individuals using the internet (percent of population) (19 countries in 2017).
[4] We removed the anomalies in the data for ICT service export (percent of exporters BoP) in Malawi, Mali, and Niger.

Technical Appendix II. Matching O*NET occupation data to South Africa labor force survey data

Step 1: We match the O*NET occupational codes to the 2018 Standard Occupational Codes (SOC) list, which is US-based and developed by the Bureau of Labour Statistics. As shown in Table A2, two O*NET occupational codes (11-1011 and 11-1011.03) apply to only one SOC 2018 code (11-1011)

Table A2. O*NET occupational code to 2018 SOC occupational code matching

O*NET code	O*NET title	SOC 2018 code	SOC 2018 title	Digital score
11-1011.00	Chief Executives	11-1011	Chief Executives	49.73846544
11-1011.03	Chief Sustainability Officers	11-1011	Chief Executives	55.67774384

Step 2: We next match the 2018 SOC occupational codes to the 2010 SOC occupational codes. This was done because currently, no official list which match the 2018 SOC codes to the occupational coding system used by South Africa and many other countries—the International Standard Classification of Occupations (ISCO)—has been released. We also combine the two individual digital scores into an equally weighted overall score. We do this because going forward, the 2010 SOC occupational codes—rather than the more granular O*NET occupational codes—will be used for matching purposes.

Table A3. 2018 SOC occupational code to 2010 SOC occupational code matching

2018 SOC code	SOC 2018 title	SOC 2010 code	SOC 2010 title	Digital score	Average digital score
11-1011	Chief Executives	11-1011	Chief Executives	49.73846544	52.7081
11-1011	Chief Executives	11-1011	Chief Executives	55.67774384	

Step 3: In the next step, we match the 2010 SOC occupational codes to the ISCO-08 occupational codes. As can be observed in Table A4, there are three ISCO-08 occupational codes related to the 10-1011 SOC 2010 occupational code and we give each ISCO-08 occupation the same digital score. However, ISCO-08 occupational codes do not necessarily apply to only one 2010 SOC occupational code.

Table A4. 2010 SOC occupational code to ISCO-08 occupational code matching

2010 SOC code	SOC 2010 title	ISCO-08 code	ISCO-08 title	Digital score
11-1011	Chief Executives	1112	Senior government officials	52.7081
		1113	Traditional chiefs and heads of villages	52.7081
		1120	Managing directors and chief executives	52.7081

In Table A5, we show that the ISCO-08 occupational code '1112' is matched to three different SOC 2010 occupational codes. To provide a single digital score for each ISCO-08 occupation, we provide an unweighted average digital score which is comprised of the digital scores of the SOC 10 occupation(s) related to the single ISCO-08 occupation.

Table A5. ISCO-08 occupational code to 2010 SOC occupational code matching

ISCO-08 code	ISCO-08 title	SOC 2010 code	SOC 2010 title	Digital score	Average digital score
1112	Senior government officials	11-1011	Chief Executives	52.7081	58.00972
		11-1021	General and operations managers	60.8869	
		11-9161	Emergency management directors	60.43416	

Step 4: In our penultimate step, we match ISCO-08 occupational codes with the previous iteration of ISCO, ISCO-88. This is necessary because Statistics South Africa still uses the ISCO-88 occupational coding in its labor force surveys. Continuing with the 1112 ISCO-08 occupation, we observe that there is a one-to-one match with an ISCO-88 occupational code.

Table A6. ISCO-08 occupational code to ISCO-88 occupational code matching

ISCO-08 code	ISCO-08 title	ISCO-88 code	ISCO-88 title	Digital score
1112	Senior government officials	1120	Senior government officials	58.00972

Step 5: South Africa has developed its own occupational classification system known as the South African Standard Classification of Occupations. For the large majority of occupational codes, these are the same as in ISCO-88, however, there are some occupational codes unique to South Africa, such as "3241 – Traditional Medicine Practitioner" and "5231 – spaza shop owner". For unique SA occupational codes, we are unable to assign them a digital score because there is no related ISCO-88 code and thus we discard them from our analysis. In the case of current example—"1112: senior government officials" – the SASCO occupational code and title are the same. Therefore, in our South African dataset, "1112 – senior government officials" are assigned a digital score of 58.00972.

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