BOOSTING DECENT EMPLOYMENT FOR AFRICA'S YOUTH

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THE FOURTH INDUSTRIAL REVOLUTION (4IR) AND THE FUTURE OF WORK: COULD THIS BRING GOOD JOBS TO AFRICA?

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by Louise Fox and Landry Signé

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Abstract

Improving employment opportunities in Africa is particularly salient now and will remain important given the number of young people expected to enter the job market. To what extent could the suite of new technologies known as the Fourth Industrial Revolution (4IR) accelerate the creation of new wage jobs in expanding, higher-productivity sectors, leading to a decline in the share of people working informally, and to what extent would youth benefit? The paper analyzes this question using the frameworks of economic transformation and the need to reduce decent work deficits.

The analysis finds that 4IR technology brings opportunities for production cost reduction, productivity and earnings improvement, and the development and introduction of new business lines, providing a wealth of new opportunities that should prove particularly attractive and accessible to Africa's youth. Deployment of 4IR technology could lead to new, often formal, wage jobs being created, especially in the service sectors at a faster rate than the growth of the labor force, and earnings improvements in the informal sector. However, 4IR technology is likely to bring only incremental change in the trajectory of employment transformation in terms of shift from the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development.

Conscientiously shaping public policy guiding technological growth to maximize benefits and minimize costs will be crucial for success in 4IR. Countries need a comprehensive, effective, and implementable strategy that will address challenges such as gaps in digital and physical infrastructure, the need for less onerous, nimbler regulation to speed the technology transfer, and basic cognitive and socio-emotional skills deficits within their country context. In both policy and project selection as well as financing, attention to inclusion needs to be paramount to avoid widening inequality.

Table of Contents

1. Introduction

Throughout the 21st century, as economies have been buffeted by volatile economic cycles—including the recent COVID-19 pandemic—and by increasingly strong technological winds of change, enhancing employment opportunities has become even more central to development policy discussions. The reasons are obvious: billions of people in the developing world are trying to exit poverty through better jobs that will provide higher incomes for themselves and their families. As the world's youngest continent, with a rapidly growing labor force, improving employment opportunities is especially important in Africa.[1]

The quality of employment opportunities in Africa is particularly salient now, and will remain important given the number of young people in Africa expected to enter the job market. After two decades of solid economic growth—particularly in Sub-Saharan Africa (SSA)—and improvements in employment opportunities, countries are back on their heels following disruptions in the global economy and blows to local economies caused by the COVID-19 global pandemic. Overall, labor incomes have fallen an estimated 10 percent (ILO, 2020). In the richer countries of Southern and Northern Africa, open unemployment has increased. In the poorer countries, where most people work for themselves or their families in the informal economy and must stay economically active in order to eat, underemployment has increased. Youth (age 15-24), who are just now entering the labor force, are particularly hard hit owing to the lack of economic opportunities. Youth unemployment, which has always been higher than adult unemployment because of issues with entry into employment, has increased substantially, especially in Northern and Southern Africa (ILO, 2020).

Before the COVID-19 crisis, many economies in SSA were growing rapidly (Signé, 2020), transforming their economies through productivity increases, and offering a larger share of their labor force wage and salary jobs, including youth entering the labor force for the first time (Fox & Gandhi, 2021; Diao, et al., 2021). Formal wage jobs are desirable because they tend to pay more and offer more income security as well as employment and social protection benefits (Sumberg et al., 2021). Despite this progress, the majority of the African labor force still worked informally, in low-productivity activities. One-third of the employed population in Africa lived in extreme poverty in 2018 (ILO, 2019), and the percentage of working poor as share of total employment was even higher in the lowest-income countries. Employment opportunities depend on the extent of economic transformation and development. Richer countries offer better jobs, and countries get rich by developing productive employment opportunities—the two processes are inextricably linked. Better jobs are generally found in modern, productive enterprises. In the low- and lower-middle-income countries (LICs and LMICs) in SSA, economic development has not created enough of these enterprises, and enough jobs within them, relative to the supply of labor coming from the population. As a result, youth entering the labor market often end up working in the same types of jobs as their parents—on family farms, in nonfarm self-employment, or in household enterprises (Filmer & Fox, 2014; Fox et al., 2019).

The post-Covid-19 economic challenge, to build the economy back better, includes increasing employment opportunities for all Africans. While youth face particular challenges in entering the labor force and securing employment, all Africans who seek employment deserve decent jobs (Njuguna and Signé, 2020) — the opportunity to use their skills productively and to earn an income that keeps them out of poverty. This requires resuming and accelerating inclusive economic transformation.

A key trend occurring in upper income countries, in parallel to developments on the African continent, has been an acceleration of innovation and technological change (Signé, 2022).[2] A group of these new technologies has been labelled as part of the Fourth Industrial Revolution (4IR) owing to their transformative potential, and because they build on the computing and digital technologies of the Third Industrial Revolution (3IR).[3] It is widely agreed that these next-generation cyber-physical technologies will

1 This report draws on Landry Signé's forthcoming book on Africa's role in the Fourth Industrial Revolution: ''Riding the world's biggest wave of disruptive innovation'' (tentative title, Cambridge University Press, 2022). Throughout this paper, the term "Africa" refers to all the countries of the continent, both North Africa (NA) and Sub-Saharan Africa (SSA). Often, data are not available for the whole continent; in this case, data for NA and SSA are cited separately.

2 Scientific innovation is the discovery of new scientific knowledge. Technological change is the application of that knowledge to solve existing problems (e.g., mobility, lighting, communication, preventing or curing a disease, etc.).

3 The First Industrial Revolution, which began around 1770, used water and steam power to mechanize production. The Second, beginning about 100 years later, used electric power to create mass production. The Third Industrial Revolution began another 100 years later.

significantly change production, consumption, trade, the cost of goods and services, and living standards across the globe—more rapidly than previous industrial revolutions, owing to the scope and speed of innovation (Signé, 2022). Although developed in the rich countries, where adoption has been most rapid, the 4IR technology wave has already begun washing up on Africa's shores (Ndung'u and Signé, 2020).

Technological development and adoption are key to economic growth and development.[4] By allowing goods and services to be produced at lower cost, improvement in material welfare is possible. Adoption of technology during the Industrial Age accelerated and sustained economic growth in Western Europe and the U.S., allowing these countries to reach levels of income and welfare unimaginable in previous centuries. Technology adoption in developing countries has helped close the income gap with the post-industrial West, especially in East Asia.

Most observers and analysts agree that 4IR technologies have great potential to advance ongoing economic growth and development processes in Africa (Signé, 2022; Banga et al., 2020), and in particular to benefit Africa's youth, who have been quicker to adopt the digital technologies of 3IR. However, this optimism is usually tinged with varying degrees of caution. Worries include the potential for good jobs to disappear to automation, and for inequalities between and within countries to widen, leaving large swaths of the population even farther behind those in the leading, high-income economies (UNTAD, 2017; cited in Lippolis, 2019).

Advising on the impact of 4IR on African economic development and the welfare of citizens is a growth industry. In the last two years alone, multiple long reports (150 pages+) have been issued, some of which include a partial analysis of the implications for employment opportunities.[5] These employment analyses have tended to build on previous work done on the employment consequences of 4IR technology adoption in the U.S., especially automation and advanced robotics. Several analyses of the recent economic history of the U.S have concluded that these technologies have eliminated middle-skill, middle-class jobs and increased inequality, and predict that this trend will continue (e.g., Frey & Osborne, 2017). Others, such as Acemoglu and Restrepo (2019), argue that it is economic policy as much as technological change that has driven the U.S. result. Analyses of the prospects for developing countries are also split on the extent of technological determinism.

Objective and methodology

The objective of this paper is to synthesize, in a relatively short paper, the current evidence on the existing and potential benefits of 4IR technology for economic development in Africa, and to apply this knowledge to analyze the possible effects of adopting 4IR technology on future employment opportunities in Africa. Our contribution to the large body of existing literature is (i) a critical review of this literature, and (ii) a focus on technology adoption in production units and the employment opportunities this could produce.

Following the lead of Lippolis (2019), Banga et al. (2020), and others, as summarized in the recent Pathways for Prosperity Commission report (PfPC, 2018), we adopt a more holistic and conceptually broader approach than the "counting job losses and gains" approach popular in much of the literature to date on potential labor market impacts.[6] Our review of the evidence is not encyclopedic in the way that a review of evidence on program outcomes would be, given the breadth of the Fourth Industrial Revolution. Instead, our methodology is a selective literature review, discussing primarily the most relevant recent academic and institutional publications that address our core research question, and sub-questions as presented below. We focus on the recent major reports on 4IR and Africa, and the evidence therein regarding the possible benefits to production units, whether formal or informal. In assembling the evidence, we have given priority to analysis focused on Africa; we also use examples from other developing countries. At times, we refer to the experience of richer countries, including the U.S., as these countries have the widest experience with the technology in question.

4 Economists usually trace this insight back to the work of Schumpeter. See https://www.economicsdiscussion.net/articles/role-of-technology-in-economic-development/4455

5 See, for example, AUC/OECD (2021); Choi et al. (2020) – prepared at the World Bank; Technopolis (2019) – commissioned by the AfDB; the Broadband Commission's "Digital Moonshot Initiative" (BC, 2019), as well as the work of the Pathways for Prosperity Commission headquartered at Oxford which has covered all developing countries and produced multiple reports.

6 As Korinek and Stiglitz (2021) note, these papers have shown the "vast uncertainty" surrounding the employment effects of this technology.

The core question we address is ***whether 4IR technology can unlock better jobs for Africa's labor force, especially its youth***. Like Acemoglu and Restropo (2019) and Korinek and Stiglitz (2021), we take the view that the distribution of gains and losses from the adoption of new technology can be governed by economic and social policy. As with economic growth itself, technology is not inherently equal or unequal. In organizing and synthesizing the literature, we use the conceptual framework of (i) economic development as economic transformation, and (ii) desired economic development outcomes as ones which expand people's choices and capabilities to work productively and earn a fair income (decreasing decent work deficits). This conceptual framework was used to select the literature we reviewed and to organize our findings. Rather than focus on the quantitative range of possible job creations and disruptions, we instead highlight opportunities for and threats to the realization of development objectives that the technologies hold. We focus on how public policies could harness the innovative power of 4IR technologies to support improvement of overall employment opportunities, including for youth currently entering the labor market and for those who will enter within the next 15 years.

In attempting to answer the core question, we address the following sub-questions:

- What is 4IR? What is new and different that could affect the economic trajectory of African economies?
- How could 4IR technologies affect production systems in Africa? How will this differ by sector? How does this differ by type of country—income level and extent of digital and economic transformation?
- Could 4IR technologies advance economic transformation, leading to more sustained growth? How and through what mechanisms?
- Will 4IR-led transformation create better job opportunities? What is the evidence that youth entering the labor force will benefit?
- What complementary investments and policies are needed to realize the potential of 4IR to improve employment opportunities? In particular, how might recommendations for youth skill development change?
- How should African countries and outside stakeholders (donors, international financial institutions, etc.) approach 4IR to unlock this opportunity-improving potential for Africa's labor force?

Main findings

Africa's employment challenge in the post-COVID-19 era is to regain the previous, and in many countries, successful, trajectory of economic and employment transformation. While African countries still faced serious challenges in improving employment outcomes before the pandemic hit—as demonstrated by continued high levels of informal employment and working poor—it is important to remember that Africa as a continent had achieved a great deal between 2000 and 2020. Wage employment grew as a share of total employment (employment transformation) and nonwage earnings on and off the farm increased on average (Fox & Gandhi, 2021).

Our review finds that in a post-pandemic crisis Africa, 4IR technology has the potential to support countries to regain this positive trajectory. 4IR technology brings opportunities for production cost reduction, productivity and earnings improvement, and the development and introduction of new business lines, providing a wealth of new opportunities that could prove particularly attractive and accessible to Africa's youth. Most income earning opportunities will be found outside of the information and communications technology (ICT) sector. Deployment of 4IR technology throughout the economy could lead to new, often formal, wage jobs being created at a faster rate than the growth of the labor force, reducing the share of informal employment in total employment. It may also enable earnings improvements in the informal sector. Some sectors will offer more opportunities than others:

- The ***services sector is where the opportunities for formal wage employment expansion appear greatest***. Through the growth of existing firms and new firm entry—especially in sectors such as e-commerce and business process outsourcing (BPO)—Africa can create new jobs by expanding service sector exports and meeting the demand in the growing domestic and regional market. However, given the starting place, the share of service sector employment which is informal in lower-middle-income countries (LMICs) and low-income countries (LICs) can only be expected to decline slowly.
- In ***the agricultural sector, 4IR technology could support an increase in farm earnings and a reduction in poverty***, as well as bring important environmental benefits, but will not lead to an large expansion of employment, as this sector has been losing its share of employment for years.
- In ***the manufacturing sector***, which has recently expanded its share of output and employment in SSA's LICs and LMICs, ***4IR technology may open new opportunities for smaller-scale production for domestic and regional markets***. But the sector is not likely to continue increasing its share of employment, because when applied to manufacturing, 4IR technology is labor-saving.
- Substitution of capital for labor—i.e., destroying jobs—is less likely in Africa than in rich countries, owing to a higher cost of capital compared to labor, and a lower level of industrialization using 20th century technology.

While we see potential in 4IR technologies to support the maintenance of the pre-COVID-19 economic transformation trajectory and eventually help "build back better" (Fox and Signé, 2020), 4IR technology is likely to only bring incremental change in the trajectory of employment transformation in terms of shift from the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development (AU/OECD, 2021; Fox and Gandhi, 2021).

To capitalize on the potential employment and other benefits, countries need a comprehensive strategy covering the significant challenges governments will face in the future. Strategies should cover:

- ***How to revise regulatory frameworks, develop agile governance, improve business environments, and create inclusive policies to encourage technology innovation, importation, and adoption***. Key solutions include adopting 4IR technology within the public sector to permit a nimbler regulatory environment, encouraging the development of fintech, including to serve angel and equity investors, and developing cybersecurity frameworks.
- ***How to reduce gaps in physical and digital infrastructure to spur technology adoption***. Solutions will have to involve private finance, with incentives for inclusion of poorer household and more remote and rural areas.
- ***How to build the skills of the future labor force equitably, in view of the skill-intensive nature of 4IR technology***. Given the inadequate learning achievement outcomes of the current educational system and the pressure that past (and in some countries current) high fertility is expected to place on educational infrastructure in the next two decades, skill development and public expenditures will have to focus on increasing access and improving the quality of basic education, including secondary school. This will be the most inclusive strategy. To develop needed high-tech skills, countries should encourage post-secondary educational institutions to mobilize private financing.

Developing and implementing these strategies is urgent. Apart from Kenya, most LMICs and LICs in SSA have not established the conditions for widespread adoption of the technologies of 3IR, much less 4IR. This issue affects economic opportunities for all, not just youth. In many countries, mobile phone and fixed or mobile broadband usage significantly lags behind that of developing countries in other regions. In most countries it is also more expensive—an economic policy issue, not a technological one. Lack of energy and transportation infrastructure limits the adoption of advanced technologies across the continent, but especially in SSA. 4IR technology is skill-intensive, but SSA's skill development institutions are not adequate for the needs of the current labor force, much less the future one's, and there are few cost-effective strategies to address this. By contrast, in the upper middle-income countries (e.g., South Africa) and in the LMICs of North Africa, 3IR technology adoption has advanced, and strategies have been prepared to support 4IR adoption. Yet even in these countries, youth unemployment remains high and the strategies have not sufficiently focused on how to maximize youth employment outcomes from technology adoption.

Africa cannot escape 4IR, as African states become increasingly integrated into the global economy. The balance between the positive and negative outcomes from 4IR will depend on initial country conditions and policy choices. Poorer youth, especially those from rural areas, with limited access to electricity and ICT services, and less access to quality education and training, are at the highest risk of being left behind. The current digital gender divide, driven mostly by access to resources rather than education, could end up disadvantaging women, especially in the informal sector. Widening inequality, especially spatial inequality—an overall risk to economic development and transformation—is therefore a likely outcome in some countries, and will affect the employment outcomes of both youth and adults. External stakeholders should cooperate with each other, and follow the lead of countries, to help realize needed investments and help reduce potential challenges.

Roadmap

The paper is organized as follows. In the next section, we describe 4IR technologies and elaborate the conceptual framework we apply to organizing the evidence. Additionally, we review a few key facts about the status of the economic and employment transformation in Africa, including the current job landscape and the opportunities and challenges for youth. In section 3 we use the framework and landscape analysis to synthesize evidence on opportunities and challenges of 4IR technologies for Africa, segmenting the evidence by economic sector (agriculture, industry, and services). In section 4 we discuss labor demand and the skills-development conundrum African countries will face as they prepare to adopt 4IR technology. In section 5 we consider the critical role that public sector strategies, investments, programs, and policies need to play in supporting positive development outcomes from the adoption of 4IR technology, and discuss how African countries and outside stakeholders should approach the 4IR challenge. We conclude with some areas where further empirical research would be helpful to policymakers and stakeholders in formulating strategies, investment plans, and policy options.

2. Landscape and Conceptual Framework:

What is 4IR, and what is the scope for technology in improving African employment opportunities?

Klaus Schwab of the World Economic Forum is thought to have originated the term "Fourth Industrial Revolution." According to Schwab, 4IR is the advent of technologies that fuse the digital, biological, and physical, and disrupt the industries around the world (Schwab, 2016). These technologies have the potential to increase the speed, efficiency, and sustainability of the production of goods and services including in Africa (Signé, 2022).

Schwab (2016) identifies three distinct features of the Fourth Industrial Revolution: velocity, scope, and systems impact. Velocity refers to the speed at which 4IR technologies are spreading and evolving. While it took decades—almost a century—for the steam engine to fully revolutionize production globally in the 18th century, and there was a space of roughly 100 years between 1IR, 2IR, and 3IR, the inventions and innovations of 4IR are coming online less than 50 years after 3IR started. Globalization is spreading them at a breathtaking pace. Scope refers to the wide range of sectors, industries, and occupations affected by these technologies. For example, 3D printing, also known as additive manufacturing, could become a method of production for a wide range of light and heavy products, from circuit boards to custom sports shoes to wind turbines, and anything in between. Finally, systems impact refers to the breadth and depth of changes that are already occurring and are expected to continue to develop in entire systems of production, management, and governance. This combination of velocity, scope, and impact is expected to be disruptive to many patterns of human existence (Schwab, 2016), including the economies of Africa (Ndung'u and Signé, 2020; Signé, 2022). The key interlinked technologies of 4IR are described in the Annex.

This group of technologies holds particular significance for economic transformation. One important characteristic is that the technologies are not inherently saving of any factor of production (land, labor, financial or physical capital), although advanced robotics and AI have been designed and used in high income countries to save low skilled labor. Unlike the technologies of the First or Second Industrial Revolution, they are for the most part not subject to economies of scale.[7] which is a benefit for small countries. They can be combined in different patterns depending on the task at hand. For example, either cloud computing or mobile broadband services can enable an artificial intelligence (AI) or an Internet of things (IoT) application. Quantum computing speeds discoveries and applications of advanced biotechnology and material science.

Can these technologies ignite or accelerate economic growth and employment transformation in Africa? If so, where, how, and why? To assess these questions, we use the conceptual frameworks of development as economic transformation, and ethical development outcomes as the development of peoples' capabilities and opportunities for decent work.

Conceptual framework

It is widely agreed that the expansion of better income earning opportunities depends on progress in economic transformation. Economic transformation refers to two linked development processes: (i) structural transformation – the shift of workers and resources from low-productivity, low-earning sectors such as traditional agriculture to higher-productivity sectors through the more rapid entry and growth of firms in the higher-productivity sectors; and (ii) sectoral transformation – the growth of productivity within sectors, especially the lower-productivity ones. Economic transformation reflects both the use of new technology (e.g., mechanical, digital, and management technology) to lower the costs of production and to increase the diversity and the sophistication of what is produced—in economic terms, the value added—and improved allocation of resources (physical resources, including land, human, and financial resources) to higher-productivity uses. Economic transformation sustains economic growth and economic development (McMillan et al., 2017).

7 One exception is cloud computing.

Progress toward economic transformation is measured by: (i) within-sector labor productivity gains; (ii) progress in shifting employment and output to higher labor productivity sectors; (iii) export diversification, increased domestic value addition in exports, and upgrading in value chains; and (iv) economy-wide convergence in labor productivity (McMillan et al., 2017).

Economic transformation enables the growth of labor earnings in the economy as well as the employment transformation: a shift in the share of employment from self- and family-employment in household farms and microbusinesses to wage employment in private firms (or the public sector) (Fox & Thomas, 2016). This shift occurs when wage/salary jobs grow faster than the labor force. Formal wage/salary jobs are preferred by most in the labor force, as they have a lower level of income risk than self- and family-employment in the informal sector (ILO, 2021). These jobs tend to be the ones that African youth want when they leave school (Fox et al., 2016; PfPC, 2018; Lorenceau, et al., 2021). Previously, most analysis of economic transformation focused on structural change, especially the growth of the share of output and employment in manufacturing, as in the past, this sector has provided a large share of new wage jobs (McMillan et al., 2017). Recently, authors have shifted focus to other sectors as well (Gollin, 2018).

Economic transformation, leading to employment transformation, improves employment opportunities and reduces poverty in developing countries (Fox & Gandhi, 2021), but this outcome is not inevitable. It is important to note that labor productivity gains enabled by new technology do not, by themselves, necessarily create more jobs. New jobs are created when (i) productivity gains lower the cost of production, increasing demand and therefore allowing firms to produce more output by hiring more workers, or (ii) new firms enter, producing new items and creating new jobs. In agriculture, for example, within-sector productivity gains (sectoral transformation) have brought higher incomes but a decline in employment growth in the sector; however, through multiplier effects, these gains have led to higher employment growth in nonfarm sectors (structural transformation) (Timmer, 1988; Jayne et al., 2020).

While overall employment opportunities improve over time with transformation, jobs and occupations are usually gained and lost. The jobs gained are not necessarily more desirable than the jobs lost. It is critical, therefore, to examine not only whether the new 4IR technologies, if adopted in Africa, could advance economic transformation, but also what kinds of jobs (or job opportunities in the case of self-employment) could be created, what jobs could be lost, and what groups in society might be affected. Ideally, the new jobs will be development-enhancing—meaning, in the words of Sen, that they increase "the capability of people to live the kind of life they have reason to value" (Sen, 2001, p. 53). In the employment space, Sen's concept of ethical development outcomes has been characterized as "decent work." According to the International Labor Organization (ILO), decent work provides the opportunity for "full and productive employment with rights at work, social protection, and the promotion of social dialogue" (ILO, 2021b). Some dimensions of decent work are determined by a country's social policies (e.g., the framework for employee collective action, social dialogue, and bargaining, the body of labor laws and the institutions which oversee their implementation, and social protection policy and institutions). These aspects are mostly independent of the rate of technological change, except to the extent that technological progress enables economic growth and transformation, which helps generate the resources the public sector needs for implementation of decent work social policies.

Other dimensions of decent work are characteristics of a specific type of employment, and it is these dimensions that adoption of new technology can affect (and will be the focus of this analysis). These include:

- *Type of job*: ideally formal, wage-paying, with contract, in compliance with national labor legislation
- *Earnings*: ideally full-time earnings above the poverty line
- *Full-time*: no involuntary part-time work or excessive overtime
- *Lack of discrimination* in access to employment
- *Safe working environment* (low probability of occupational injury) (ILO, 2021b)

Of these, the most consequential dimension is the distinction between formal and informal employment, because other aspects of decent work (social protection, rights at work, freedom from injury, social dialogue) are primarily enforced through the government regulation of employers—which is much easier when the firm is registered with the government, reports on employment, enrolls employees in public social protection programs, collects employee contributions to social protection systems, and maintains a system to adjudicate worker complaints and workplace disputes. On the other hand, self- and family-employment is usually not covered by labor and social protection laws and institutions – in either developing or developed countries. The self-employed and their families do not have a labor contract with each other; self-employment income is difficult to establish and contributions to social protection systems are difficult to collect, and self-employment earnings are uninsurable owing to moral hazard.[8] Informal employees by definition have limited to no social protection, so they have no social insurance and may face higher risks of exposure to unsafe and unhealthy work and abuse.

Informal sector income is subject to both more risk and more volatility; as a result, households that depend on informal income contain a higher share of the working poor (Fox et al., 2020).

- *High risk*: people who work for themselves, work only with household members, or run a microbusiness with a few casual employees have no income floor. They carry all the risk associated with variable weather, crop pests, disease, price fluctuations, market disruptions, theft, and so on. They most often work in high-risk, low-reward situations, especially in the family farming sector. In addition, as gig-economy-type work spreads, more own-account workers become dependent contractors, meaning that they have no control over the price of their services (e.g., an Uber driver) or hours of work (e.g., the driver of a hired truck or a minibus).

- *Instability* arises because many work activities on farms, in informal businesses, or even as wage employees in formal businesses are temporary or are affected by seasonality, including rainfed family farming and casual daily labor activities (e.g., farm wageworkers or unskilled construction workers, etc.). This trend leads to underemployment (not being able to work enough hours during the year) and thus to low income.

The share of informal employment in total employment usually declines as countries transform and develop. This trend has been slowing recently in upper income countries with the growth of gig employment (ILO, 2016). While in some cases gig employment may be classified as formal, for the most part gig employment comes with more income instability and risk and limited to no protections.[9] In our review, we focus on whether adoption of 4IR technology in Africa has the potential to (i) reduce the share of informality by growing formal jobs through the creation of new firms and more formal, wage-paying jobs as a share of total employment, and (ii) raise earnings for those employed, regardless of type of job. But before we assess the future, we need to know Africa's starting place in terms of economic and employment transformation, and what this means for youth.

Box 1: Statistically, what does it mean to be working informally?

Based on discussions with labor statisticians, policymakers, researchers and stakeholders, the ILO has issued clear criteria (statistical standards) to identify informality as an employment outcome. These standards have two parts (i) people who are in informal production units (the informal sector); a production-unit based concept; and (ii) people who are employed informally, in either a formal or an informal production unit; a job-based concept.

(i) The informal sector consists of production units that are not constituted as separate legal entities independently of their owners (they do business in the owners' name). They are owned by individual household members or several members of the same or different households. Typically, they operate at a low level of organization and on a small scale. Earnings depend on income after costs of production; they are commonly called "nonwage earnings" or gross profits. They may be farm or nonfarm production units.

(ii) Informal employment includes employees (people who work for a wage for someone who is not a member of their family) who (legally or illegally) are not subject to national labor legislation, income taxation, social protection, or entitled to certain employment benefits (advance notice of dismissal, severance pay, paid annual or sick leave, etc.). It also includes all self-employed, contributing family members and employers who work in the informal sector.

The union of (i) and (ii) is defined as employment in the informal economy.

Source: ILO (2018)

8 Moral hazard refers to the insuree's ability to influence the insured risk.
9 See ILO 2018 for a discussion of the characteristics of this new employment classification.

The transformation and employment landscape in Africa, and what this means for youth

From 2000 until the recent COVID-19 shock, the economies of SSA made substantial progress in economic transformation, allowing sustained per capita income growth in most countries (Jayne et al., 2020 based on WDI data).[10] Region-wide, productivity growth averaged almost 2 percent per annum through 2013, driven by both within-sector productivity growth in agriculture (the lowest productivity sector) and structural change (McMillan et al., 2017). Outside of the agricultural sector, productivity growth was lower, primarily because as the share of employment in agriculture decreased, the share of employment in activities with a level of productivity lower than the economy-wide average (such as informal retail trade and small scale manufacturing) expanded faster than the share of employment in the highest labor productivity activities (Diao, et al., 2021). Notably, manufacturing sector output and employment expanded, especially in East Africa (Mensah, 2020), but the sector still only accounts for 5 percent of GDP in the low-income countries (LICs).[11] Trade diversification advanced substantially as well: in 2015, the manufacturing share of total exports reached 50 percent for SSA as a whole (Jayne et al., 2020). This number includes South Africa, which has the lowest share of agriculture in output and employment and a high share of manufacturing in output and exports, but reflects growth in regional manufactured goods trade as well. Mirroring trends around the world, manufacturing is becoming more capital-intensive in Africa, limiting employment creation potential (Mensah, 2020; Diao, et al., 2021).

Most African countries, especially in SSA, are characterized by low employment transformation with an ensuing high level of informal employment (Fox et al., 2020). The share of informal employment in total employment—including both casual informal wage employment and nonwage household production activities—is estimated at a high 86 percent for Africa as a whole (Table 1).[12] Non-wage household production activities may be family farms or nonfarm household enterprises (HE). North African countries, which are mostly richer, have more formal employment than SSA, which contains a number of LICs. Within SSA, the share of informal employment varies by region; the Southern Africa region has the lowest share, estimated at 40 percent (34 percent in RSA; ILO, 2018). A surprising amount of informal employment is found in formal firms: in North Africa, 50-70 percent of all employment is classified as wage-earning, but almost half of all wage-earning employment in North Africa is informal.[13] Women are more likely to be in informal employment in SSA, but less likely to be in informal employment in North Africa; in particular, they are less likely in NA to be found in nonagricultural informal employment (ILO, 2018). Overall, 68 percent of all employed people in Africa do not earn a wage (AUC/OECD, 2021).[14]

Table 1: Distribution of employment by type (percent)

	Formal*	Informal		
		Total	of which: Wage	of which: Self-employed & family workers
All Africa	14	86	26	60
North Africa	33	67	27	40
SSA	11	89	25	64

Source: ILO (2018) *Includes wage workers, employers, and formal (e.g., registered) self-employed and family workers

10 Similar trend data are not available for the countries of North Africa as a whole.
11 In classifying countries by income, we use the World Bank classification. See https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.
12 See ILO (2018) for the international definition of informality.
13 North African figures exclude Algeria and Libya owing to lack of data.
14 Includes nonwage informally employed plus nonwage formally employed.

The share of employment in nonwage jobs on the continent is not projected to decline substantially over the next 15 years (AUC/OECD, 2021; Fox & Gandhi, 2021). The AUC/OECD report predicts that if current trends continue, the share of total employment that is wage/salary (including informal wage) will only increase by 3 percentage points. This is quite a stark prediction, as it is based on a trend of substantial transformation over the past 15 years (Fox & Gandhi, 2021). However, it rings true, owing to (i) high projected labor force growth overall, based on past fertility, and (ii) particularly high labor force growth in populous countries with high levels of informality (e.g., DRC, Niger, Nigeria; Fox & Gandhi, 2021). Projected labor force and income per capita growth are well known determinants of informality, with labor force growth having a stronger effect (La Porta & Schleifer, 2013). The AUC/OECD prediction is consistent with other, earlier predictions for SSA (Filmer & Fox, 2014). Of course, countries such as Ghana, Kenya, and Tunisia, with lower projected labor force growth and higher starting incomes, will have an easier time reducing their shares of informal employment. The question addressed in this paper is ***to what extent could new 4IR technologies alter this trend by speeding up the creation of new wage jobs in expanding, higher-productivity sectors, leading to a decline in the share of people working informally, and to what extent would youth benefit?***

Youth employment issues

Discussions of youth employment issues in Africa usually start by highlighting Africa's role as the youngest continent, and the projected growth in Africa's share of the world's young working-age population (Filmer & Fox, 2014). Youth is a time of transition from dependent childhood to independent adulthood, and economic independence—often achieved through employment—is an important aspect of this transition. Youth are still developing their brains and their skillsets (Filmer and Fox, 2014), and about half of African youth age 15- 20 are still in school (Fox & Gandhi, 2021).[15] Labor force participation by youth age 15-24 is only 43 percent in the LICs and LMICs of SSA (and is falling as educational access expands) and it is even lower in North Africa and in the UMICs of Southern Africa.

Africa's youth are more educated than their parents, which could position them to seize new employment opportunities generated by technology adoption. 78 percent of youth are literate, compared to only two-thirds of the entire working-age population (AUC/OECD, 2021). While primary education rates have risen substantially, African youth have not yet registered a level of secondary education common in other regions. The share of youth who have completed secondary education in Africa, 28 percent, is much lower than in Asia, where it is 46 percent (AUC/OECD, 2021). Completion of at least lower secondary education or higher is usually required to obtain a formal wage job in Africa (Filmer & Fox, 2014). African schools are of poorer quality, on average, than those in Asia, leaving African youth at a disadvantage in a globalized world (World Bank, 2018a). After leaving school, youth still lack some of the socio-emotional skills necessary for success at work, skills that are often acquired through learning-by-doing rather than through formal learning (Filmer & Fox, 2014; Fox, 2018). African education systems do a poor job of developing these skills (Filmer & Fox, 2014; Arias et al., 2019).

Owing to the high level of informality (especially in SSA), even educated youth entering the labor force face a set of constrained choices, not unlike those faced by their parents. Lack of preparation for employment while in school has often prolonged the search for a satisfactory livelihood among African youth (Lorenceau et al., 2021). In situations where wage jobs are not being created fast enough relative to the number of youth entering the labor force, youth have to create their own employment. In the agricultural sector, this may mean acquiring land, inputs, and tools. In the nonagricultural sector, it may mean acquiring inventory to sell, tools to provide services such as hairdressing or repair, or raw materials needed to produce home-made goods such as food or craft furniture. In all cases, this means savings are needed, either from one's family and network, or from earnings acquired by working for someone else as a wage worker or dependent contractor, or a combination. The need to meet this challenge may cause youth to experience spells of unemployment or underemployment combined with shorter employment duration than adults (Bridges et al., 2016). However, youth unemployment is not high in Africa compared with the rest of the world (ILO, 2018), but it is still concerning. Even more concerning is the fact that unemployment increases with education, indicating that economies are doing a poor job of absorbing the rising levels of educated youth on the continent (Fox & Gandhi, 2021).

15 The share of youth under the age of 20 in school may have fallen in 2020 owing to education distriptions caused by COVID-19 containment measures.

Most youth who work—either while in school or after leaving school—end up working informally. 38 percent of employed youth were working poor in 2018 (ILO, 2018). The probability of wage employment rises with age. This statistic is somewhat misleading, however; it does not mean that people transition to wage jobs as they get older. Rather, it reflects the fact that more educated youth are not counted in this estimate of youth working informally because they are still in school. Controlling for education level, youth are not more likely to be working informally (Dolislager et al., 2020). Nonetheless, informal employment remains the starting—and ending—place for most youth in the labor force, especially in lower-income countries (Lorenceau et al., 2021).

Young women in Africa are more likely to be excluded from good employment opportunities. All over the world, gender norms and customs circumscribe economic opportunities, and Africa is no exception. African women have less access to post-primary education (Fox and Gandhi, 2021). In LICs and rural areas, women have the highest rates of marriage and childbirth before the age of 18 in the world, which interrupts education and contributes to maternal mortality (Jayne et al., 2020). Even if women have education, they have less access to wage employment, and their farms and businesses are less productive than men's (Jayne et al., 2020). Adult women have lower access to digital and finance services and a high burden of household chores and care, which often prevents them from engaging in more remunerative economic activities. In North Africa, women's labor force participation rate (LFPR) is particularly low compared to the rest of the world. At the root of these symptoms are legal, social, and economic conditions that result in less economic empowerment for women (Jayne et al., 2020).

In sum, while African countries have made progress in economic and employment transformation, both youth and adults still face challenges in earning a living. These problems are economically and socially complex, and technology is unlikely to be the silver bullet. The question is whether 4IR technology can alter the current trajectory, and if so, how would this happen, and who would gain?

Africa has shown its potential for digital technology innovation and adoption through the development of mobile money, an innovation that has spread throughout the developing world, raising productivity in formal and informal economic activities and bringing the benefits of financial services to a vast previously unbanked population. Youth were among the first adopters of this technology, reflecting both higher education levels and increased interest in, and proclivity for, technology adoption. Can this experience be repeated with 4IR technologies? In the next section, we use the conceptual framework outlined above to elucidate the opportunities and challenges of 4IR technology in increasing value added, product and export diversity, and labor productivity in the production of goods and services, starting from the current landscape. We identify the factors driving the potential impact on economic transformation and employment opportunities, including what this might mean for youth.

3. What could 4IR mean for African economies and livelihoods?

4IR technology has the potential to improve material welfare in Africa through multiple channels: by improving labor productivity throughout the economy; by improving education and health services access and quality; by improving urban management and service delivery through the adoption of smart city technology; and by reducing the cost of consumer goods, raising the real incomes of the population. While all channels are important, in this paper we focus on the production channel, as it is the most important for the creation of new and better jobs in the economy. We mostly ignore the role of the public sector as a direct job creator, since employment in this sector tends to expand regardless of technology—it is driven more by demand for publicly-provided services and by resources available.

Production units (firms or households) adopt a new technology when the benefits (profits) are higher than the cost.[16] If the benefits involve producing the same amount of product at a cheaper unit cost, the owners of the production unit would expect an increase in earnings, but no new jobs. If the benefits involve producing and selling more product or better quality product, or starting a new business in a different sector, this might involve new job creation. Producing product more cheaply would lead to sectoral transformation; starting a new business could lead to structural transformation, if labor is reallocated to other sectors.

In this section, we look for both transformation effects within the context of the three major sectors of the economy: agriculture, industry, and services. Of these, the services sectors, including both public services and privately-provided services, account for the largest share of GDP, 46 percent, while industry accounts for 28 percent, of which 10 percentage points come from the manufacturing sector, and agriculture accounts for 25 percent (AUC/OECD, 2021). Employment is distributed slightly differently than output, reflecting a lag between changes in the structure of output vs. changes in the structure of employment owing to differences in labor productivity by sector—as output shares rise in sectors that use more capital and/or technology per unit of output, labor shares must follow more slowly (Table 2).

Table 2: Distribution of employment by sector (percent)

	SSA			North Africa	All Africa
	LIC	*LMIC*	*UMIC*		
Agriculture	64	42	7	25	44
Industry	10	12	22	24	15
of which: Manufacturing	5	8	10	12	8
Services	26	45	70	50	41

Sources: AUC/OECD, 2021; Fox & Gandhi, 2021

The main employment effect of 4IR technologies will not be found in the sectors that provide the technology services – mainly the ICT sector. Even in the U.S., an ICT giant in terms of output, employment in the ICT sector – including software development and applications - was only 3.8 percent of all employment in 2017; the telecoms sector in Africa only employs 240,000 people (AUC/OECD, 2021). But Hjort and Poulsen (2019) found that the arrival of high-speed internet in Africa created substantial jobs primarily by pulling people into the labor force to seize opportunities created, increasing overall employment rates. They also found a significant increase in new firm entry in South Africa. Houngbonon et al., (2021) also found that access to internet increases the probability that a household will operate a nonfarm enterprise. Similarly, Cariolle et al. (2019) found that a 10 percent increase in e-mail use by firms in a geographical area increases the number of full-time employees by 12-14 percent in the same area. Thus the analysis will

16 This is obviously an over-simplification because the cost is usually fixed and up front, and may have to be financed, while the benefits will be realized over time, with a degree of uncertainty. Evaluating investment in new technology therefore involves, among other things, using discount rates and probabilities.

focus on key employment sectors – agriculture, manufacturing, and services – and how the adoption of 4IR technologies could affect employment opportunities there. While we find opportunities for earnings increases (an element of decent jobs) in all sectors, the main effects on the extensive margin – new formal jobs – can be expected primarily in the services sectors.

Agriculture

Agriculture is an essential sector in Africa, both today and in the future (Signé, 2020). In lower-income countries, agriculture provides income for most poor households, food for a growing urban population, and export earnings. In the higher-income countries in Northern and Southern Africa, agriculture's importance as a share of output and employment has declined substantially, but agricultural commodities and processed agricultural products (e.g., juices, wine, olive oil) still account for a significant share of exports and local food supply. Productivity gains in the agricultural sector have played a catalytic role in boosting structural transformation through downstream and upstream linkages with the rest of the economy (Jayne et al., 2020). For example, in Kenya, agriculture accounts for 26 percent of GDP directly, but an additional 27 percent indirectly through linkages with other sectors (Banga et al., 2020). As a result, increasing output and improving productivity and earnings in agriculture is critical to reducing decent work deficits in Africa.

Agriculture in Africa has dualistic characteristics. In LICs and LMICs, smallholder family farms (SHF, less than 3 hectares) dominate the sector, and even medium-sized farms (up to 10 hectares) tend to be family owned and operated. In SSA, after decades of poor performance, output grew at an average rate of 4.3 percent per annum on farms in LICs and LMICs during 2000-2018, and farm incomes and productivity increased as well (Jayne et al., 2020). Yet productivity remains low, reflecting a range of challenges faced by SHFs, including low usage of modern inputs, lack of secure land tenure, lack of irrigation systems, poor roads resulting in high transportation costs (raising the price of inputs and lowering returns to the farmer), and low public investment in the sector, especially in research and development (R&D), meaning that there are limited science-based options tailored to SSA's many microclimates (Jayne et al., 2020). As a result, much of SSA remains uncompetitive on world markets in the production of grains and livestock, and farm incomes are still low in traditional tropical crop production (tea, coffee, cocoa, cotton, oilseeds). Poverty and food insecurity rates are high among SHF in SSA; constraints on productivity particularly affect women SHF, as they are less likely to have secure land tenure or access to credit.

In contrast to LICs and LMICs in SSA, the agricultural sector in Northern Africa and South Africa is more developed, mechanized, productive, and profitable. Northern African agricultural products are increasingly quality-controlled and branded. For example, Egypt is a large exporter of extra-long staple cottons, which command a premium price; many premium bedding manufacturers advertise that their sheets and towels are made from "100% Egyptian cotton," while South African wines and juices have earned an international reputation. With support from donors and foreign direct investment (FDI), SSA is learning this approach. For example, African premium coffee branded by bean and origin is appearing more frequently in higher-end retail outlets in the Western world. But these products represent a very small share of total agricultural exports from SSA.

If increasing the use of digital and other 4IR technologies could be deployed to support improvements in on- and off-farm productivity, agriculture could be an important growth sector in Africa for several reasons. First, SSA is home to most of the world's unused farmland (Jayne et al., 2020). As the world's population grows, especially in the population-dense regions of Asia, Africa has the potential to feed the world if productivity can be raised. Already, Africa is supplying an increasing share of the world demand for tropical products (Jayne et al., 2020). Even within Africa, demand for food is growing quickly as population grows and countries get richer. The food system, including agro-processing, is expected to account for up to 40 percent of net new jobs over the next 10 years (Filmer & Fox, 2014; Jayne et al., 2020). Agro-processing could be one of the largest sectors for business-to-business spending by 2030, at an estimated $915 billion (Signé, 2020).

4IR technologies are already in use in the agricultural sector in Western Europe, North and South America, and East Asia. AI, IoT, Big Data, and autonomous vehicles and drones, along with cutting-edge biotechnologies such as CRISPR, are being used together in a model called "precision agriculture," a method of site-specific crop and farming management used to improve farm profitability, efficiency, and sustainability.[17] For example, GPS-based mapping systems including yield monitors are already being used on half of all corn and soybean farms in the U.S.[18] Autonomous vehicles for soil preparation, planting, and harvesting are also already in use, and advanced robotics is expected to take over many farm tasks currently done by workers, such as fruit and vegetable harvesting. Radio chips embedded in a IoT system are widely used to manage livestock production, and IoT technology using field sensors is enabling precise irrigation and fertilization, reducing water wastage and pollution of water resources from agricultural runoff. Drones are taking over crop spraying, and connect with sensors on the ground to measure crop health and soil conditions.[19] 4IR technology is expected to help farmers around the world cope with and mitigate the challenges of a warming and more unstable climate.

By following the lead of upper-income countries, Africa could deploy 4IR technology to modernize and improve productivity, reducing poverty and food insecurity (Signé, 2022). Already, mobile phones are bringing more information to farmers about when and what to plant based on weather forecasts and technical information about crop varieties, building a knowledge-based agricultural community. Mobile phones are aiding in price discovery and helping to match farmers and wholesalers, reducing price dispersion and transaction costs (Fabregas et al., 2019). Ghana-based companies Farmerline and Agrocenta offer farmers mobile and web technology for agricultural advice, weather information, and financial tips. Zenvus, a Nigerian startup, measures and analyzes soil data to help farmers apply the right fertilizer and optimally irrigate farms (Signé, 2022). The African Soil Information Service uses remote sensing, providing soil data on an open-source basis, bringing down the cost of soil mapping by 97 percent (PfPC, 2018). If more AI and GPS-coded sensors were used, information could be even further customized, and supply chains could track the progress and quality of crop production in any area. Smartphones are enabling farmers to access pricing data on platforms, reducing the cost of price discovery and shrinking price variation among buyers (Technopolis, 2019; PfPC, 2018). Meanwhile, Hello Tractor, a start-up in Nigeria and Kenya that allows farmers to hire affordable tractors via mobile phone, is expanding operations, bring the efficiency of mechanization to African SHF. The company had already served up to 22,500 customers and reported yield increases of 200 percent for its clients by 2015; it has grown substantially since then (Theunissen, 2015). The Moroccan company Visio-Green Africa is partnering with the Moroccan Association of Producers and Exporters of Fruit and Vegetables to use IoT to bring smart irrigation techniques to Morocco's farmers, saving water in an increasingly water-limited country (Technopolis, 2019).

4IR technologies are helping to address other longstanding issues in African agriculture, including land tenure issues, advancing use of irrigation, and reducing water pollution from fertilizer over-use (Ncube et al., 2018). However, application is spotty, and lacks a supportive policy framework. For example, in countries that have adopted and implemented land tenure reform policies designed with SHFs needs in mind, GPS systems are already being used to register land, improving land tenure security and willingness to invest. Insecure land tenure is one reason for women's lower agricultural productivity and earnings, so addressing this issue is important.[20] Likewise, blockchain is beginning to be used to create a safe repository for land records and to reduce the transaction costs of land rentals and sales; Uganda is one example, but few other countries have followed its lead, in part because of a lack of knowledge and understanding of the technology (Technopolis, 2019). Solar panels are starting to be used to power irrigation systems, reducing costs and eliminating the carbon-laden exhaust from gasoline-powered generators.

Increased use of 4IR technology could raise productivity and earnings even more. Blockchain and AI could improve farmers' access to credit and weather-based credit insurance (see below); blockchain can also improve the traceability of products, helping establish quality standards and brand identities and ensure higher prices for Africa's agricultural exports. Drones can spray crops about 40 times faster than humans, and help ensure that all farmers' crops are sprayed so that pests cannot return (Technopolis, 2019). Drones are currently expensive, however, so their widespread use will require support for producer organizations (Technopolis, 2019).

17 See https://agriculture.trimble.com/blog/what-is-precision-ag/; https://www.precisionag.com/.
18 Ibid.
19 https://www.precisionag.com/
20 Note that preliminary research in Ghana found that when women get secure land registration, they tend to exit the sector for non-farm self-employment. Suri and Jack (2016) found the same effects with access to mobile money. This suggests that the income effect of technology use occurs outside the sector for most women. However, secure land registration enables women to rent or sell their land, leading to much-needed land consolidation.

The agricultural sector is not the first choice of livelihood for African youth owing to the perception that it is not profitable (Lorenceau, 2021). But the opportunity to use digital technologies to modernize agricultural production is drawing others into the field (USAID, n.d.). Contrary to widespread belief, the average age of farmers is not increasing (Jayne et al., 2020). While the share of the labor force working in agriculture is declining, the absolute number of people active in the sector continues to rise, another indication that youth remain engaged in it (Fox & Gandhi, 2021). A Mercy Corps study in Kenya found that most rural youth are active and networking on social media and that rural youth with a secondary school education are being drawn to agriculture, using tech platforms for information and networking, and mobile money for credit.[21]

Adoption of 4IR technology in agriculture is hindered by a lack of information and communications technology (ICT) and energy infrastructure. In contrast to the Kenya example above, most of Africa's rural areas, especially in West Africa, are underserved even by basic mobile phone technology. Only 27 percent of rural adults in Africa have ever used the internet (AUC/OECD, 2021). Many areas, especially in LICs, do not have the electricity supply to power 4IR technology. In SSA LICs, only 20 percent of the rural population report access to electricity; very few are using the internet, either through fixed broadband or mobile. The situation is better in LMICs, where 50 percent of the rural population has access to electricity. This is one reason why most of the action on adopting 4IR technology in agriculture is taking place in LMICs such as Ghana, Kenya, and Nigeria.

Persistent sector profitability and competitiveness issues also inhibit technology adoption. Issues such as costly transportation beyond the farmgate and incomplete markets have lowered agricultural prices and earnings and inhibited adoption of modern inputs; these will inhibit the adoption of 4IR technology as well if not addressed. For this reason, Gaus and Hoxtell (2019) are pessimistic that 4IR technologies will be adopted in SSA in the next 10 years. However, prior to the COVID-19 crisis, countries such as Ethiopia, Senegal, Ghana, Rwanda, and others had experienced rapid, productivity-led output growth, in part by chipping away at these issues (Jayne et al., 2020). SSA is also seeing the emergence of medium-sized commercial farms, owned by absentee urban owners or educated rural elite farmers who will be keen to adopt this technology, which could lower the price for other farmers in the area (Jayne et. al, 2018). Thus, a case can be made for technology adoption optimism in the post-COVID-19 era.

Increased use of precision agriculture techniques could help create new formal jobs in the upstream and downstream off-farm aspects of the agro-food systems, and indirectly create jobs elsewhere in the economy as well (Gaus & Hoxtell, 2019). Formal firms will be created to sell and service precision agriculture inputs. Meanwhile, lower costs of food in urban areas, made possible by increased output and lower transaction costs as well as by expanded intra-Africa trade if the AfCTA comes to fruition, will increase real incomes in urban areas and help keep Africa's labor force internationally competitive. Finally, a competitive and productive agriculture sector is a key pre-requisite for the expansion of the agro-processing industry, a manufacturing sector where Africa could still be competitive.

In sum, while 4IR technology will not solve all the problems faced by African farmers, increased adaptation and adoption in the agricultural sector could bring substantial economic and social benefits. 4IR will not lead to the creation of formal jobs on the farm in Africa; family farms characterize the sector all over the world. But it should lead to increased incomes and wealth for some of Africa's poorer households, including those headed by youth, which has high economic and social benefits, including reducing rural poverty and spatial income inequality. Higher SHF household income means rural children can be better educated and healthier, so that those who leave farming to seek work in other sectors will be employable and productive (Deaton, 2013). Precision agriculture techniques are already saving water and lowering pollution caused by fertilizer and agro-chemical runoff, two major social benefits.

21 https://www.mercycorpsagrifin.org/farmer-insights/

The Industrial Sectors

The industrial sectors include construction, mining, manufacturing, and utility services (e.g., energy and water supply). Within industry, the manufacturing sector has attracted the most attention in terms of 4IR potential, but this sector is mostly underdeveloped in the LICs and LMICs of SSA where output and employment shares lag the averages for all LICs and LMICs (Fox & Gandhi, 2021). The lack of an export manufacturing sector is often blamed for the shortage of wage-earning jobs in SSA (Filmer & Fox, 2014; ACET, 2017).

Manufacturing

SSA countries, especially the LICs and LMICs, got a late start in developing a privately-owned manufacturing sector. Technological change in the manufacturing industry over the last 30 years has not favored late entrants. In part to standardize and improve quality, manufacturing has become more capital-intensive, and the labor share of value added has dropped globally (Rodrik, 2015). 4IR technologies, especially advanced robotics, are accelerating this trend in upper-income countries, where new manufacturing plants use little labor. This global substitution of capital for labor particularly disadvantages developing countries, as their low-paid workers are no longer a source of comparative advantage, and now have no place in global value chains (Baldwin, 2019). Even the robots are made in rich countries (Rodrik, 2018). It is therefore instructive to briefly review the experience of automation and advanced robotics in high-income countries as this experience often drives the discussion in developing countries (Kenny, 2019).

In the U.S., inequality in wages, incomes, and wealth has been rising steadily since the late 1970s (Stanford Center on Poverty and Inequality, 2011), and adoption of advanced robotics—including AI and IoT—is widely seen as contributing to these inequality trends (Kenny, 2019). On the one hand, total jobs in the economy grew during the recent automation period (Arntz et al., 2016; Gaus & Hoxtell, 2019), demonstrating that automation does not necessarily lead to widespread unemployment. But the job loss-job creation effects were not equal across gender, skill level, and region. In particular, the share of medium-skill jobs (those requiring a high school diploma plus experience and/or vocational training), disproportionately held by men and disproportionally located in the U.S.'s industrial heartland in the Northeast and Northern Midwest, fell substantially between 1987 and 2017 (Acemoglu & Restrepo, 2019). Meanwhile, demand increased for highly skilled labor to design, deploy, finance, and maintain robots (contributing to a rise in the wage premium for tertiary education; Acemoglu & Restrepo, 2019). This led to a widening of earnings inequality. [22]

According to Acemoglu and Restrepo (2019) there are several reasons why advanced robotics have taken so many jobs in the U.S. without creating replacement jobs at the same skill level. First, as noted above, the combination of AI and robotic design has allowed the creation of machines that are uniformly better than people at repetitive, physical tasks, which is what many medium-skill jobs were before robots replaced them. Not only did robots replace humans in auto and electronics assembly, but they also proved better at assembly-line tasks requiring judgement such as sorting and grading food for processing and/or packaging (by using sensors). But a second, and quite important reason, is that taxes on labor have remained the same in the U.S. for 20 years, while taxes on capital investments have declined substantially. This means that in tasks where people and machines have similar productivity (or people's is higher), the low cost of capital (low interest rates, accelerated depreciation allowances, low corporate taxes) favors robots in the U.S. This difference in factor prices is helping to drive technological innovations in the U.S., which then spread around the world in global value chains.

It is clear that the type of displacement caused by the automation of manufacturing processes that occurred in the U.S., and to a lesser extent in Europe, will not occur in the LICs and LMICs of Africa because the jobs were never there in the first place. Countries in Southern Africa and North Africa with a share of employment in manufacturing above 10 percent, most of which is formal, could be vulnerable to a decline in employment share, depending on what they produce and whether it is for the domestic market (e.g., building materials, processed food) or for export.[23] The critical question is whether the

22 Other factors, such as globally mobile capital but immobile, disempowered labor have no doubt also contributed to the U.S. result.

23 Manufacturing exporters in Africa are few but diverse, with diverse prospects. Countries such as Lesotho and eSwatini, with a light-manufacturing export sector which takes advantage of RSA's logistics and trade preferences such as AGOA but pays lower wages may be able to keep manufacturing employment up for a period of up to 10 years. Countries such as Egypt and

adoption of 4IR technology in Africa could support an increase in the share of manufacturing in output and employment, or would reduce it. Researchers and observers have mixed views on this topic. Banga and te Velde (2018) are among the optimists, noting that the sectors that have been recent growth areas for SSA manufacturing, including textiles, garments, leather, and furniture, have also been more resistant to automation. If African countries can maintain a cost advantage, they could expand output and employment in these sectors, especially if 4IR technology reduces costs inside the factory (energy) and outside the factory (e.g., transportation to markets). Bang and te Velde (2018) provide the example of the "A to Z" garments factory in Tanzania, where automated laser cutting reduced cutters' jobs, but the increased productivity and quality in cutting led to increased orders, creating about 5 percent net new jobs. This is an example where automation reduced the number of jobs per unit of output, but lower unit cost increased product demand and overall employment. Banga and te Velde (2018) also analyze cost per hour for labor and robots in furniture making in Kenya and the U.S., and conclude that while robots are competitive with labor in the U.S., they will not be competitive with labor in Kenya for at least one decade. Meanwhile, Mensah (2020) uses new data to reveal that since 2010, the share of employment in manufacturing has risen in Africa, particularly in East Africa.

The pessimists note that factor prices (e.g., low wage labor) matter much less for competitiveness in manufacturing than they did in the past (Baldwin, 2019). In fact, payroll costs in export manufacturing plants in Africa are now a small share of total costs—less than 15 percent, a bit higher in garments (Diao et al., 2021)—so the African advantage of low wages does not hold anymore. Increasing economies of scale in production and increasing quality requirements in transport and distribution are cited more often than labor costs as determining manufacturing plant location (McKinsey, 2019a).[24] This is not an area where Africa excels compared to the rest of the world (World Bank, 2019b). Customs and other border delays for imports and exports are much longer in Africa than in other developing regions, impeding competitiveness (except in South Africa, where the logistics sector is well advanced; AfDB, 2018).

The problem for Africa is that in order to be competitive and attract investment, late industrializers must adopt the technologies used by their competitors and within global value chains. Diao et al. (2021) compared the capital intensity and the technology used in productive export manufacturing plants in Tanzania and Ethiopia with plants in Vietnam and in the Czech Republic, and found them to be similar, despite vastly different factor endowments. They conclude that for an African export manufacturing sector to compete with richer countries, there is no choice but to import the capital-intensive technologies developed in the rich countries. Some have suggested that owing to the spread of global value chains within regional blocs (such as East Asia, Europe, and North America, which have advanced robotic technology and well-developed trade logistics both within the bloc and with the rest of the world), the door to employment transformation through growth in export manufacturing is closing fast for Africa, or may even have already closed (Hallward-Driemeier & Nayyar, 2017; Technopolis, 2019).

One key element of 4IR technology is that it makes customization of production cheaper, disrupting the economies of agglomeration that have held back the development of a competitive manufacturing sector in Africa (Murray, 2017). So, while advanced robotics increases scale and erodes the cost advantage of workers in developing countries because robots do many tasks much better and more reliably than humans, technologies such as 3D printing reduce the need for scale. In this way 4IR technologies could make manufacturing more democratic, and more profitable in smaller and land-locked countries. Medium and even small enterprises will be able to set up shop in African cities far from an international port and supply a wide variety of industrial and consumer goods without delay or transport costs, and without needing a large investment in specific machinery to produce specific parts. This is likely to decrease costs of production, increase productivity, increase demand for new and existing products, enable new firms to enter markets, decrease the cost of trade, and increase global value chain participation in Africa. These impacts will spread to the labor market, where there could be an increase in manufacturing jobs in high-skill areas such as programming and maintaining 3D printers. 3D printers could give a boost to Africa's burgeoning design sector. Already, start-up entrepreneurs have set up shop in Nairobi using 3D printers

Tunisia, which produce inputs such as auto parts for export, may be affected earlier by the adoption of 4IR onshoring in auto and high-tech manufacturing in Western countries such as Japan, Korea, the EU and the U.S. Finally, countries such as RSA, which do a mix of assembly and production for the domestic markets as well as regional export, should be able to hold on to their manufacturing employment owing to logistics advantages relative to potential exporters outside the region.

24 Recent research has found that services embodied in traded goods account for one-third of the value of manufactured exports in OECD countries (Hallward-Driemeier & Nayyar, 2017). This is a major reason why shop floor wages matter less and less in determining manufacturing competitiveness.

to manufacture items out of waste products based on open-source designs, an example of one potential environmental contribution of 4IR products in manufacturing: less waste (Banga & te Velde, 2018).

An important issue for Africa will be gaining access to technologies and the skills needed to use them. Finance for capital investment is cheaper in Asia and the West than it is in Africa owing to more developed capital markets (Technopolis, 2019; The Economist, 2020). While 3D printers are cheaper than a whole manufacturing plant, they still require a capital investment in imported machinery; Deloitte (2016) reports that the cost of machines has reduced their adoption in markets such as South Africa, despite a large supply of labor with digital skills. In countries open to FDI such as Morocco, multi-national corporations are financing the acquisition of 4IR technology themselves. While this avenue creates formal wage jobs, it does not help potential domestic producers. Beyond the cost, 3D printers require a high skill level to operate, including training in working with Computer-Assisted Design platforms (CAD). To be able to create new or modified products that respond to the needs in Africa markets, even more sophisticated CAD skills are required. 3D printing is an area where partnerships between the higher education sector and private industry to set up technology hubs could advance technology adoption (see skills discussion below).

In sum, owing to the capital intensity and skill-bias of new manufacturing technology, 4IR is unlikely to be the engine for creating vast amounts of new, formal, wage-paying, manufacturing jobs for Africa's labor force. On the contrary, according to Baldwin (2019) it is likely to reduce the share of employment in manufacturing in Africa, although Banga and te Velde predict that this will take a decade or two and that the share of manufacturing employment could well go up first. For those who are entering the labor force and are able to develop the required skills—a select group of youth—some decent, higher-paying jobs should be available in small-scale production for local or regional markets. And jobs associated with manufacturing, ranging from design to marketing and sales to within-factory services such as cleaning and maintenance will still be needed and will provide opportunities for people without digital skills, including youth (Banga & te Velde, 2018).

Mining

While the mining sector is not a large employer, the share of employment in mining in SSA is larger than in similar countries in other regions owing to large mineral reserves, many of which are still unexploited (Fox & Gandhi, 2021). Africa is home to the largest global reserves of aluminum, chromium, cobalt, diamonds, gold, manganese, phosphate, platinum-group metals, and vanadium (Assegaf et al., 2017). The number of countries exploiting and exporting mineral reserves has grown rapidly over the past 10 years, and only a handful of African countries are not mineral exporters (Chuhan-Pole et al., 2017). Mining operations create jobs in surrounding communities indirectly, through backward and forward linkages, and revenue from mining leases supports public administration and service provision (which also creates jobs).

Wage jobs with formal mining enterprises—mostly foreign—are well paid in Africa, while informal artisanal mining tends to be low earning (Chuhan-Pole et. al., 2017). Mining is physically difficult work and is often dangerous due to the likelihood of work accidents and exposure to dust and toxins (Stewart, 2019). 4IR technology—robots and sensors—is already being used in mining around the world, particularly in large underground mines (Gaus & Hoxtell, 2019). IoT technology allows better monitoring of conditions underground. Use of these technologies is likely to reduce jobs in older, large underground mines and improve the safety of those that remain (Gaus & Hoxtell, 2019; Technopolis, 2019). 4IR technology is mostly being adopted by large multi-national mining companies; Africa's dangerous informal, artisanal mining industry is so far not affected.

Global demand for "rare earth" minerals offers new opportunities for Africa if more mineral reserves can be identified. 4IR technology such as drones and satellite imagery are an efficient way to prospect (Gaus & Hoxtell, 2019). 4IR technology could therefore increase employment in mining by supporting new mineral discoveries.

Energy

Africa has some of the world's most expensive energy, and it is often unreliable (Bond, 2016). Installed capacity is too low, and outages and blackouts are frequent. Businesses and households are forced to rely on energy from back-up generators, which is even more expensive than grid energy—an estimated $.40 per kWh vs. $.10-.20 per kWh from grid-based energy (IFC, 2019). Nigeria spends three times as much money on back-up generators as it does on grid energy (IFC, 2019). Generators are powered by burning diesel fuel, which emits emissions that are both a health hazard and contribute to climate change. Grid electricity in Africa is still highly dependent on fossil fuels, even though renewable sources are abundant (sun, wind, and hydro; IFC, 2019). The unreliability and cost of energy is frequently cited as one of the top three obstacles to business expansion in SSA (IFC, 2019).

4IR technology cannot make up for a lack of installed generation capacity, but it does have the potential to improve the reliability of the grid and the network, which could indirectly lead to new wage job creation and increased earnings for (household) enterprises. It could also reduce non-revenue energy use (electricity theft) by using IoT and other 4IR technologies (Technopolis, 2019), improving the financial position of electricity distributors. 4IR technology already supports microgrids, energy on demand, and pay-as-you-go schemes for rural villages and towns. Advanced material science is bringing down the cost of key parts of the system, including solar panels and windmills, as well as the batteries needed to store energy for nighttime use or when the wind dies down. A key issue is the quality of operational and financial management in legacy state-owned electricity (SOE) companies. Major structural reforms are needed in the sector, which involve either overhauling the regulatory approaches to SOE monopolies or moving to private sector competitive ones. Electricity generation is a sector often cited as most likely to benefit from a private sector, competitive approach (Bond, 2016).

In sum, while Africa will need 4IR technologies to make the industrial sector more competitive and increase the range of products made in Africa available to African consumers (as well as lower their prices), the prospects for large-scale increased employment and earnings are moderate. While the new jobs are most likely to be formal sector, stable, and higher earning ones, they will also require more skills than jobs in traditional light manufacturing or mining. Not considered in this section are the employment implications for the service side of manufacturing—marketing and sales. For example, the expansion of mobile phones and the development of mobile money has indirectly created many more new jobs (e.g., sales, agents) than the production and installation of ICT infrastructure. These jobs are for the most part not high-skill ones; on the contrary, most are in the informal retail sector. In the next section, we turn to the opportunities and challenges of 4IR technology in services.

The service sectors

The service sector group is the most heterogeneous, as it includes trade, transportation (air, road, rail; people and freight), hospitality (including tourism), finance, and real estate (sales, rental, and management), professional and administrative services (including ICT), public administration, security, urban services, education, health, social work, arts, entertainment and recreation, personal services (e.g., hairdressing) and domestic services (household chores and care, home security services, etc.). For the most part, service sectors are labor-intensive, but notable exceptions include transportation, ICT, and finance. Service sectors' share of output and employment has grown rapidly throughout Africa. Yet the majority of service sector employment outside of the public sector is informal (Fox & Gandhi, 2021; Diao et al., 2021).

It used to be thought that service sectors could not contribute much to economic growth and transformation due to their low potential for productivity improvement.[25] The adoption of 3IR and now 4IR technology has changed this picture. For example, containerization and digital trading records have reduced international shipping costs by more than 90 percent since the 1960s, reflecting a huge productivity improvement (Murray, 2017). Wholesale and retail trade in the U.S. has recorded annual productivity growth of 1.3 percent since 1987 (Gollin, 2018), reflecting a number of technological changes including using software to improve purchasing, inventory, and warehouse management, bar codes to improve checkout, automated card readers to speed up payment, and most recently, e-commerce and automated checkout (Gaus &

25 W. Baumol's famous question "How do you increase the productivity of a string quartet?" is still sometimes used to characterize the lower growth and productivity potential of the service sector.

Hoxtell, 2019). The air transport sector loads and unloads passengers and freight faster by using barcodes and sensors to manage the process. Tourism is planned online; the occupation of travel agent has almost disappeared in high-income countries (Acemoglu & Restropo, 2019). The healthcare sector has substantially automated by using robots and sensors, as well as modern software to manage complicated supply chains more effectively. 4IR technology, including platforms, is spurring the development of e-commerce, the gig economy, and crowdsourcing (e.g., online contracting for discrete tasks carried out virtually). All these changes, by lowering costs and raising quality, have helped expand employment in the service sector in rich countries (Arntz et al., 2016; Gollin, 2018).

This cost-lowering, quality-improving technology has also arrived in Africa, but adoption has been limited, resulting in an increasingly segmented services sector. Low-tech informality coexists with high-tech formal services. In urban areas, the retail sector includes modern supermarkets and "big box" stores using much of the latest technology, but these exist alongside informal roadside stands, kiosks, and market stalls (Fox & Sohnesen, 2016). Productivity improvements in domestic freight transportation and logistics are few as of yet, and as a result, costs are high and delays are frequent, especially in the LICs and LMICs of SSA (McKinsey, 2018; World Bank, 2018). While internet use is common in large businesses (87 percent), only 16 percent of self-employed people report using the internet (AUC/OECD, 2021). Exceptions to this low-tech story can be found in airports (including air freight) and high-end hospitality, which use all the latest technology to provide the level of service that international travelers expect, as well as in the financial sector, where Africa has the highest rate of mobile money adoption in the developing world (66%; AUC/OECD, 2021).

Service sector output and employment is expected to grow rapidly in Africa, reflecting both increased demand as incomes rise, and ease of entry into service sectors for Africa's growing labor force, especially in the case of informally-supplied services. Demographic dynamics, especially in the lower-income countries, imply that low-tech, informally supplied services will continue to offer employment opportunities for a large share of youth entering the labor force, even as formally supplied services also increase their employment share. The question is, in what ways can 4IR technology contribute to better employment outcomes? The business models and employment dynamics in the sectors where formal firms dominate versus where informal firms dominate are quite different, so it makes sense to consider their potential to adopt 4IR technologies separately.

Services primarily provided by formal firms

Several authors consider the formal African service sector to be the next export frontier as well as a source of higher-earning, more productive jobs if 4IR technology is adopted. Newfarmer et al. (2018) argue that many service sectors share similar characteristics with export manufacturing, including capacity for productivity growth, agglomeration economies, and the capacity to create better jobs. Between 2002 and 2015, Africa's service exports grew more than six times faster than merchandise exports (Newfarmer et al., 2018). One example is the tourism sector. Consumer spending on tourism in Africa is projected to double between 2015 and 2030 (Signé, 2020). Tourism has been a major source of income growth and jobs at multiple skill levels, including both customer-facing jobs, which tend to require higher skill levels, and low- and medium-skill jobs in cleaning, transport, maintenance, etc. In Tanzania, tourism accounts for 14 percent of GDP; in South Africa, it creates 36 percent of jobs in the food and beverage sector (Page, 2019). Big data analysis and cloud computing are changing the tourism industry. Digital tools allowing airplane passengers to book flights and check-in online are already staples of the airline industry, as noted above. The cloud, AI, and blockchain may be able to further facilitate travelers' access to transportation or other services. For example, the international expansion of Uber and the development of local ride-hailing transportation platforms provide a safer environment for international passengers. Many countries already use the internet for international tourism visas, vastly improving the customer experience before arrival at the border. Blockchain has the potential to improve the security of the visa and entry process for international travelers if governments adopt the technology. Meanwhile, smartphone-based navigational mapping technology has been extended to the majority of African capitals and other large cities, supporting both tourists and local transportation. Photos posted online on various platforms (social media and others) attract travelers to Africa's unique geological and historical sights.

Baldwin (2019) argues that 4IR technology, which has drastically reduced the cost of face-to-face communication, will enable a massive globalization of customer-facing services, creating vast new opportunities for decent jobs in developing countries. Africa's lower wages relative to rich countries could once again be a source of comparative advantage. Expansion of the internet has already enabled the business process outsourcing (BPO) export business in non-customer-facing services, including call centers, digital data entry and processing (e.g., insurance claims processing, basic accountancy services), and software development. Africa's share in this market is small, however, compared to BPO powerhouses such as the Philippines and India (PfPC, 2018). It is not clear that this "first-wave" BPO is a growth sector now; much first-wave BPO business will soon be replaced by robots, AI, and IoT technology, and may then go back to rich countries through onshoring. For example, "chatbots" are replacing call center outsourcing (PfPC, 2018). Baldwin (2019) predicts that a "second wave" may emerge, however, more focused on customer-facing skills and enabled by video communications software. Banga et al. (2020) and Baldwin (2019) note that Africa's southern and often landlocked geography, a disadvantage in manufacturing, will not matter for future service exports as no products need to be transported. COVID-19 lockdowns have demonstrated that high-speed broadband technology and conferencing software eliminates the need for everyone to be in same place, so it will be much easier for firms to contract out business services to lower wage economies.

While Baldwin's predictions may hold for Asia, opportunities in Africa could be significantly lower. Murray (2018) notes that:

> "*Competitiveness in online service exports typically requires a combination of fluency in an international language, cultural understanding or technical skills, and competitive wages*."

Service exports (as opposed to domestically sold services) usually require ***higher skill levels*** than manufacturing or agricultural exports, and a competitive wage. Most of Africa is at a skill disadvantage compared with Asia; the exceptions are South Africa and some countries in North Africa. While African wages are low in PPP terms (that is, the cost of living) they are high in USD, especially for workers with post-primary education (Gelb et al., 2020). Thus, service exports based on Africa's other sources of comparative advantage (such as natural resource-based tourism) or designed for a regional market (e.g., Nollywood in Nigeria, which now employs over 1 million people) may grow rapidly and create new employment opportunities, but Africa's prospects in the second wave of BPO may be less rosy.

Services for domestic or regional markets show more potential for formal wage employment expansion. Formal retail operators, both stores and e-commerce, have already been a growth sector in terms of both output and employment, and this trend can be expected to continue. E-commerce operators have some of the largest employment impact of any digital start-up. For example, Jumia Group, the Nigeria-based e-commerce company, had over 7500 employees in 2020 (AUC/OECD, 2021). Interestingly, larger companies co-exist with small household-based e-commerce operators who sell a limited range of high-volume items such as electronics (Technopolis, 2019). E-commerce operators in Africa face several challenges, including cross-border payments and logistics, but 4IR digital technology is enabling fintech companies and the private logistics sector to become a growth industry, responding to this demand. As e-commerce takes off, both through B2B and B2C business models, start-up entrepreneurs are setting up digital platforms linked to brick-and-mortar warehouses and are contracting with transport providers to provide the services start-ups need. Individually, these companies are not large employers: for example, Kobe360, a well-known Nigerian company, had only 149 employees in 2020, while Twiga foods had 275. But through their links with farmers and independent truckers, they help stabilize incomes in both sectors.

Digital technology in Africa (3IR and 4IR) has arguably been most disruptive, and most beneficial in terms of employment outcomes, in the financial sector. Mobile money, invented and developed in Kenya, has revolutionized banking in Africa, in the process creating jobs for over 240,000 self-employed agents in Kenya alone (AUC/OECD, 2021). As a result of its expansion, Sub-Saharan Africa lags in formal bank accounts per person but leads the world in terms of digital financial usage per capita (Chironga et al., 2018; Signé, 2022). Mobile financial services have expanded from savings and payment accounts into credit, insurance, and cross-border remittances, all of which help businesses to survive and, depending on scale, to employ workers. There is significant scope for further improvement and for new applications using 4IR technologies such as blockchain and machine learning. Advanced analytics and machine learning are already being used to increase the accuracy of credit risk models. In Kenya, IBM has analyzed purchase records from mobile devices and then applied machine learning algorithms to predict creditworthiness, giving lenders the confidence they needed to provide $3 million in loans to small businesses, some of which are owned by youth. Studies have documented the positive impact of fintech services on the performance and growth of micro, small, and medium (MSM) enterprises throughout Africa.

Numerous studies (mostly done in Kenya) have also documented the effect of mobile money on non-farm informal business profits and SHF access to credit, as well as positive effects on women's economic empowerment. In addition to documenting the poverty-reducing impacts of the mobile money service M-pesa's rollout in Kenya, Suri and Jack (2016) also showed that access to M-pesa accounts, by increasing and protecting women's savings, allowed women to move out of subsistence agriculture and start new non-farm businesses. Women owners of informal businesses in Tanzania who received training on the use of an MFI linked to M-pesa saved almost four times more than the control group used for measuring project impact, and were 16 percent more likely to receive a loan (World Bank, 2019b). In Niger, women who were given access to mobile money savings accounts increased their earnings from their economic activities and their bargaining power in the household (Ahmad et al., 2020). The adoption of uniform national identity systems, often through biometric identification (another 4IR technology), has helped improve system security and functioning and has enabled the system to receive international payments and remittances. Access to mobile money platforms is not equal across Africa. Countries with nimble and enabling regulatory systems such as those in East Africa have seen rapid growth in accounts, and clear benefits. Kenya leads all other countries in SSA in mobile money accounts per capita, while adoption of these financial innovations in Central and Southern Africa and North Africa (Morocco and Egypt) remains relatively low (AUC/OECD, 2021).

4IR technologies can benefit formal financial institutions as well. In the U.S. and U.K., they are already breaking down the barriers between online and traditional, brick-and-mortar banks. Africa's retail banking penetration remains low, at just half the global average for emerging markets (Chironga et al., 2018). Retail banks struggle to find consumers given widespread low income levels, the popularity of cash, high fixed costs and thus high fees for small accounts, and little information about individuals' credit (Chironga et al., 2018). As noted above, 4IR-enabled digital solutions can be used to improve credit risk models and operational risk and compliance, and can reduce fixed costs by reducing the need for branches. Digital credit risk management, for example, uses automation, connectivity, and digital delivery and decision-making to allow for faster decisions and superior risk assessment than is possible with current manual processes (Signé, 2022). Blockchain technology could revolutionize payment systems, allowing contracted payments to be executed directly upon fulfillment of contract conditions, without an intermediary. This would substantially reduce transaction costs in Africa.

Services sectors such as formal finance (and ICT), while expected to grow rapidly as a share of output, are not currently large employers in Africa, and this is not expected to change very much. But, like the energy sector, they are indirect job creators. Both sectors are likely to continue to benefit from 4IR technology adoption as well as to support adoption in other sectors.

Services mostly provided by household enterprises and self-employment

Several studies are optimistic that a large swath of self-employed, family-employed, and dependent-contractors will be able to raise their earnings and "formalize" through 4IR technology (PfPC, 2018; Choi et al., 2020). For example, most of these family and micro-business operators face market fragmentation, and thus have trouble connecting with customers and occasionally with suppliers. Significant earnings gains have already been realized in this sector through the improved communication and access to finance the spread of mobile telephones has made possible. Optimists point to the potential role of digital platforms in connecting service providers and customers, reducing down-time for household business owners and search time for customers. The e-commerce platform Alibaba has helped many family businesses in China connect to the vast domestic and international market by reducing customer discovery and transaction costs. Transportation platforms have made the process of ride-hailing—supplied by informal sector drivers of cars or motorcycles—more efficient, providing a much better service for customers and safer working conditions for drivers (PfPC, 2018). They have also contributed to the expansion of e-commerce by enabling informal bicycle, motorcycle, and taxi drivers to provide on-demand delivery services for vendors, including food service, creating more and better informal sector jobs in the process.[26] It is envisaged

26 Most drivers are required to register their vehicle with the local municipality (if they own it; if not, the owner should do so). They also must get a drivers' license, so they are not completely informal. However, these drivers rarely have a business license or a business bank account separate from their personal one, so they would not be considered formal.

that these platforms could soon be used routinely to request and book services delivered in-home by informal service providers such as hairdressers and manicurists, as well as to find a reliable self-employed craftsperson (e.g., plumber or gardener/home repair person).

However, aside from improving efficiency for on-demand drivers, the promise of 4IR technology seems elusive in the face of the reality of the African non-farm informal sector. Most workers are in the informal sector because of a shortage of wage jobs on offer in the economy, not because of entrepreneurial drive (Fox et al., 2020; Lorenceau, 2021). They are poorly capitalized. The majority are in retail trade, selling a broad range of products to households (Filmer & Fox; 2014; Fox & Sohnesen, 2016). They sell these items in small kiosks, in market stalls, or by the side of the road. In many cases, they are patronized because they (i) they are convenient, or (ii) they sell items in small quantities, matching the cash flow of their customers (e.g., they sell a few tomatoes, less than a full pack of cigarettes, small quantities of cooking oil or dish soap, etc.). Informal business owners also perform services for household members, including personal services, custom dressmaking/tailoring, and repair of small items. They run small hospitality businesses such as renting out a room in their house (small hotel), or operating a small bar or fast-food restaurant.[27] In most cases, informal sellers of goods and services cluster in specific areas, so customers can find them, or they work at home. Some have regular street locations while others roam the streets looking for customers. Their advertising is word of mouth. Their use of technology is extremely limited. While most have a mobile phone to connect with customers or suppliers and use mobile money, as noted above, use of the internet is rare.

The business models are simple, and for this reason, attempts to "formalize" them have had limited success (Bruhn & McKenzie, 2014).[28] The issue is not whether they pay taxes or register their business—in most cases their earnings are low enough to slide under the floor for paying taxes, and often they get charged taxes (or fees or bribes) by local authorities. The issue is how these workers can reduce their precarity. Would the use of mobile platforms to sell home-made products (such as Etsy in the U.S.) lead to more stable income and more reliable payment, as platforms seem to have done for drivers in countries such as Mexico and India? We do have evidence that expansion of mobile phone technology has allowed people (mostly women) to leave subsistence agriculture and start businesses, and this has raised their earnings (AUC/OECD, 2021). We do not yet have evidence on the use of internet platforms by informal household businesses in Africa. Would an electronic record of transactions simply lead to higher taxes, or could it also lead to access to an improved safety net? Most importantly, is the public sector prepared to help the informal sector make money and keep their businesses going, rather than treating them like a pariah, to be eliminated as part of urban cleanup efforts (see the discussion in Chen & Carre, 2020). These are not technology issues; they are policy decisions that precede even 3IR.

Some have argued that 4IR technology is a boon for women working in the informal sector, who earn less than men (Chen & Carre, 2020). These women often end up working from home owing to the burden of unpaid household responsibilities and/or the hazards of leaving home such as unsafe public transport, workplace harassment, or norms which punish women's mobility. Broadband internet allows these women to take on services activities on a flexible schedule (see citations in Hunt & Samman, 2019, section 3). However, all is not a bed of roses for women homeworkers. Hunt and Samman (2019) point out, women in Africa are more likely to be present in crowdwork, which as noted above, is low-paying. Meanwhile, in the on-demand economy, patterns of occupational segregation persist: men still dominate the transport sector, for example (perhaps because women have limited opportunities to learn to drive). Hunt and Machingura (2018) show that technology is reinforcing old discrimination patterns through platform ratings and review systems. Chen and Carre (2020) document the isolation often felt by informal home-based workers, which leaves them vulnerable to exploitation. Once again, social equity is not a technology issue—it is related to culture, norms, and patterns of human engagement.

In sum, as economies grow, demand for services increases. Formally-supplied services, which provide formal jobs, tend to have a high income elasticity of demand owing to their higher quality. Wage jobs, mostly formal, can be expected to increase in this sector. Exported services could become a significant, if not large, source of wage and nonwage employment, both through platforms and through contracts between formal firms. Domestic retail trade is likely to be a major source of future employment as business gradually shifts away from informal traders. The extent of informality in some occupations and

27 For a detailed description and analysis of this sector in SSA, see chapter 5 of Filmer & Fox, 2014.

28 Projects to "formalize" informal non-farm household businesses involve several different interventions, ranging from business registration (originally thought to be helpful for obtaining finance) to setting up a business bank account.

sectors may decrease, improving jobs on the intensive margin (earnings, income stability, and safety). For example, the tourism and hospitality sectors as well as associated taxi and delivery sectors may become less informal through platforms, in part to cater to higher spending customers. Employment in the gig economy for drivers is so far an improvement over previous employment relationships, but for home-based workers the evidence is thin on whether employment conditions have improved.

Nonetheless, most employment in the service sector is currently informal, and is likely to remain so, at least in lower-income countries, in part due to the pressure of labor supply—a growing labor force. Household enterprises (HEs) are poorly capitalized businesses with limited scope for technology adoption.[29] If internet usage prices fall substantially, informal service suppliers may start using it to their benefit, setting up websites, for example, and advertising on social media sites such as Facebook.

Africa's youth will compete for both formal and informal employment opportunities in the growing service sector. Formal jobs in start-ups such as Jumia and Twiga Foods require more education and internet savvy, which favors youth, as will jobs in "second-wave" BPO companies. But most youth entering the labor market over the next 10 years will not have this level of education. They will start small household service businesses. They will mostly likely apply their longer experience with, and better knowledge of, technology to get ahead. This may allow them to expand the overall market, which would raise incomes for all, as opposed to taking market share away from less productive HE owners in their sector.

Overall, our conclusion is that apart from economies with an already high share of wage employment (e.g., 70 percent or higher), the main potential employment impact of the adoption of 4IR technologies in production processes is higher earnings for nonwage employees, on the farm and in HEs (agricultural and service sectors). With respect to wage employment, 4IR technology will not support a significant expansion of formal wage employment in manufacturing. It will probably bring about a contraction in employment, although the time frame is uncertain. The only hope in countries without a large manufacturing sector is if 4IR technology (mostly 3D printing) supports the emergence of a niche manufacturing sector. 4IR technology could support an expansion in wage employment in service sectors such as BPO, tourism, logistics, and wholesale and retail trade, including e-commerce. This expansion is likely to start first in the economies which already have a substantial number of exporting firms and wage employment, and in the case of expanded BPO, where broadband connections are fast and reliable enough to support video-conferencing and international customer interactions.

29 See Filmer and Fox, 2014, chapter 5 for a detailed discussion on the charaterisitics of household enterprises (HEs) in Africa.

4. Skills, Labour Demand, and Productivity

Unlike the technologies of the first and second Industrial Revolutions, which were biased toward lower skilled workers, and brought millions of unskilled workers around the world into factories but put skilled artisans such as blacksmiths and hand weavers out of work, both 3IR and 4IR embody skill-biased technological change (Rodrik, 2018; Acemoglu & Restrepo, 2019). Routine tasks that are non-consumer facing are being eliminated around the world by digital and 4IR technology, which has an absolute advantage over humans in many tasks, especially those that are routine, physically demanding, and/or dangerous. As Rodrik (2018) and other have noted, this reduces the comparative advantage of African countries in global trade – their low-wage, low-skill workforce.

One overarching recommendation often found in reports on 4IR and developing countries to counter the loss of comparative advantage is to raise the skill level of the labor force up to the needs of 4IR technologies, especially in the post-secondary STEM skill areas (Naude, 2017; Technopolis, 2019; AU/OECD, 2021). This recommendation deserves further scrutiny. Post-secondary STEM skill development, especially engineering, is very expensive compared with social sciences or humanities (or even secondary education) and African countries already face a shortage of technically-trained graduates in these fields. More importantly, despite a rapid expansion of educational access, African countries still need to expand infrastructure at the primary and secondary levels in the years to come owing to past high fertility, which every year expands the need for places at all levels just to maintain current progress. The quality of basic education is an issue as well. ***This means that with limited resources, African countries face tough spending tradeoffs.*** Expanding expensive post-secondary education could leave few resources available for needed improvements in the primary and secondary system which will develop most of the future labor force, especially those who will make a living in the informal sector, trying to use 4IR technology to raise earnings. This trade-off is often ignored in discussions on the future of work and 4IR technology, which tend to focus on the demand for post-secondary skills in formal firms. We explore this trade-off in more detail below.

SSA's workforce is the least skilled in the world. Despite recent catch-up, Africa's youth lag behind their counterparts in other regions in educational achievement, and this situation is expected to persist (AUC/OECD, 2021). Primary and secondary education systems in LICs and LMICs in SSA currently face a learning crisis (World Bank, 2018). While major progress has been made in access to basic education (primary and junior secondary), too many students in too many African countries leave school without mastering the skills that they need (Arias et al., 2019). For example, an analysis of learning outcomes in SSA based on the most recent data showed that only 15 percent of primary students in their final year possess a minimum proficiency in mathematics (Arias et al., 2019).

In SSA, where 40 percent of students are stunted by age 5, and thus disadvantaged for life in learning capacity, the basic skill development needs of the future labor force cast a huge shadow over current educational and social policy and priorities (Arias et al., 2019). The most effective period for learning is the first 1000 days of a child's life. Yet early childhood development programs are rare in SSA; only 0.3 percent of public expenditures on education is allocated to this level in SSA (World Bank, 2018, 2019a). It is difficult to remedy these deficiencies later; learning occurs less rapidly as minds mature.

Skills deficiencies in the basic education system constrain the region's transformational potential (Choi, et al., 2020) and reduce the inclusiveness of economic growth. Informal sector operators as well as low-skilled labor in the formal sector rely on the basic education system to develop the skills they need for productivity and earnings growth. For example, if effective and low-cost provision of training and information to farmers on what technology to use when and how to improve crop management is the route to higher earnings, then farmers need to be able to absorb this information and use it effectively (Fabregas et al., 2019). This requires literacy and basic cognitive and problem-solving skills. Many proposals offered up to increase job mobility and ensure the labor force remains productive and in demand over their lifetime call for the development of "lifelong learning systems" and increased on-the-job training (World Bank, 2019a). But skills beget skills, so children need first and foremost ***to learn how to learn early on in their education process***, otherwise life-long learning cannot be a reality (World Bank, 2018). Furthermore, development of higher-order skills (including technical and vocational skills) requires the foundation of basic cognitive skills (World Bank, 2018).

Post-secondary education systems are struggling as well. Outside of South Africa and a few universities in Egypt, the quality of education in African universities is low. Tests in Kenya and Ghana showed that university-educated, working adults could not pass basic tests of reading comprehension (Arias et al. 2019). Particularly concerning, given expected future demand, is that engineering graduates in SSA are low in quantity and in quality (Arias et al., 2019). Africa currently has a misalignment between the skills taught in post-secondary education and the skills demanded. Already, employers in medium and large firms in SSA, especially exporters, report that inadequate technical education can be a constraint on firm growth (although not as important as other factors such as energy supply and costs, for example; see Arias et al., 2019). Yet the highest unemployment rates in LMIC countries are among university graduates, who may spend several years trying to get a job (Filmer & Fox, 2014; Fox et al., 2020). The cost per student at African universities is quite high compared with other developing countries (Arias, et al., 2019). Universities have little interaction with the local labor market, and face no pressure or incentives to improve the relevance of their curriculum. In some second-tier universities in SSA, graduates lose money over their lifetime by going to university—they would have been better off putting the money in the bank (Arias et al., 2019).

TVET programs in Africa also mostly fail to deliver value for money (Arias, 2019). Curricula and teaching methods in Africa are predominantly stuck in the mid-20th century, when a narrow set of vocational skills training was adequate for a lifetime of work. TVET systems have poor linkages with employers and do little outreach to understand and meet employer needs. Too often, TVET in Africa is offered as a substitute for general secondary school. But 21st-century technical jobs in sectors such as health, manufacturing, machine/appliance repair, or ICT require a base of general education, especially in math and science, at the higher secondary school level. Secondary level TVET is between 2-6 times more expensive than general secondary education, raising questions about sector expansion given the need for more students to complete general secondary school. A study in Egypt concluded that TVET graduates lost lifetime earnings by attending these institutions (Krafft, 2018); similar results were found in Kenya (Hamory Hicks et al., 2016).

Africa's future workforce skill needs are considerable, and include technical and engineering skills needed for adapting and adopting new technology, (e.g., skill for the production, maintenance, and repair of robots, drones, and networked computer systems); health care skills for a rapidly expanding sector; elementary digital skills in all sectors to apply 3IR technology and advanced digital skills in professional occupations; managerial and entrepreneurial skills; and socio-emotional skills such as adaptability, communication, collaboration, initiative, grit, and self-regulation (Signé, 2020; Choi, et al., 2020). Africa is not currently producing enough of any of these skills, and all require the foundation of basic cognitive skills. African governments face several options to meet these needs.

(1) ***Focus on improving the quality of primary and secondary education***. This would include improving teacher qualification and better training in pedagogical methods. Studies show that in Kenya, for example, only one-third of grade four teachers in public schools had the minimum knowledge necessary to teach the grade (Bold et al., 2017). Pedagogical methods in most SSA countries are out of date, emphasizing rote learning over critical thinking and problem solving. Old fashioned rote learning systems are not effective at building learning skills. Changing this situation requires investments in teacher training, new equipment, and instructional materials, including computers. Currently most secondary schools in SSA LICs and LMICs do not have access to computers for teaching purposes; if they did, it is not clear that their teachers would know how to deploy them as a learning tool (Technopolis, 2019). In countries where fertility is still high and the school-age population is growing rapidly there is constant need to expand education infrastructure (build schools, print textbooks, train teachers). Improving teacher quality while expanding access will be difficult, but is necessary (Bold et al., 2017); increases in system efficiency are required.

(2) ***Focus on developing STEM skills in TVET and universities***. As noted above, African universities are already high cost. Within the university departments, instruction and materials costs for credit hours in engineering, physical sciences and health sciences are 2-3 times the cost of credit hours in social sciences and humanities (Altonji and Zimmerman, 2017), which is one reason that university places in these disciplines are expanding much more slowly than demand in Africa. Some have suggested that the best response to developing the 21st century skills needed in Africa is to expand vocational education and training (World Bank, 2019b; AUC/OECD, 2021). This also expensive, and to be successful would require a major system restructuring.

Countries which focus most of their public sector resources on the first option could produce a labor force with a broad range of cognitive (literacy, numeracy), basic digital, and socio-emotional skills. These future workers could be ***productive in all sectors expected to adopt 4IR technology*** as they would be able to learn about new technologies (including basic 4IR technologies) and production processes and apply them in formal or informal employment. They would not, however, have the skills to innovate with these technologies. Countries which focus most of their resources on the second option would produce a small set of graduates able to adapt, innovate and adopt the most advanced and productive of 4IR technologies. The question is whether under option (2) most of the labor force would be able to benefit from 4IR technologies at all. Inclusiveness matter, although country context will determine the balance chosen.

Africa is often faulted for having limited entrepreneurship skills (Technopolis, 2019). Starting and growing new firms which use 4IR technology is critical to expanding opportunities for wage employment, and for productivity growth. Experience with entrepreneurship education and training in Africa has thus far been lackluster. While secondary and tertiary entrepreneurship education programs seem to be successful at developing the mindsets and skills closely tied to entrepreneurship (such as self-confidence, leadership, creativity, risk propensity, motivation, resilience, and self-efficacy; see Valerio et al., 2014; AfDB, 2017), a recent evaluation of several African programs concluded that students who completed the program could not start their own businesses after graduation (Choi et al., 2020). Programs that target existing entrepreneurs tend to be more successful on metrics of business growth and profitability (Valerio et al., 2014). Country context matters as well; in countries with a poor business enabling environment, outcomes from entrepreneurship education and training are worse (Valerio et al., 2014).

In sum, Africa needs improvements in quality at all levels of education to deliver the skills that will be demanded and rewarded in tomorrow's economy. These skills needs are much broader than digital skills. 4IR innovations will require the African labor force and students (young people) to develop a broader and more diverse skillset that can add value to new systems of production/marketing/selling/service. To achieve this, quality basic education needs to be available to all, and both cognitive learning outcomes and socio-emotional skills need to be prioritized and delivered in a cost-effective manner. Africa's higher education system, which will be responsible for training the high-skill labor to complement 4IR technology, has expanded rapidly owing to increased demand, but needs a quality upgrade. An increased focus on educational relevance and on providing the skills needed to participate in working life of today and tomorrow is critical to ensure that skills are not the binding constraint as to whether an economy can participate in 4IR. Possible solutions to the complex skills gap and mismatch challenges, including how to balance the public expenditures tradeoffs, are discussed in the next section.

5. Key challenges and strategies to capitalize on the fourth industrial revolution and ensure quality job creation and inclusiveness in the labor market and beyond

One common theme is present throughout the discussion in the previous sections: realizing the potential economic growth and employment opportunities of 4IR technology in Africa depends on government action. Many authors have broadly discussed the challenges governments face in harnessing the potential of productive technologies (including 4IR) for quality job creation (AUC/OECD, 2021; Choi et al., 2020; Calderon et al., 2019; Solutions for Youth Employment, 2018). These authors have identified human capital, physical capital, regulatory frameworks, inclusive policies, access to technology, and access to finance as the main barriers preventing digital transformation. In the context of the COVID-19 pandemic, the challenges faced by governments have substantially increased. The shift in donor aid flows and public expenditure toward health and social protection, combined with the suspension of education and training have drastically complicated governments' ability to direct resources towards enabling investment to improve employment opportunities. These challenges are more prominent in lower-income countries, where essential infrastructure is still lacking, and public resources are scarce. It is therefore important to understand the challenges that governments face in creating an environment that will allow 4IR technologies to positively impact employment and economic growth, and to explore options to address these challenges.

Challenge 1: Governance - Inadequate regulatory frameworks and business environments

Despite the variation across countries, it is well established that weak governance and Africa's poor regulatory frameworks - which create challenging business environments - currently hinder firm entrance and growth, a prerequisite for increasing the amount and share of formal wage employment (AfDB, 2018). Africa's excessive red tape and corruption deter both domestic and foreign investment and cost jobs (AfDB, 2018). As a consequence, fewer firms enter and grow, thus creating fewer new formal wage jobs—the essence of decent work. These regulatory frameworks also inhibit an upgrading of the mechanical and managerial technology needed for African firms to remain competitive in a globalized economy, including adaption and adoption of 4IR technology (Choi et al., 2020; AUC/OECD, 2021).

Governments regulate contracts and payments systems, but these regulations usually do not permit the use of blockchains for financial transactions without the intermediation of a third party, or for customs documentation or healthcare records (The Law Library of Congress, 2018). Legislation to develop a single digital identity for residents is also needed in about half of African countries, in order to enable mobile finance 2.0 and blockchain-based transactions (Signé, 2022). At the same time, governments are scrambling to effectively regulate drones, as these have only recently arrived on the scene (Technopolis, 2019).

Furthermore, the business legal environment (regulations and implementation) does not sufficiently encourage importation of 4IR investments. Some countries still tax digital equipment imports heavily, viewing them as a luxury rather than the necessity they have become. FDI is increasingly important for gaining access to 4IR technologies. However, despite recent increases, FDI in Africa remains low, at around $46 billion in 2018, and little of this FDI is directed towards the ICT sector or the adaption and adoption of 4IR technology (UNCTAD, 2019).

4IR brings new challenges to public sector regulators, such as insuring cybersecurity. Cybersecurity is crucial at the individual, corporate, leadership, and systems level. Cybersecurity will take on unprecedented importance as cyber-warfare expands, and the increasing interconnection of systems and the importance of data provides new targets for attack. Capitalizing on 4IR requires effective cybersecurity to protect critical infrastructure, digital data systems, and ensure the sustainability of the firms creating jobs. With any digital infrastructure development, governments must implement legislation to protect the data and privacy of their citizens and critical infrastructure to avoid disrupting firms with cyberattacks, as it could impact jobs.

Access to finance is one of the biggest challenges for high-tech companies, not only for technology acquisition but also for scaling operations. 4IR technology is expensive, and these high fixed costs need to be financed. Limited access to finance is a major obstacle to firm entrance, survival, and growth, especially for young entrepreneurs: it hinders the adoption of digital solutions and impedes the creation of employment opportunities across sectors. Capital costs in Africa (interest rates and fees) are among the highest in the world, and spreads are high (Chironga et al., 2018). While this is partly caused by the economies of scale involved in the banking industry today, which makes a competitive banking sector less feasible in small and/or poor countries, it is also related to the lack of public sector risk-reducing institutions such as loan registries and credit bureaus. High-speed internet allows these information systems to be created entirely online, reducing the costs to participants, but limited access to high-speed internet constrains this option.

Solution 1: Revise regulatory frameworks, improve business environments, and create inclusive policies

Restructuring regulatory frameworks is required for effective innovation policies (Oyelaran-Oyeyinka, 2014) and to capitalize on the 4IR technology to ensure quality job creation (Ndung'u and Signé, 2020). As the use of ICT in banking has shown, governments must be nimble to keep up with new products and services, encouraging technology adoption and protecting consumers while avoiding over-regulating. The ease of doing business depends on reforming government legislation, regulatory policies, and implementation, including service provision. Such reforms should aim at facilitating the legal process of creating a business, obtaining licenses, and registering intellectual property, thus allowing firms to enter the market faster and more efficiently (Signé 2020).

It is also important that standards, rules, and regulations be firm-friendly for domestic and Foreign Direct Investment (FDI) - especially in terms of intellectual property ownership (Deutch, 2005; IFC, 2016). Increasing FDI has enormous potential to accelerate digital transformation and innovation among firms. Beyond the skill and technology transfer that comes along with FDI, policies that attract FDI can ultimately bring more confidence about the market to domestic firms (PwC, 2010; IFC, 2016). FDI can also work indirectly by fostering global industry networks.

A stronger, deeper, and more efficient formal finance system for medium and large enterprises (those employing more than 50 workers) will be critical to 4IR technology adoption in Africa. Countries can encourage development of new sources of finance for 4IR technology adoption from inside and overseas by encouraging web-based platforms, including more equity-based and early-angel investor financing. Other forms of finance, such as trade credit, can be enabled through blockchain technologies, which remove the need for an intermediary, thus reducing financing costs (Technopolis, 2019). Public-private partnerships will move sectors' interests forward by offering new financing models, including the "pay-as-you-go" method (Deutch, 2005; IFC, 2016).

Governments can achieve necessary reforms by adopting digital and 4IR technology themselves, to simplify administrative processes and create more economic opportunity for entrepreneurs. Additionally, digitalizing tax collection could create more revenue the government can use to fund human or physical capital projects (AUC/OECD, 2021). For example, Kenya's government, legal institutions, and central bank have taken concrete steps to prepare for 4IR: the government has adopted open data and e-government solutions, created a national digital identity framework, increased funding for R&D, and is proactively playing a role in encouraging the further development of M-Pesa and other fintech solutions.

Government should address cybersecurity at the systems level, but also engage with firms to find cybersecurity solutions at other levels. Ensuring the security of systems requires both new legislation (e.g., data privacy laws) and access to the necessary tools such as cutting-edge data encryption software. It is essential that African governments pursue global multi-stakeholder engagement for data security and sufficient protections for the privacy rights of citizens (AUC/OECD, 2021). Other recommendations include developing a cybersecurity agency dedicated to firms and citizens, as opposed to only national intelligence and defense or internal government agencies, as well as to create an accreditation service for providers, and an emergency response plan for cyber-attacks at the firm level (Fadia et al., 2020).

Tax reforms, including investment and employment tax incentives, as well as technology adaptation, adoption, and R&D tax incentives, are also widely recognized as key tools to encourage innovation, quality job creation, and social inclusion (World Bank, 2019b; Choi et al., 2020; PricewaterhouseCoopers, 2010; AUC/OECD, 2021; Deloitte, 2018; Millington, 2017). Numerous African countries (including Rwanda, Cameroon, and South Africa) use a broad variety of tax incentives (including extraordinary tax benefits, exemptions, government grants, employment tax incentives, and preferential corporate income tax) to attract domestic and foreign investments in priority sectors, as long as investors meet the minimum requirements in terms of investment levels and number of jobs created, among other factors (KPMG, 2017). The effectiveness of these employment tax incentives is mixed; sometimes there is no follow-up once the investment is complete so the effectiveness is unknown and probably limited (Ebrahim et al, 2017).

South Africa may be succeeding in using incentives effectively. The R&D Tax Incentive was introduced in November 2006, along with other measures to stimulate private sector R&D. This example shows how tax incentives can be part of broader institutional support for innovation and R&D: the incentive is overseen by the Department of Science and Technology, which also manages a variety of programs and agencies that promote innovation, including the Technology for Human Resources in Industry Program, which encourages R&D collaboration between the private sector, universities, and science councils, and the Technology Innovation Agency, which funds strategic technological innovation with the aim of commercialization (Naudé, 2017). For such tax incentive mechanisms to be effective, corruption and clientelism must be minimized, as they must also be in broader public and private governance.

Finally, in the context of the African Continental Free Trade Area, which aims to create a single market between 55 African nations, governments should also accelerate cooperation to remove roaming fees at the continental level and to successfully harmonize or integrate payment systems and cross-border payment mechanisms to accelerate intra-African trade, especially e-commerce and trade in services (Fofack, 2020).

Challenge 2: Gaps in physical and digital infrastructure and limited access to technology

Many of the productive innovations and technologies associated with the Fourth Industrial Revolution build on critical physical and digital infrastructure, whether electricity, internet backbone, fixed broadband, mobile telecommunications, communication satellites, network infrastructure, data centers, cloud computing, or others. Expanding electricity and transport infrastructure, and, more recently, ICT infrastructure, is one of the biggest challenges faced by African governments.

Reliable and affordable electricity is a prerequisite for 4IR technologies, and is critical in numerous sectors with high job creation potential. In 2017, not even half of households in SSA had electricity (BC, 2019) and electricity is expensive compared with other developing regions (Signé, 2018). Unreliable electricity can damage or reduce the efficiency of expensive 4IR machines. For example, blockchain technology is a major user of energy owing to its computation requirements; cloud computing also needs reliable energy to keep its servers running and fuel the required cooling systems (Signé, 2022). Africa's infrastructure deficit, including in electricity, is longstanding and dates back to the colonial period. The effects of this on employment and earnings, especially in the informal sector, are well documented (Filmer & Fox, 2014; Bond, 2016; AfDB, 2018).

Despite growing recognition that access to the internet provides high social benefits that exceed cost (AU/OECD, 2021), many countries are still lagging in basic digital infrastructure (Ndung'u and Signé, 2020), particularly in rural areas, which are home to over two-thirds of African youth, the continent's future workforce (AU/OECD, 2021). While access to mobile phones in Africa has expanded faster than anywhere else in the world since 2010, too many households, especially in rural areas, still do not have access to mobile telephone connections or mobile internet (Leke & Signé, 2019). The main reason is the high price of mobile internet connectivity, in large part due to import tariffs on infrastructure materials and the common practice of governments imposing inconsistent fees and unequal taxation on ITC firms (BC, 2019). In US$, the average price for a low-usage package in Africa is below the average for all developing countries, but in PP$ or as a percentage of GNI it is quite high. On average, users pay 8.25 percent of their monthly income to purchase 1GB of mobile data, compared with the UN Broadband Commission target of 2 percent (Latif Dahir and Kazeem, 2018). Notably, Africans who are able to afford 1GB of mobile data account for less than one-fifth of the population (AU/OECD, 2021).

Solution 2: Increase access to technology and close the gap in physical and digital infrastructure, especially in sectors with high-quality employment potential

Closing the physical and digital infrastructure gap to address employment will require bold action by African leaders, including capitalizing on 4IR. 4IR technology offers some solutions to reduce the electricity infrastructure deficit. As noted above, new technology is bringing African governments cheaper options to invest in renewable energy technologies; partnering with the private sector and seeking multilateral support could move this agenda forward. Governments need to expand internet access in ways that will grow networks and digital hubs, so that both larger firms as well as informal firms and businesses can become more productive. Some studies suggest priority should be placed on fixed broadband penetration and electricity, as this is more closely linked with accelerating job growth than mobile internet access (Calderon et al., 2019). However, some observers suggest that Africa could leapfrog over fixed-line broadband and simply adopt 5G infrastructure, including free public Wi-Fi in urban areas (Technopolis, 2019).

Equipping rural areas and towns with affordable internet access will provide enormous resources for youth to participate in the digital economy. ICT infrastructure in small cities and towns can allow these places to act as "transmission hubs" that will serve rural areas (AU/OECD, 2021). This will strengthen connections between rural and urban areas and drive rural transformation. As much as possible, private investment should be encouraged for this effort, as public finance will be in short supply owing to its decimation during the COVID-19 shock and response. Alliances and partnerships between public and private actors can help provide cost-effective solutions to allow access in less densely populated rural areas (Chakravorti & Chaturvedi, 2019; AU/OECD, 2021, PfPC, 2019). For urban informal sector operators and digital start-ups, extending Commons within a spectrum-sharing environment would help expand access while keeping prices down.[30]

To influence the market and foster competition between ICT firms, the government can auction off spectrum licenses, encouraging new players to enter the market (AU/OECD, 2021; PfPC, 2019). A variety of solutions have been offered to the problem of broadband affordability, including expanding the spectrum/broadband, increasing competition among key providers, regulating prices for lifeline packages while letting the cost be set by the market in other sectors (cross-subsidization), and enhancing public sector actions to aggregate demand and unlock private investment (BC, 2019; PfPC, 2019). In fact, governments can allow the prices for higher use voice-SMS-data packages to be set by companies in the market (while ensuring interoperability), but they will need to restrain mobile phone service providers from operating as an oligopoly to exclude lower-income users by only providing high-usage, high-cost bundles.

Proactive strategies promoting inclusion will be critical. For example, aggregating demand from public buyers seeking to reach marginalized communities can help make broadband more affordable and ensure inclusion; if government and NGO programs aggregated their demand, this would guarantee a market and could encourage network expansion (PfPC, 2019). Governments should restructure taxes so they are not discriminatory and should provide incentives to firms that prioritize underserved communities (BC, 2019). Universal service funds, sourced from ICT industry taxation, can be used to provide ICT services to those who otherwise could not afford them (BC, 2019). The Pathways for Prosperity Commission (PfPC), however, recommends against their use because of a history of poor transparency and unknowledgeable, uninformed program managers. Instead, governments should encourage or require the ICT industry to raise the cost of services in more prosperous areas (usually cities), in order to subsidize the loss of revenue among poorer communities. Subsidies could also be directed toward funding free Wi-Fi zones (PfPC, 2019).

Ensuring that the benefits of 4IR technology reach working-class and farm households, including women within these households, will require government programs, nudges, and regulation. Ultimately, ensuring access and protection for all will unlock extensive opportunities for young workers and entrepreneurs to participate in a competitive marketplace.

30 These systems use unused spectrum to provide low-cost, high-quality broadband access. See Technopolis (2019).

Challenge 3: Limited knowledge, skills, and information

There is widespread agreement among scholars that the biggest challenge faced by governments is limited human capital (AUC/OECD 2021; Choi et al., 2020). From preschool through university, students are not acquiring the skills needed for the 4IR job market (Choi et al., 2020). Furthermore, policymakers and economic stakeholders have an insufficient awareness of the benefits of 4IR for job creation (AUC/OECD, 2021). Governments themselves often do not have the skills to respond to 4IR regulatory and investment challenges. A lack of awareness and limited information dissemination also make it difficult to capitalize on 4IR for job creation.

A lack of skills development, as we have noted, has created an obstacle to the adoption of 4IR technologies in Africa. In almost every sector, 4IR technologies need to be complemented by high skill labor. The skills needed—digital engineering, for example—are developed in tertiary education, but only after the necessary cognitive skills and information have been absorbed in primary and secondary education. In Africa, the private costs of upper-secondary and tertiary education, as well as the lack of school places, often excludes youth from less elite families, especially those who grow up in rural areas and towns. Yet most recommendations to developing countries on how to prepare for and support 4IR technologies stress the need to develop the quantity and quality of these high-level skills (for example, Technopolis, 2019; PfPC, 2018; Choi et al., 2020). These studies and reports advising African governments are silent on how to equitably finance skill development.

In considering how to reform education systems to meet the needs of the 21st-century economy and 4IR (and in some cases, even the needs of 3IR technologies and the late 20th century), countries face difficult choices. The most significant one, highlighted above, is between building the high-level STEM skills, versus improving the quality of primary and secondary education and reducing dropouts to help the informal sector labor force build a livelihood and raise their earnings.

Skills needed by high-tech sectors are expensive to develop, and Africa does not have the financial resources necessary. In SSA, countries are already spending about 4.5 percent of their GDP on education (including both public and private expenditures), and the systems are inadequate for current needs (Arias et al., 2019). Of that total, 1 percent already goes to higher education. The African Union suggests that member countries spend 1 percent of GDP on developing STEM skills (Technopolis, 2019). It is hard to envision LICs and LMICs finding another 1 percent to spend on STEM in secondary and post-secondary education, given competing spending priorities in health and nutrition, infrastructure, etc. to realize inclusive growth and poverty reduction. In LICs and poorer LMICs, expansion of post-secondary education to cover even 25 percent of new entrants by 2035 or 2040 seems unattainable (Technopolis, 2019; Arias et al., 2019).

Solution 3: Close the skills gap and increase human capital

Countries will need to face up to their skill deficits, not only in order to take advantage of 4IR opportunities, but to avoid stalling their transformations completely. Closing the skills gap will require continued investment in basic education, and a search for new financing models to support continued upgrading of post-primary education. In SSA's LMICs and LICs, both equity and productivity concerns imply that public expenditures should be directed towards improving the quality of basic education. Countries will not succeed in benefitting from 4IR technology if skills development programming and public expenditures are oriented mostly towards the high-level skills of the elite who are able to enter tertiary education—not the least because basic skills are needed to master higher-level skills (World Bank, 2018).

To develop the necessary high-tech skills, countries should try to mobilize public and private financing together toward post-secondary STEM and digital skills development needs. Several country technology and innovation strategies among innovation leaders include partnerships with leading ICT or other firms to develop a skilled workforce with some success. As an example, South Africa's Ministry of Communications and Digital Technologies has partnered with the digital learning platform Coursera to offer free courses to young South Africans in areas such as data science, digital marketing, artificial intelligence, coding, and app development. Another example is Kenya's Ajira Digital Program, which has reportedly enabled over 630,000 youths to have access to online jobs (Ajira Digital, 2020). Partnerships between firms/ sector groups and higher education are an especially fruitful area. Both firms and graduates complain that higher education has not prepared them for the labor market. If public educational institutions worked with industry to reform curricula and pursue work-based learning opportunities, they could help higher education graduates attain the range of skills they need to succeed at a variety of tasks—technical, cognitive, and socioemotional.

Education strategies, even at the basic level, need to also focus more on developing socio-emotional skill development (Arias et al., 2019; World Bank, 2018). Problem-solving and teamwork-related socio-emotional skills in children such as tolerance, responsibility, and independence, are valued by adults in OECD countries, while African adults value hard work and obedience much more, reflecting different cultures, history, and life challenges (Arias et al., 2019). The socio-emotional skills valued in OECD are associated with successful entrepreneurship as well as higher earnings and mobility, incorporating these skills is clearly needed. Parents in African countries may need to be encouraged to value these socioemotional skills more highly (Arias, et al., 2019), and to support educational systems, including afterschool programs, that support developing these skills (Fox and Gandhi, 2021). This is another challenge for leaders of education reform in Africa.

Knowledge about key 4IR technologies is low in numerous African countries, whether in policy or business spheres, hindering preparation and adoption. Government is well placed to disseminate information about 4IR technologies by developing public sector initiatives, and it can also facilitate the emergence of private sector networks to address business information asymmetry.

The need for a comprehensive strategy

While the challenges presented above are complex, they are not insurmountable. Efforts to conscientiously shape public policy guiding technological growth to maximize benefits and minimize rewards will be crucial for success in 4IR. This section discusses some key country strategies for harnessing these opportunities. Countries can utilize these strategies to create high-quality and inclusive employment opportunities for young people as well as drive sustainable economic development on the continent. But policymakers cannot fully unlock the potential of the Fourth Industrial Revolution on their own; they must also forge partnerships that facilitate cooperation and multi-stakeholder support.

Wider access to technology increases the potential for job creation, but throughout Africa, firm-level access to technology remains limited. African governments need strategies to increase new technology adoption and foster innovation to maximize growth, transformation, and inclusion. Governments should approach this challenge for firms, in order to spur job and economic growth, from three angles: fostering innovation; facilitating technology adoption (including 4IR technologies); and increasing access to finance. Strategies should address the challenges for the public sector described above, and for other important actors as well: businesses, educational institutions, NGOs and associations, and the broader population. Taking specific action to increase technological readiness and adoption, while ensuring fair and open processes, is crucial.

A critical assessment of the literature shows that what is missing, beyond the specific deficits highlighted, is a comprehensive, effective, and implementable strategy that will address the various challenges faced by governments (AUC/OECD, 2021; Signé, 2022; PfPC, 2019). Rather than having a single ministry or body dedicated to the task, government bodies should be agile and accelerate multi-stakeholder collaboration, engaging various public agencies, but also the private sector, civil society, and external partners in the policymaking process, to bridge the gap between policy intentions and implementation outcomes. A comprehensive strategy should include education, employment, youth, technology, finance, infrastructure, and cybersecurity, and the broad variety of stakeholders must all be involved in the transition to 4IR technology and employment—and, ideally, will all work together as part of a coordinated effort. The successful implementation of such a strategy will also require evidence-based policy making, with experimentation, economic evaluation of the use of public funds, and impact studies, to guide better project choice and ensure follow-through to final delivery (Signé 2018).

The donor community should help governments as they formulate and implement such strategies, including through technical assistance, but also by providing resources when investment is needed, following the lead of African governments and regional institutions. Development organizations, using grant funding, should focus on education and training programs, sharing public sector expertise – including South-South collaboration - and on involving and facilitating contacts between professional organizations. MDBs and RDBs, with their longer term financing, should deepen their commitment to ICT Infrastructure. UN agencies should focus on providing policy advice but can also help in the co-ordination of technical, economic, and regulatory issues (BC, 2019).

Multilateral institutions are addressing these issues, but there is much more to be done. The African Union rolled out the ambitious "Digital Transformation Strategy for Africa (2020-2030)," an all-encompassing plan for job creation and digital inclusion through skills development programs, capacity building, and digital identity systems, among others (African Union, 2020). The African Development Bank has a nine year strategy entitled "Jobs for Youth in Africa," with a goal of developing both technical and socio-emotional skills in 50 million youth to prepare them for the 25 million jobs the strategy aims to create (AfDB, 2016). Several international institutions and partnerships have committed to providing loan facilities to increase access to finance for SMEs, particularly those owned by women, including The African Guarantee Fund (AGF), International Finance Corporation (IFC), the Agence Française de Développement (AFD), and the European Investment Bank (Capital Business, 2021). Other agreements prioritize regional trade, like Afreximbank's $350 million facility loan to OCP Group (Afreximbank, 2021). Efforts to stimulate a competitive business environment across the continent include the World Bank's "Digital Economy for Africa Initiative".

Private and corporate philanthropy have an important role to play. A major initiative includes "Coding for Employment," a public-private partnership with the Rockefeller Foundation, Microsoft, and Facebook (The Rockefeller Foundation, 2018). In keeping with a focus on youth, the Korea-Africa Youth Forum, established at the Seoul Dialogue on Africa in 2018, empowers African and Korean youth to pursue entrepreneurship together within the African startup market (Republic of Korea Ministry of Foreign Affairs, 2018; Signé, 2018).

While these initiatives promote an inclusive, competitive business environment and access to financing, they do not alleviate other barriers to doing business in African countries, like poor administrative processes, unenforced or insufficient health and security standards, and intellectual property constraints (Devermont and Harris, 2021). More emphasis must be placed on assisting African governments directly with regulatory infrastructure, systems development, and agile policymaking to enable and encourage both domestic and foreign businesses and investors to pursue the local markets. Africa's limited energy infrastructure should not be forgotten, as providing reliable electricity to communities will in itself unlock opportunities for business growth and innovation. Most financing for electrification projects comes from the AfDB, the World Bank, the United States, and the European Union (EU), but the EU initiatives struggle with fragmentation, and the financial support is not equally supplemented with technical assistance and capacity building (Simone and Bazilian, 2019).

Overall, by accounting for and actively embracing the requirements, implications, and consequences of 4IR technologies at every level, African governments can take steps to ensure an inclusive, sustainable, and profitable work future for their youth, today and tomorrow. External stakeholders have an important role to play in supporting these efforts, following the lead of African governments and regional institutions.

6. Conclusion

4IR technologies could lead to economic growth and transformation, and improve material welfare, but the impact on the future of work and for youth will depend on policy. Given the wide range of technologies and their impacts, as well as the complex country contexts across Africa, policymakers and stakeholders must do more than count potential job losses and gains. It is crucial for them to look at the potential of 4IR technology holistically, including effects across different social groups, sectors, and, in particular, indirect job creation potential. 4IR technologies can help countries return to, and build on, their positive pre-pandemic trajectory by improving productivity and earnings, encouraging the production of new and cheaper products and services, and increasing economic opportunities for youth.

4IR technologies can enable the creation of new employment opportunities across all sectors, providing a wealth of new opportunities that should prove particularly attractive and accessible to Africa's youth. Deployment of 4IR technology could lead to new, often formal, wage jobs being created at a faster rate than the growth of the labor force, and earnings improvements in the informal sector. In the service sector, e-commerce and BPO represent the greatest opportunities for formal wage employment expansion, under the condition that regulatory and infrastructure requirements are met. In agriculture, the 4IR technology can increase earnings, reduce poverty, and have environmental benefits, although agriculture's share of employment will continue to decline with structural transformation. In manufacturing, 4IR technologies may open new opportunities for smaller-scale production for domestic and regional markets, but it is unlikely that it will increase employment due to its inherent labor-saving nature. 4IR technologies may help increase earnings for informal household enterprises. An example of how this could work is mobile money, first adopted by youth, which has improved opportunities within the informal economy, and resulted in increased earnings, savings, and opportunities for women.

The potential of 4IR in each country context depends on policies and investments. Countries must adopt comprehensive strategies that involve public and private sector and international actors and include ministries of youth, employment, technology, finance, infrastructure, and cybersecurity, etc. working together rather than siloing the issue of digital transformation in one body. Key recommendations include improving regulatory and business environments to make them more welcoming of 4IR firms and technology; addressing gaps in infrastructure (energy, broadband, and mobile) and access so all populations, especially rural areas and smaller cities, have reliable internet access and mobile phone service; and developing human capital by reforming education, specifically focusing scarce public resources on foundational skills and basic education rather than costly tertiary education programs that only a small portion of the population can access.

Africa is the world's youngest continent, with a rapidly growing labor force. Youth entering the workforce now face a lack of economic opportunities, made worse by the disruptions to the economy and education brought on by COVID. Despite the economic transformation of the past two decades leading to more wage and salary jobs in the formal sector, the majority of the African workforce still works informally, which entails some precarity and risk. While we see potential in 4IR technologies to support the countries to continue and enhance positive pre-COVID-19 economic transformation trajectories, 4IR technology is likely to only bring incremental change in the trajectory of employment transformation, in terms of shift from the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development (AU/OECD, 2021). It is crucial that policy makers recognize that the informal sector will remain strong, and work to improve access to opportunity, including technology, rather than treat it as a pariah.

Africa cannot escape 4IR, as African states become increasingly integrated into the global economy. The balance between the positive and negative outcomes from 4IR will depend on initial country conditions and policy choices. Despite the number of pages published on 4IR in Africa over the past few years, the way forward seems still muddy in several areas. African countries, with more limited resources and infrastructure than many upper-middle-income and high-income countries, will have to develop and try new approaches to address their challenges. Some key questions highlighted above include:

- ***How can lower-income countries with limited resources expand access to mobile telephone and internet connections?*** What is the binding constraint—infrastructure or knowledge? Suggestions offered include auctioning more spectrum and using the funds to subsidize lower-income users, developing programs to support more women using mobile phones and the internet, trying new approaches to expand access in low density areas, etc. But which ones would be most cost-effective, for whom, where, and why?
- ***How can countries find new financing models for skill development that are equitable and effective?*** What changes in incentives could the public sector use to encourage universities to look for these opportunities?
- ***Are investment, R&D, and employment tax incentives worth the fiscal cost in allowing 4IR to deliver quality decent jobs for youth in Africa?*** What are the key drivers of success for such policies? Are they more effective in given countries, regions, sectors than others, or is this irrelevant in the 4IR context?
- ***How would African continental institutions such as the African Continental Free Trade Area contribute to shaping African digital economies and making 4IR work for decent jobs in Africa?*** To what extent will continual policy harmonization constitute an opportunity or challenge in terms of enabling 4IR quality jobs?

Given the unique and complex nature of the challenges Africa faces in this regard, stakeholders and policy makers would benefit from more case study research at the national level. Authors writing on 4IR have produced many case studies of individual start-ups, some of which we have referred to here. Meanwhile, some countries have also produced strategies. But we are lacking assessments of how these strategies have played out. To what extent did they achieve their goals, and was there a job impact? Is anybody tracking the job impact of 4IR strategies—admittedly, a difficult task given the lack of a counterfactual. Nonetheless, such assessments must be attempted in a future research strategy.

Annex: Landscape of 4IR technologies

Technology	Definition and Purpose	Potential Application in Africa
Additive manufacturing (3D printing)	Produces objects by computer-aided, layer-by-layer addition of materials, resulting in a much more customizable process than traditional (subtractive) manufacturing.	Lowers economies of scale in manufacturing, benefitting small countries and SMEs (small and mid-size enterprises)
Advanced materials science	Optimizes the use of raw materials and develops new sustainable materials for use in batteries, electronics, water filtration, etc.	Evolving battery technology using advanced materials science could allow Africa to realize its vast potential for renewable energy generation (wind and solar).
Artificial intelligence (AI)	AI refers to the ability of machines, computers, or computer-controlled robots to perform operations analogous to human intelligence, including processing information, recognizing complex patterns, drawing conclusions, and making decisions.	Could improve planning processes, supply chain management, equipment maintenance plans, medical diagnoses, among other uses.
Automation (robotics)	Design, construction, and use of machines to execute tasks automatically, with speed and precision.	Improve quality and speed of routine tasks; reduce hazardous work.
Big data	Extremely large data sets that can be computationally analyzed to reveal otherwise hidden patterns and trends; is an underlying requirement for many other 4IR technologies. Supports better informed decisions.	Could provide analysis to improve planning and decision-making across a range of activities including demand forecasting, public health surveillance, and traffic management in cities.
Blockchain (distributed ledger technology)	Create and exchange digital records without a centralized, trusted agent. It includes a suite of computing services supporting the digital recording process of transactions that is distributed across computing systems over the internet using cryptography.	Managing land and property records, recording and completing financial transactions, managing sensitive supply chains such as in the health sector.

Cloud computing	On-demand, remote availability of computer system resources such as software, infrastructure, platforms, data storage, and computing power to users over the internet. Reduces computing costs.	Extend access to information and communications technology (ICT) by minimizing up-front ICT infrastructure costs; protect valuable data. Particularly useful in countries where inconsistent electricity has the potential to damage data and electronic devices.
Drones/Autonomous vehicles	Use AI to move remotely with minimal or no human input. These have a wide range of applications, from information collection to transportation of people and goods.	Drones will have wide application in agriculture, industry, and energy services in Africa, and are already improving cargo delivery to remote areas (e.g., emergency medical supplies).
High-speed, high-bandwidth internet (including 5G technology)	Massively increases the speed of wireless networks, extending internet access.	5G will allow African countries to leapfrog over the stage of fixed broadband internet, avoiding the costly process of laying fiberoptics cables all over the country.
The Internet of Things (IoT)	Network of devices, machines, animals, or people with sensors that have unique identifiers and transfer data over a network without requiring human interaction. IoT has wide-ranging applications both on a small scale (devices that connect home appliances, reduce home energy usage) and on a large scale (national energy and water systems, manufacturing, tracking cargo, health, and waste management).	IoT could increase trade and reduce counterfeiting by increasing traceability.
Nanotechnology	Microscopic materials and service robots. Nanobots can serve welfare-enhancing purposes (e.g., deliver drugs to repair cellular damage) or welfare-diminishing purposes	Technology is expensive, therefore not many uses in Africa yet.

	(enhance chemical weapons and explosives).	
Quantum computers	Exponential increase in computing power by manipulating information based on quantum bits instead of digitally.	Quantum computers are still in the development stage. High energy requirements reduce their potential uses in Africa

Source: Signé, 2022

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INCLUDE was conceived in 2012 by the Dutch Ministry of Foreign Affairs to promote evidence-based policymaking for inclusive development in Africa through research, knowledge sharing and policy dialogue. INCLUDE brings together researchers from African countries and the Netherlands who work with the private sector, non-governmental organizations and governments to exchange knowledge and ideas on how to achieve better research-policy linkages for inclusive development in Africa. Since its establishment, INCLUDE has supported more than 20 international research groups to conduct research on inclusive development and facilitated policy dialogues in Africa and the Netherlands.