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From subsistence to disruptive innovation

Africa, the Fourth Industrial Revolution, and the future of jobs

Louise Fox
Landry Signé

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FROM SUBSISTENCE TO DISRUPTIVE INNOVATION:

AFRICA, THE FOURTH INDUSTRIAL REVOLUTION, AND THE FUTURE OF JOBS

Louise Fox

Landry Signé[1]

[1] Louise Fox is Non-Resident Senior Fellow; and Landry Signé is Senior Fellow at The Brookings Institution, Managing Director and Professor at Thunderbird School of Global Management, and Distinguished Fellow at Stanford University. This report draws on Landry Signé's forthcoming book on Africa's Fourth Industrial Revolution (Cambridge University Press 2022), Louise Fox's Brookings-supported research on Youth Employment in Sub-- Saharan Africa, and a paper they co-authored for the INCLUDE platform, University of Leiden, The Netherlands.

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ABSTRACT

Improving employment opportunities in Africa is already a major development policy issue, and given the number of young Africans expected to enter the job market over the next two decades, it will undoubtedly remain a concern. Academic research and think tank reports tend to herald the technologies emerging in the Fourth Industrial Revolution (4IR; Schwab 2016) as game changers that can accelerate the economic transformation of developing countries, leading to the creation of wage jobs in expanding, higher-productivity sectors. African governments are being advised to organize and invest for this revolution by building labor force skills. Yet how realistic are these predictions for Africa? And what might be the consequences for inclusive development if Africans follow this advice?

Moreover, one central question has so far been ignored in the literature: Just how likely are African producers to adopt the new technology? Although economic theory has long argued that if they adopt the technology of developed countries, less developed countries can grow faster and expedite income convergence across countries. Yet in Africa adoption of productive technology has been slow, because the costs can be high and because many technologies do not sufficiently address the current barriers to increasing productivity and profitability that confront African producers. This is especially true in the informal sector (household farms and firms), where the majority of Africans work today, and are likely to continue to do so.

Using new data on trends in output and employment in Africa, we review the main productivity issues that are preventing transformation in the agricultural, industrial, and service sectors, and ask how 4IR technologies might address them. We then ask whether in these sectors 4IR technology might also unlock better job opportunities for African workers.

Our review finds that 4IR technology creates opportunities for businesses to reduce production costs, improve productivity and earnings, and introduce new business lines. Deployment of 4IR technology could lead to creation of new wage jobs, mostly formal, for skilled labor, especially in services, where rather than being labor-saving (as in manufacturing), technology complements labor. Use of digital and 4IR technology could also improve earnings in the informal sector, reducing the potential for worsening earning inequality that is associated with skill premiums in the formal sector.

But the analysis also found that many of the longstanding obstacles to upgrading production in Africa will also deter adoption of 4IR technology; prominent among those obstacles are infrastructure and logistics bottlenecks, insecure land rights, difficulties in importing inputs and exporting output, and bureaucratic red tape. This is especially a problem in agriculture and urban informal services, where technology adoption has so far been slow. If future public investments give priority to the needs of high-tech firms, such as building post-secondary STEM skills, rather than on the productivity issues of the vast informal sector, such as improved access to, and the quality of, primary and lower secondary education, improving rural-urban connectivity, and access to low-cost mobile Internet, earnings inequality will widen and economic development will not be inclusive. African governments should act promptly to meet the dual challenge, which is how to encourage innovation and productivity gains without compromising inclusion.

1. Introduction

In the 21st century, as economies were buffeted by external and internal economic cycles as well as setbacks such as the COVID-19 pandemic, and the intensifying technological winds of change, enhancing employment opportunities became even more central in development policy discussions. The reasons are obvious: Billions of people in the developing world are seeking to move beyond poverty through jobs that will provide higher incomes for themselves and their families. As the world's youngest continent, where national labor forces are growing rapidly, improving employment opportunities is especially important in Africa.[1]

After two decades of solid economic growth and improvements in employment opportunities, African countries have been set back on their heels by the disruptions to the global economy and the blows to local economies caused by the COVID-19 global pandemic. Before the COVID-19 crisis, many economies in Sub-Saharan Africa (SSA) were growing rapidly (Signé 2020; Jayne et al. 2020) and were transformingtheir economies through productivity increases, which enabled a growing share of their labor force to gain access to wage and salary jobs (Fox & Gandhi, 2021; Diao, et al. 2021). Nevertheless, most employed Africans still work informally in low-productivity activities. In 2018 one-third of the workers employed in Africa still lived in extreme poverty (ILO 2019), and in the lowest-income countries the percentage of the working poor in total employment is even higher.

Employment opportunities depend on the extent of national economic transformation and development. Richer countries offer better jobs, and countries get rich by creating productive employment opportunities—the two processes are inextricably linked (Fox et al. 2020). 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 such enterprises, or enough jobs within them relative to the increasing supply of labor. 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. 2020). The post-Covid-19 economic challenge to build the economy back better requires includes increasing employment opportunities for all Africans.

Parallel to developments on the African continent, a noticeable trend in upper-income countries has been an acceleration of scientific innovation and technological change (Signé 2022).[2] Combined, many of the resultant new technologies have been labelled the Fourth Industrial Revolution (4IR) because of their transformative potential, and because they build on the computing and digital technologies of the Third Industrial Revolution (3IR).[3] 4IR is characterized by a fusion of technologies that has blurred the boundaries between the digital, biological, and physical worlds (Schwab 2016), and by a generalization of technologies like artificial intelligence, the Internet of things, big data, cloud computing, autonomous vehicles, blockchain, advanced materials, additive manufacturing, and nanotechnologies, among others (see Annex 1 for the definitions and functions of selected 4IR technologies). The hallmark of 4IR technology is the integration of development and production processes that had previously occupied separate domains. Examples are the CRISPER biological technology, which transforms the building blocks of biological organisms into software code that can then be altered using computers. Similarly, 3D printing translates the mechanical processes of manufacturing into software code that can be used almost anywhere in the world. It is generally agreed that these next-generation

[1] Throughout this paper, the term "Africa" refers to Sub-Saharan Africa.
[2] Scientific innovation is the discovery of new scientific knowledge. Technological change is the application of that knowledge to existing problems (e.g., mobility, lighting, communication, preventing or curing a disease).
[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 began another 100 years later in the mid- to late 1990s, when there emerged personal computers and other small electronic devices, the Internet, and containerization to automate production, speed up information transmission, and enable globalization of production and consumption.

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

Innovation is key to economic growth and development.[4] Production of goods and services at lower cost can certainly improve material welfare. 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. Over the last 70 years, adoption of technology in developing countries has helped to rapidly raise incomes and reduce poverty, especially in East Asia.

Most observers and analysts agree that 4IR technologies have great potential to advance economic growth and development in Africa (Signé 2022; Banga et al. 2020), and can especially benefit Africa's youth, who were quicker to adopt the digital technologies of 3IR. However, this optimism is usually tinged with some degrees of caution. Worries include the potential for good jobs to be lost to automation, and for inequalities, both within and between countries, to widen, leaving large swaths of the population even farther behind those living in 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 analyze to some extent the implications for employment.[5] The employment analyses usually build on previous studies of the employment consequences in the U.S. of adoption of 4IR technology, especially automation and advanced robotics; some of these analyses (e.g., Frey & Osborne 2017) have concluded that such technologies have eliminated middle-skill, middle-class jobs and increased inequality. However, Acemoglu and Restrepo (2019), among others, argue that the U.S. findings have been driven more by economic policy than by technological change. Analyses of the prospects for Africa are also split on the extent of technological determinism.

Objectives and methodology

The objectives of this analysis are to synthesize the evidence on the current and potential benefits of 4IR technology for economic transformation in Africa; identify possible barriers to its adoption; and then analyze how adopting 4IR technology might affect future employment opportunities in Africa. Our contribution to the discussion is based on (1) critical review of the extensive literature, (2) giving priority to the opportunities for and deterrents to production unit adoption of technology, and possible resultant employment opportunities, and (3) emphasizing the informal sector in discussing employment prospects.

The core question we address is *whether 4IR technology can unlock better job opportunities for Africa's labor force*. Following the lead of Lippolis (2019), Banga et al. (2020), and the recent Pathways for Prosperity Commission report (PfPC 2018), we adopt a more holistic conceptual approach than the "counting job losses and gains" approach popular in much of the analysis to date on potential labor market impacts.[6] Like Acemoglu and Restropo (2019) and Korinek and Stiglitz (2021), we take the view that both the extent to which new technology is even adopted, and the distribution of gains and losses from technological change, may be governed by economic and social policy. As with economic growth itself, technology is not inherently

[4] Economists usually trace this insight to 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 et al. (2019), commissioned by the AfDB; the Broadband Commission's "Digital Moonshot Initiative" (BC, 2019); and the work of the Pathways for Prosperity Commission (PfPC) headquartered at Oxford, which covers all developing countries and produced numerous reports.

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

equal or unequal. We focus on evidence of the possible benefits of technology adoption for production units, whether formal or informal. In organizing and synthesizing the literature, we base the analysis on (1) economic development as economic transformation (within-sector productivity gains and structural transformation), with technology adoption central to this process; (2) technology adoption as a constrained choice of production units; and (3) economic development objectives as expansion ofworkers' choices and abilities to work productively and earn more income, whether they work formally or informally. Rather than focus on the quantitative range of possible job creation and disruption, we illuminate opportunities for and threats to the realization of economic development objectives that can result from the technology adoption. We also look closely at how public policies could harness the innovative power of 4IR technologies to support expanded employment opportunities (jobs and earnings) for those already in the labor market and for those who will enter it within the next decade.

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

- What is 4IR? In what ways could 4IR technology address issues that restrain productivity increases in Africa and thus accelerate economic transformation?
- What prevents production units from adopting technology?
- Could adopting 4IR technologies help improve employment outcomes through higher earnings, job security, and related employment outcomes?
- Will the outcomes be inclusive? Or will they worsen inequality?
- What public investments and policies are needed to realize the potential of 4IR to improve employment opportunities?

Main findings

Our review finds that in a post-pandemic Africa, 4IR technology could help countries to move to a positive economic trajectory. 4IR technology brings to production units' opportunities to lower their costs, heighten productivity and earnings, and introduce new products and business lines. Adopting 4IR technology could lead to new employment opportunities that could prove particularly attractive and accessible for Africa's young labor force. Upgrading production technology could open up new, often formal, wage jobs faster than the labor force is growing, which would reduce the share of informality in total employment. It might also allow earnings in the informal sector to improve if supported by policies that reduce the cost of basic ICT services and reduce producer risk. Thus, 4IR technology could accelerate economic transformation by enabling within-sector productivity gains and the expansion of complex and productive economic activities in non-agricultural sectors (structural change). However, 4IR technology is likely to bring only incremental changes in the pre-COVID-19 trajectory of employment transformation in terms of how quickly there is a shift from the informal to the formal sector, because the trajectory has been already set by past demographic change and the degree of current economic development (AU/OECD, 2021; Fox and Gandhi, 2021).

Some sectors offer more opportunities than others:

- *Services* offer the greatest opportunities for 4IR technology to accelerate economic transformation and expansion of formal wage employment because the technology is used mostly to complement human labor rather than replace it. 4IR technology organizes data that humans can then use to communicate results and exercise judgements. Through the growth of current firms and entry of new ones—especially in retail and e-commerce, logistics and transportation, tourism, and business process outsourcing (BPO)—Africa can create new formal jobs by expanding exports of services and meeting the growing demand in domestic and regional markets. However, given where Africa is starting, the informal share of employment services will decline only slowly, and 4IR technology is likely to have a relatively small impact on earnings from informal services because of longstanding obstacles to innovation and productivity, such as small margins and insecure working conditions.

- In *agriculture*, by reducing information frictions that increase risk, 4IR technology could support productivity gains, higher farm earnings, and a reduction in rural poverty. It could also have important environmental benefits, but only if longstanding risks that inhibit technology adoption can be overcome through improved policies and public investment. Adopting technology will not expand employment much; the share of agriculture in employment has been eroding for years because opportunities are better elsewhere (structural transformation).
- In *manufacturing*, which has recently expanded its share of output and employment in Africa's LICs and LMICs, 4IR technology may open up opportunities for smaller-scale production for domestic and regional markets. But the sector is unlikely to continue increasing its share of employment, because for manufacturing, 4IR technology is labor-saving.
- Massive substitution of capital for labor—destroying jobs—is less likely in Africa than in rich countries, because the cost of capital is higher there than the cost of labor, and there is less industrialization.

For the potential gains to be realized, however, some enduring challenges to technology adoption by the private sector in Africa need to be addressed, among them infrastructure and logistics bottlenecks, the high cost of finance, land tenure rights, difficulties in importing inputs and exporting output, and bureaucratic red tape. Meanwhile 4IR technology presents new problems such as cyber security and the need for a wider variety of skills. Countries therefore need comprehensive strategies that cover:

- How to revise regulation, develop agile governance, improve business environments, and create inclusive policies to encourage innovation, importation, and adoption in technology. Options include the public sector adopting 4IR technology to permit a nimbler environment that encourages the development of fintech, offering services to angel and equity investors, and drawing up cybersecurity plans.
- How to reduce gaps in physical and digital infrastructure to spur technology adoption. Solutions will have to involve private finance, with incentives for including poorer households and more remote areas.
- How to build the skills of the future labor force equitably, given how skill-intensive 4IR technology is. Recognizing that the learning outcomes of the current educational system are inadequate 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 must give priority to increasing access and improving the quality of education through secondary school. This will be the most inclusive strategy. To expand needed high-tech skills, African countries should encourage post-secondary educational institutions to work closely with the private sector and mobilize private financing.

Drafting and applying 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.

African states have become increasingly integrated into the global economy, so Africa cannot escape 4IR. The balance between positive and negative 4IR outcomes will depend on initial national conditions and policy choices. Poorer households, especially those in rural areas, who have little access to electricity and ICT services and even 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. Inequality, especially geographic inequality—a general risk to economic development and transformation—is therefore likely to widen in some countries, affecting employment outcomes. National development strategies will need to respond to this challenge.

In what follows, the next section describes 4IR technologies and elaborates the analytical framework we use in organizing the evidence. It also reviews a few facts about the status of economic and employment transformation in Africa, especially opportunities and challenges arising from the current job landscape. In section 3 we use the framework and landscape analysis to organize and synthesize the evidence on opportunities and challenges of 4IR technologies for Africa as it relates to agriculture, industry, and services. Section 4 considers the critical role that public strategies, investments, programs, and policies need to play in supporting the positive development outcomes of the adoption of 4IR technology, and discusses how African countries and outside stakeholders should approach the 4IR challenge. We conclude by identifying where further empirical research would be helpful to policymakers and stakeholders in formulating strategies, investment plans, and policy options.

2. Landscape and analytical framework

Klaus Schwab of the World Economic Forum is thought to have originated the term "Fourth Industrial Revolution." He defines 4IR as the advent of technologies by fusing the digital, biological, and physical disrupt industries around the world (Schwab, 2016). As we explain, these technologies thus have the potential to increase the speed, efficiency, and sustainability of the production of goods and services 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 evolving. While it took almost a century for the steam engine to fully revolutionize production globally in the 18th century, and there was roughly 100 years between 1IR and 2IR, and between 2IR and 3IR, the inventions and innovations of 4IR are coming online less than 50 years after 3IR started, and globalization is spreading them at a breathtaking pace.
- *Scope* refers to the wide range of sectors, industries, and occupations that 4IR technologies are affecting. For example, 3D printing, a custom manufacturing process driven by software code that is also known as additive manufacturing, could become useful for producing a wide range of products, light and heavy, from circuit boards to custom sports shoes to housing to wind turbines. '
- Finally, *systems impact* refers to the breadth and depth of changes that are already occurring and are expected to continue in entire systems of production, management, and governance.

The combination of velocity, scope, and impact is expected to disrupt many patterns of human existence (Schwab 2016), including the economies of Africa (Ndung'u and Signé 2020; Signé 2022).

4IR technologies have particular significance for economic transformation. It is notable that the technologies are not inherently saving of any single factor of production (land, labor, or financial or physical capital), although advanced robotics and artificial intelligence (AI) have been used in high-income countries to save labor. Unlike 1IR and 2IR technologies, they are usually not subject to economies of scale, which is a benefit for small countries: They can also be applied in different patterns depending on the task at hand. For example, either cloud computing or mobile broadband services can enable AI or Internet of Things (IoT) applications. Quantum computing accelerates discovery and applications of advanced biotechnology and material science.

Can these technologies ignite or accelerate economic and employment transformation in Africa? If so, where, how, and why? To assess these questions, we use the analytical framework of economic transformation, incorporating factors in technology adoption and employment transformation to indicate how economic and employment transformations create inclusive economic development.

Analytical framework

It is generally agreed that expansion of income-earning opportunities depends on progress in economic transformation. Economic transformation refers to two linked processes: (1) *structural transformation,* the shift of workers and resources from low-productivity, low-earning sectors like traditional agriculture to higher-productivity sectors through more rapid entry and growth of higher-productivity firms; and (2) *sectoral transformation,* the growth of productivity within sectors, especially less-productive ones. Economic transformation reflects the use of new technology—mechanical, biological, digital, and organizational—to lower the costs of production (*process* innovation) and to increase the diversity and the sophistication of what is produced (*product* innovation). It also reflects better allocation of resources (land, buildings and machinery, human capital, and financial resources) to more-productive uses through firm entry and exit. Economic transformation sustains economic growth and economic development (McMillan et al. 2017).

Economic transformation promotes both the growth of labor earnings and *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 because they carry less income risk than informal self- and family employment (ILO 2021b). These tend to be the jobs African youth want when they leave school (Fox et al. 2016; PfPC 2018; Lorenceau et al. 2021). Previously, most analyses of economic transformation focused on structural change, especially, as in the past, the growth of the share of output and employment in manufacturing; this sector has provided a large share of new wage jobs (McMillan et al. 2017). Recently, however, authors have been directing structural change analysis to other sectors as well (Gollin 2018).

Economic transformation, leading to employment transformation, improves employment opportunities and reduces poverty (Fox & Gandhi 2021). But inclusive transformation is not inevitable. Labor productivity gains enabled by new technology do not, alone, necessarily create more jobs. New jobs are created when (1) productivity gains lower the cost of production, which heightens demand and thus allows firms to produce more output by hiring more workers, or (2) new firms enter, producing new items and creating new jobs. In agriculture, for example, sectoral transformation has pushed up incomes but employment growth has fallen; however, through multiplier effects, these gains have led to higher employment growth in nonfarm sectors (structural transformation) (Timmer 1988; Jayne et al. 2020). In most cases, economic and employment transformation, led and supported by productivity improvements in agriculture, has been inclusive (Jayne, et al., 2020).

Most new technologies capable of transforming the production of value-added in an economy are invented and first adopted in rich countries before spreading to less-developed countries (Griffith and van Reenen 2021).[7] In theory, poorer countries can grow more rapidly than rich ones if production units in the poorer countries simply adopt new technologies already used in rich countries. However, as Verhoogen (2021) has noted, such technological upgrading[8] has been at best slow in African countries.

Production units (firms or farms) adopt a new technology when it solves a production problem, meaning that the benefits (profits) are higher than the cost.[9] Constraints to technology upgrading appear on both the demand and the supply side (Verhoogen 2021). Context-specific constraints may lead producers to conclude that adopting technology offers few benefits and too much risk.[10] If the constraints are not addressed, transformation stalls. On the demand side, a producer may encounter a lack of demand for upgraded products at a profitable price in the domestic market owing to, for example, a small market that discourages scale economies. The producer could gain scale in export markets but cannot access these markets owing to trade or informational barriers. On the supply side, a producer may not have access to all the inputs supporting technology adoption. For example, the energy needed could be neither reliable nor affordable; tariffs and transport costs may make the imported inputs or machinery needed for production unavailable or too expensive; financing may not be available for capital upgrading; or the worker skills needed to use the technology may not be available. Patent protections may also render the technology unaffordable. Relational (long-term) contracts with suppliers, necessary where contract enforcement institutions are weak, may inhibit change in production processes. Finally, producers may lack the entrepreneurial skills, or there may be cultural

[7] Mobile money as a form of fintech is a notable exception; see discussion below.
[8] Often called "industrial upgrading" given that most research focuses on industrial sectors, this concept refers to the adoption (or adaption and adoption) of new technologies by production units (farms and firms) to increase productivity through process or product innovation. See Calabrese et. Al. (2020), and Verhoogen (2021).
[9] This is obviously an over-simplification because the cost is usually fixed and upfront, and may have to be financed, but the benefits will take time to be realized over time, and are uncertainty. Evaluating investment in new technology therefore involves, among other things, using discount rates and probabilities. See Verhoogen (2021) for a mathematical formulation of a firm's technology adoption decision.
[10] Magruder, (2018), makes this point clearly with respect to the adoption of improved inputs in the agricultural sector.

or organizational barriers within firms that inhibit the adoption of a specific technology.[11] Any of these constraints may inhibit African adoption of 4IR production technologies.

Widespread adoption of 4IR technology in an economy could lead to rapid growth in output and productivity, without much impact on the structure of employment. If the technology adopted involves producing the same amount of product at a cheaper unit cost, the owners of the production unit might expect an increase in earnings, but few new jobs would be created. If the benefits involve producing and selling more product or a better-quality product, or starting a new business in a different sector, that might create new jobs. Producing product more cheaply or of higher quality would lead to sectoral transformation; starting a new business could lead to structural transformation if labor is reallocated to growing, more productive sectors.

Whether a country is developed or developing, adopting technologies that transform production processes or the outputs produced is disruptive. In general, transformation improves employment opportunities over time, but jobs and occupations are usually lost as well as gained. Technology that substitutes for labor, such as robots, will cause losses of jobs and occupations, though technology that complements labor, such as video conferencing or service platforms, will help create or preserve jobs. It is critical, therefore, to examine not only whether the new 4IR technologies could be adopted and would advance economic transformation in Africa, but also what kinds of jobs, or opportunities for self- employment, could be created; what jobs might be lost; and what groups in society might be affected. Ideally, new jobs will be development-enhancing—meaning that they increase "the capability of people to live the kind of life they have reason to value" (Sen 2001, p. 53). Development-enhancing technology can upgrade jobs whether they are formal or informal. However, as previous industrial revolutions have demonstrated, the diffusion of technology and the process of employment transformation do not necessarily occur in parallel, and may not initially be development-enhancing for those using the new technology.[12]

The policy questions for Africa, therefore, are (1) how 4IR technology can be deployed to raise productivity and aggregate income, and (2) how to have inclusive 4IR-driven economic and employment transformation. Our review focuses on whether adopting 4IR technology in Africa could (1) reduce informality as new firms create more formal, wage-paying jobs (structural transformation), and (2) raise earnings for those employed, whether their jobs are formal or informal (sectoral transformation). But before we assess the future, we need to consider where Africa is now in terms of economic and employment transformation.

The transformation and employment landscape in Africa

From 2000 until the recent COVID-19 shock, in most countries in SSA there was sustainable growth in per capita income (Jayne et al. 2020, based on WDI data). Structural transformation was substantial, helping to sustain growth. Regionally, agriculture's share of GDP declined by 5 percentage points between 2000 and 2018, and its share of total employment declined by 9 percentage points. Output and employment surged in non-agricultural sectors, especially services and especially in East Africa (Mensah 2020); however, services still account for only 5 percent of GDP in LICs.[13] Trade diversification also advanced substantially: In 2015, the manufacturing share of total exports reached 50 percent for SSA (Jayne et al. 2020). This 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 also reflects growth in regional trade in manufactured goods.

Growth in within-sector productivity was also notable, especially in agriculture. Region-wide, annual growth in labor productivity averaged almost 2 percent through 2013, driven by both productivity growth in agriculture—the least productive sector—and structural change (McMillan et al. 2017). In non-agricultural sectors,

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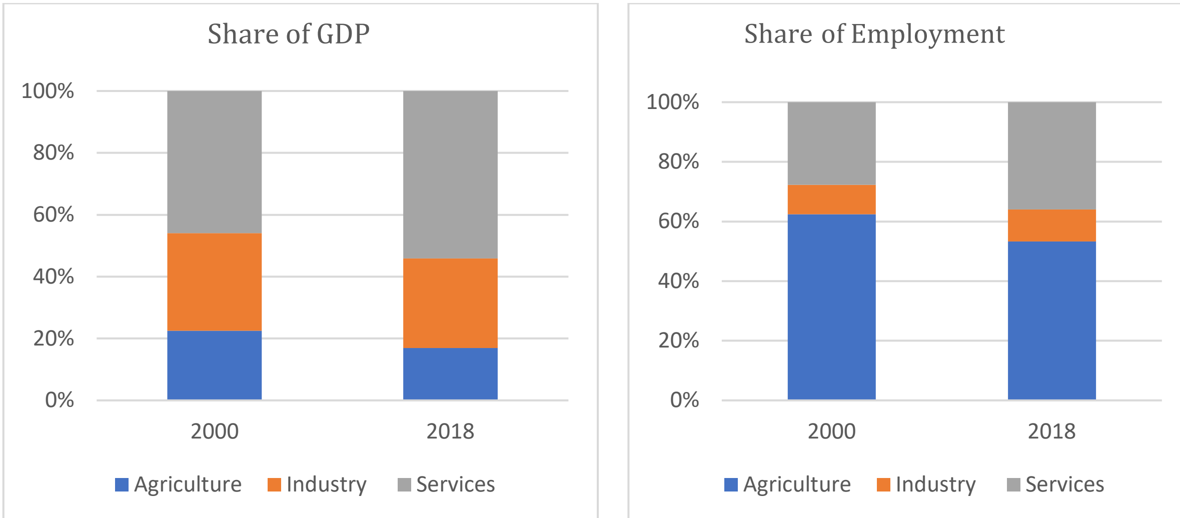
[11] Unions are often blamed for failure to adopt new technology, but as Atkin et al. (2017) demonstrate, it is often a failure of management to understand shop floor incentives at that inhibits technology upgrading.
[12] This is certainly true of factory technology, as deployed in the 19th century; see Kenny, (2019)
[13] 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.

productivity growth was low, primarily because as the share of agriculture in employment fell, the share of employment in activities that were more productive than agriculture but less so than the economy-wide average, such as informal retail trade and small-scalemanufacturing, expanded faster than the share of employment in the most productive activities (Diao et al., 2021). Africa's strong growth and heightened productivity was driven both by an increase in the capital stock, which accounted for about 40 percent of total economic growth, and by technological change, which accounted for about 30 percent, as measured by the change in total factor productivity (TFP; Gazarelli and Limam, 2019).[14] Without continued technological change, which was mostly driven by 3IR digital technologies, Africa's growth would have been less robust.

Employment transformation always trails economic transformation. In Africa, therefore, despite recent progress in economic transformation, informal employment is still high in all sectors (Fox et al. 2020). For Africa as a whole, the share of informal employment in total employment—including both casual informal wage employment and nonwage household farm and nonfarm activities—is estimated at 89 percent (Table 1).[15] The agricultural sector still accounts for the largest share of employment, especially in the lowest-income countries, and has the highest level of informality (Table 2). However, given Africa's low income levels, this result is not surprising. Notably, several countries that recorded broad-based and transformative growth since the turn of the 21st century saw the share of formal wage employment rise, to levels equal to or greater than their peers in other regions (Fox & Gandhi 2021).

[14] Verhoogen (2021) identifies serious methodological issues when using TFP as a measure of technological change.
[15] See ILO (2018) for the international definition of informality.

Figure 1 | Transformation in output and employment, 2000–18, percent



Source: World Development Indicators

Table 1 | Employment by type, percent

Formal*	Informal		
	Total	of which: *Wage*	of which: ***Self-employed & family workers***
11	**89**	**25**	**64**

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

Table 2 | Employment by sector, percent

	LIC	*LMIC*	*UMIC*	*Share Informal*
Agriculture	64	42	7	98
Industry	10	12	22	81
of which: Manufacturing	5	8	10	
Services	26	45	70	76

Sources : ILO (2018) ; Fox & Gandhi, (2021)

Women are more likely to be in informal employment (ILO, 2018)—and more likely to be excluded from opportunities for good jobs. Throughout the world, gender norms and customs circumscribe economic opportunities, and Africa is no exception. African women have less access to post-primary education, which limits their access to better employment opportunities (Fox and Gandhi 2021). Even women with some education have less access to wage employment, and their farms and businesses are less productive than men's (Jayne et al. 2020). Adult women have less access to digital and financial services and are responsible for a high burden of household chores and care, which often prevents them from engaging in more remunerative economic activities. At the root of these problems are legal, social, and economic conditions that limit the economic empowerment of women (Jayne et al. 2020).

Once recovery from the COVID-19-induced recession is underway, African countries need to restart the transformation process. This implies a return to policies and programs that encourage private investment in productivity-enhancing processes, production of new products, importation of technology and knowledge, and support for domestic producers to break into new export markets, regional and international. These policies encouraged technology upgrading in firms and farms and entry of new firms. The post-COVID economy will also need to be more resilient to external and internal shocks and stressors. Building resilience means building open political and economic institutions that encourage equity as well as agency in solving problems and negotiating change (Broadberry and Gardner 2021). Inclusive transformation is therefore an urgent priority for guiding policymakers (Fox et al. 2021).

But even with a return to pre-COVID-19 economic growth patterns, the share of employment in nonwage jobs on the continent can be expected to hold steady for the next 15 years (AUC/OECD 2021; Fox & Gandhi 2021) despite the trend of substantial transformation observed over the past 15 years. Though disappointing to some, the prediction rings true, given (1) high projected growth in the labor force, based on past fertility, and (2) particularly high labor force growth in populous countries where informality is common, such as DRC, Niger, and Nigeria (Fox & Gandhi 2021). Growth in the labor force and income per capita are well-known determinants of informality, with labor force growthhaving a stronger effect (La Porta & Schleifer 2013). Within SSA, countries like Ghana, Kenya, and Senegal, where projected labor force growth is lower and starting incomes higher, will find it easier to reduce the share of informal employment. Even so, many households in the region will find it difficult to earn a living and improve their material welfare.

Because these problems are economically and socially complex, technology is not likely to be the panacea. Nonetheless, it is worth asking whether 4IR technology can support an inclusive transformation path. In the next section, we use the analytical framework outlined above to elucidate the opportunities and challenges of 4IR technology in Africa in increasing value- added, product and export diversity, and labor productivity in the production of goods and services. We identify the factors driving the likely impact of the technology on economic transformation and employment opportunities. In doing so, we focus on three questions:

- Could 4IR technology help production units address whatever is preventing productivity increases and economic transformation?
- If so, what are the opportunities and constraints on adopting 4IR technology?
- If adopted, would the technology complement or substitute for labor? Could adopting 4IR technology contribute, directly or indirectly, to higher earnings, job security, and other positive employment outcomes?

Box 1 | What is informality?

Based on discussions with labor statisticians, policymakers, researchers, and stakeholders, the ILO has issued clear criteria (statistical standards) for identifying informality as an employment outcome. These standards have two parts (1) people who are in informal production units (the informal sector)—a production-unit-based concept; and (2) people who are employed informally, whether in a formal or an informal production unit—a job-based concept.

1. The informal sector consists of production units that are not constituted as separate legal entities independent of their owners (they do business in the owner's name). They are owned by individual members of a household or several members of the same or different households. Typically, they operate with little 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.
2. 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 (e.g., advance notice of dismissal, severance pay, paid annual or sick leave). It also includes all self-employed, contributing family members and employers who work in the informal sector.

The union of (1) and (2) is defined as employment in the informal economy. *Source:* ILO 2018.

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

4IR technology has the potential to improve material welfare in Africa by, e.g., improving labor productivity throughout the economy; improving access to and the quality of education and health services; improving urban management and service delivery by adopting smart city technology; reducing the cost of consumer goods, and raising the real incomes of the population (Signé 2022). While all channels are important, here we focus on the production channel, which is the most important to the creation of new and better jobs. 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 the resources available. Instead, we examine the factors that currently limit transformation—the expansion of output, employment, and productivity—in private production units[16] and sectors to transformation, and how 4IR technology could reduce these constraints and accelerate transformation. In this section, we look for opportunities for transformation through upgrading technology within the three main sectors of the economy: agriculture, industry, and services.

3.1 Agriculture

Agriculture is an essential sector in Africa and it is likely to continue to be essential well into the future (Jayne et al. 2020). In lower-income countries, agriculture provides income for most poor households, food for a growing urban population, and export earnings. In South Africa, although agriculture's importance as a share of output and employment has declined substantially, agricultural commodities and processed agricultural products (e.g., dairy, juices, wine) still account for a significant share of exports and local food supplies, an indication of how productivity gains in the agricultural sector have promoted structural transformation through links, downstream and upstream, with the rest ofthe economy (Jayne et al. 2020). For example, in Kenya, agriculture accounts for 26 percent of GDP directly but also another 27 percent indirectly because of its links with other sectors (Banga et al. 2020). Throughout Africa, over the next 10 yearsthe food system, including agro-processing, is expected to account for up to 40 percent of net new jobs (Filmer & Fox 2014; Jayne et al. 2020). A competitive and productive agriculture sector is a prerequisite for the expansion of agro-processing.

African agriculture is, however, confronted by several challenges. In LICs and LMICs, smallholder family farms (SHFs, less than 3 hectares) predominate, and even medium-sized farms (up to 10 hectares) tend to be family-owned and operated. Despite recent gains, productivity remains low, reflecting a range of such challenges to SHFs as:

1. The limited supplies, high prices, and uncertain quality of modern inputs, increasing the risk associated with their adoption.
2. Uncertain and limited rainfall and lack of irrigation and other systems of water management
3. Declining soil fertility; compounded by
    - Lack of secure land tenure, which deters investment;
    - Poor roads and minimal ICT infrastructure, resulting in high transportation costs, and higher information frictions and marketing transaction costs, so that farmers receive a smaller share of the final product price; and
    - Low public investment in agriculture, especially in research and development (R&D), so that there are few science-based options that can be tailored to SSA's many microclimates

[16] When reviewing the energy sector, we include state-owned enterprises.

(Jayne et al. 2020).[17]

Meanwhile, migration from rural areas and the expansion of nonfarm employment opportunities are raising the price of seasonal labor for planting, weeding, and harvesting, leading to increased demand for capital in the form of draft animals and tractors. There is evidence that credit constraints affect technology adoption, although the perceived risk and a lack of information appear to be much stronger determinants (Magruder 2018). Crop quality and safety (phytosanitary) infrastructure is also missing or weak, limiting the ability of farmers to participate in global value chains (GVCs) for high-value export crops, or even to receive good prices for some of their traditional crops. As a result, except for specific tropical crops like cacao and cashews, many countries cannot compete on world markets, and farms still earn little from traditional tropical crops (tea, coffee, cocoa, cotton, oilseeds) and livestock products. Poverty and food insecurity are high among SHF households in SSA; productivity limitations particularlyaffect SHF led by women, who are less likely to have secure land tenure or access to credit.

Most the challenges identified are not solved directly by technology; they require government interventions through public investment, service delivery, or regulation. But 4IR technology could facilitate the policies, programs, and services needed. Both digital and 4IR technology reduce the cost of information and relieve information frictions. Already, mobile phonesare bringing more information to farmers about when and what to plant based on weather forecasts and technical information about crop varieties; the result may well be a knowledge-based agricultural community (Fabregas et al. 2019). Using mobile and web technology, Ghana-based companies Farmerline and Agrocenta offer farmers agricultural advice, weather information, andfinancial tips. Zenvus, a Nigerian startup, measures and analyzes soil data to help farmers apply the right amount of the right fertilizer and optimally irrigate farms (Signé 2022). The African Soil Information Service uses remote sensing, providing open-source soil data that can lower the cost of soil mapping by 97 percent (PfPC 2018). If more AI and GPS-coded sensors were used, information could be customized even further, and supply chains could track the progress and quality of crop production in any area. Mobile phone applications have been touted as aids in price discovery and a way to help match farmers and wholesalers, reducing price dispersion and transaction costs (Fabregas et al. 2019; Technopolis et al. 2019), although to date the evidence suggests that this innovation is not at all transformative (Bergquist and McIntosh 2020), since price signals already travel efficiently, and other factors depress farmgate prices.

Insecure land tenure may contribute the most to low productivity in African agriculture (Restuccia 2020). Because it also impedes labor mobility, reduces structural transformation gains, and is another reason for women's lower agricultural productivity and earnings, it is important to address this issue.[18] Land tenure reform is politically and socially complex, and to have a transformative effect it must be carefully designed and implemented; this is not a technology issue. Once a program has been designed, however, there is some evidence that 4IR technology can provide effective support for implementation. GPS systems are already being used to register land. Similarly, 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 the technology is not well understood (Technopolis et al. 2019).

[17] Often constraints and challenges operate concurrently, so that both must be removed. See Suri and Udry (2022), for a discussion. Another issue is the wide variety of microclimates within SSA, each requiring different technologies to improve land productivity (Suri and Udry 2022). This is one reason why there has not been a Green Revolution in Africa. See Jayne (2020).

[18] Preliminary research in Ghana found that when women get secure land registration, they tend to exit the sector for non-farm self-employment (Agyei-Holmes et al. 2020). Suri and Jack (2016) found the same effects with access to mobile money. This suggests that for most women the income effect of technology use occurs outside the sector. However, secure land registration enables women to rent or sell their land, promoting the much-needed land consolidation Restuccia (2020) argues for.

Labor-saving technological improvements, such as increased use of tractors for tilling and harvesting, can raise farmers' incomes, and while some seasonal employment opportunities will be lost, such employment is insecure, not well-compensated, and leads to underemployment. Meanwhile, as capital is brought in to substitute for labor, higher-earning employment opportunities are often created in the technology supply industry. A good example is HelloTractor, a start-up in Nigeria and Kenya that allows farmers to hire affordable tractors via a mobile phone platform. The platform employs contract tractor drivers and generates business for tractor mechanics, bringing 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 and expanded into other countries (Theunissen 2015). Another cost- and labor-saving innovation for agriculture from 4IR is drones, which have been shown to spray crops about 40 times faster thanhumans and help ensure that all farmers' crops are sprayed so that pests cannot return (Technopolis et al. 2019). Drones are currently expensive, however, so their widespread use will require support for introducing this technology from the producer organizations that normally organize spraying (Technopolis et al. 2019).

Increased use of 4IR technology throughout the value chain could raise productivity and earnings even more. Use of blockchain and AI in the financial sectorcould improve farmers' access to credit and weather-based credit insurance (see below); blockchain could also improve the traceability of products and help establish the quality standards and brand identities needed to gain higher prices for Africa's agricultural exports. Use of new biological technologies for developing micro-climate-specific high-yielding seed varieties could speed up production of the inputs farmers need, tailored to the specific context. "Precision agriculture," a method of site-specific crop and farming management used to improve farm profitability, efficiency, and sustainability, is already in use in the U.S. and Europe. In Africa it could reduce the risk to a farmer of investing in more expensive though high-yielding technologies.[17] New technologies could help create new formal jobs in upstreamand downstream off-farm aspects of agro-food systems (Gaus & Hoxtell 2019).

Despite the potential of 4IR technology to speed the transformation of African agriculture, persistent profitability, and weather, and price risk problems lead some to be pessimistic about the prospects for technology adoption (Gaus & Hoxtell 2019). In addition to long-standing risk and land-tenure issues and information frictions, Africa rural areas lack the infrastructure needed to use 4IR technologies. Unlike Kenya (see above), most of Africa's rural areas, especially in West Africa, are not well-served by broadband and mobile phone technology. Only 27percent of rural adults in Africa have ever used the Internet (AUC/OECD 2021). Many areas, especially in LICs, do not have a reliable electricity supply that can power 4IR technology or even basic irrigation systems. In SSA LICs, only 20 percent of rural residents report having access to electricity, although solar energy offered through pay-per-use technology (a 4IR technology adaptation) could speedily change this situation. Very few farmers are using the Internet, through either fixed broadband ormobile.

The situation is better in LMICs, where 50 percent of the rural population has access to electricity.That is one reason why most of the action on adopting 4IR technology in agriculture is taking place inLMICs like Ghana, Kenya, and Nigeria. However, before the COVID-19 crisis, Ethiopia,Senegal, Ghana, and Rwanda had seen rapid, productivity-led output growth, in part bychipping 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, some of whom are keen to adopt this technology, which could also lower the price for other farmers in the area (Jayne et al. 2018). Thus, a case can be made for cautious optimism about post-COVID-19 technology adoption.

In sum, 4IR technology could reduce information frictions and lower the production and investment risk that pervades the whole crop and livestock value chain, but there are longstanding constraints African farmers must deal with, such as insecure land tenure and a lack of land sale and rental markets. Since these have continually held back technology adoption, private investment in the sector, and sector transformation, it is likely that they will also limit the adoption of 4IR technology, especially in LICs that have made little progress in addressing the constraints. Widespread adoption will also require significant expansion of the necessary ICT and energy infrastructure in rural areas. Yet if constraints can be overcome, increased adaptation and adoption in the agricultural sector could bring higher earnings and social benefits, the latter because lower rural poverty from higher SHF household income means rural children can be better educated and healthier.

We can therefore expect the agricultural development leaders in African LMIC countries to lead the way in using this technology if complementary public infrastructure investments and supportive regulatory frameworks are in place (see section 4). 4IR will not lead to the creation of formal jobs on the farm in Africa; all overthe world informal labor and family farms characterize the sector. But by raising agricultural productivity, adopting 4IR technology would speed the process of transformation, and government policy should encourage its use. To the extent that 4IR technologies used in precision agriculture save water and lower pollution caused by fertilizer and agro-chemical runoff, there would be major positive externalities—another reason for public policy to embrace and support use of 4IR technology in agriculture.

3.2 Industry

Industrial sectors include construction, mining, manufacturing, and utility services (e.g., energy and water supply). Within industry, manufacturing has attracted the most attention in terms of 4IR potential and challenges, but it is underdeveloped in Africa's LICs and LMICs, where the shares of output and employment are lower than the averages for all LICs and LMICs (Fox & Gandhi 2021). The lack of export manufacturing is often blamed for the slow employment transformation in Africa, and the related high informality (Filmer & Fox 2014; ACET 2017). Whether adoption of 4IR technology in richer countries reduces the potential for African countries to develop their own manufacturing sectors and compete internationally is highly relevant for future SSA economic development policy.

Manufacturing

For many reasons, SSA countries, especially LICs and LMICs, got off to a late start in developing a privately-owned manufacturing sector, including initial lower human capital and geographical and infrastructural obstacles to exporting. Because manufacturing output is highly tradable, for African firms the international competition is significant. In most subsectors manufacturing technology brings returns to scale (Murray 2017); small domestic markets force African manufacturers to export their products, except for very heavy items or those hard to transport (beverages, building materials). Factors limiting output growth in manufacturing include the cost of building and maintaining an internationally competitive plant, the costs of inputs like electricity relative to competitors' costs, and the cost of getting goods to market, especially overseas markets (including information frictions between potential sellers and borrowers). Nevertheless, manufacturing's shares of output and employment have risen over the past decade in Africa, especially East Africa, contributing to structural transformation (Mensah 2020). In some plants producing for export markets, labor productivity is quite high (Diao et al. 2021).

Technological change in manufacturing over the last 30 years has not favored late entrants. In part to standardize and improve quality, manufacturing has become more capital-intensive, and globally the labor share of value added has dropped (Rodrik 2016). 4IR technologies, especially advanced robotics, are accelerating this trend in middle- and upper-income countries, where for many manufacturing tasks new plants use little labor because robots have an absolute advantage over people. This global substitution of capital for labor particularly disadvantages developing countries, whose low-paid workers are no longer a source of comparative advantage so that there is no place for them in GVCs (Baldwin 2019). Meanwhile, to compete, countries must import expensive robots made in rich countries (Rodrik 2018), the financing of which is often expensive.

In considering the potential of 4IR technology to spur structural transformation in Africa by expanding output and employment in manufacturing—or hindering it—it is instructive to briefly review the experience of automation and advanced robotics in high-income countries, since that experience often drives the discussion in developing countries (Kenny, 2019). In the U.S., adoption of advanced robotics in manufacturing, including AI and IoT, is widely considered a factor in loss of middle-class jobs and 40 years of steadily rising inequality in wages, incomes, and wealth (Kenny 2019). Although the fact that total jobs in the economy grew during the recent automation period (Arntz et al. 2016; Gaus & Hoxtell 2019) demonstrated that automation does not necessarily lead to widespread unemployment, the job loss-job creation effects were not evenly distributed by gender, skill level, and region. In particular, between 1987 and 2017 there was a formidable drop in the share of medium-skill U.S. jobs (those requiring a high school diploma plus experience or vocational training), which are disproportionately held by men and disproportionately located in the industrial heartland in the Northeast and Northern Midwest (Acemoglu & Restrepo 2019). Meanwhile, demand increased for highly-skilled labor to design, deploy, finance, and maintain robots, which pushed up the wage premium for tertiary education (Acemoglu & Restrepo 2019). The changes in labor demand are blamed for the widening of earnings inequality.[19]

According to Acemoglu and Restrepo (2019), there are several reasons why advanced robotics has 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 the repetitive, physical tasks that had been common in medium-skill jobs. Not only did robots replace humans in auto and electronics assembly, but by using sensors robots also proved better at assembly-line tasks requiring judgment, such as sorting and grading food for processing and packaging. Another important factor is that in the U.S., although tax rates on labor have held steady for 20 years, tax rates on capital investments have plunged, as has the marginal cost of financing for capital investments. This means that in tasks where people and machines have similar productivity, or that of people may even be higher, the low cost of capital—low interest rates, accelerated depreciation allowances, low corporate taxes—favors robots. This difference in factor prices is helping to drive labor-saving technological innovations in the U.S., which then spread around the world through GVCs.

How relevant is the experience of the U.S. with 4IR technology to the possible role of 4IR technology in Africa's transformation? Perhaps not very. The type of displacement caused by automation in manufacturing in the U.S., and to a lesser extent in Europe, will not occur in LICs and LMICs in Africa because the jobs were never there in the first place. A notable exception is South Africa, which engages in a mix of assembly and production for domestic as well as regional export markets; it should be able to hold on to its manufacturing employment because it has logistics advantages over potential exporters within and outside the region. Similarly, countries like Lesotho and Eswatini, with light-manufacturing export sectors that can take advantage of South Africa's logistics and of trade preferences like the U.S. African Growth and Opportunity Act but pay lower wages, may be able to sustain manufacturing employment for up to 10 years (Banga and te Velde 2018). The critical question is whether 4IR technology, if adopted by Africa's late industrializers, could support transformation by increasing the share of manufacturing in output and employment, thus creating new formal jobs, or whether the technology might reduce manufacturing jobs in Africa.

Researchers and observers have mixed views on 4IR technology and manufacturing employment in Africa. Banga and te Velde (2018) are among the optimists, noting that the manufacturing sub-sectors in SSA that have recently grown, such as textiles, garments, leather, and furniture, have also been more resistant to automation. If African countries can sustain a labor cost advantage, they could expand output and employment in these subsectors, especially if 4IR technology deployed in other sectors reduces costs inside the factory (complementary inputs, such as the cost of electricity; see below) and outside it (e.g., transportation to markets). Banga and te Velde (2018) provide the example of the "A to Z" garments factory in Tanzania, where automated laser cutting reduced cutters' jobs but more productive and better cutting led to increased orders,

[19] Other factors, such as globally mobile capital but labor that is immobile and disempowered, undoubtedly contributed to the U.S. result.

so that about 5 percent net new jobs were created. This is an example where automation reduced the number of jobs per unit of output, but lower unit cost raised 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 price-competitive with labor in the U.S., in Kenya they will not be price-competitive with labor for at least a decade. They therefore predict that the share of manufacturing employment could rise first before declining.

Pessimists, however, note that factor prices (e.g., low-wage labor) matter much less for competitiveness in manufacturing than they used to (Baldwin 2019). In fact, payroll costs in export manufacturing plants in Africa are now less than 15 percent of total costs, and only slightly higher in garment plants (Diao et al. 2021), so that low wages are no longer an African advantage. Increasing economies of scale in production and increasing quality requirements in transport and distribution are cited more often than labor costs as determinants of where to locate a manufacturing plant (McKinsey 2019a).[20] This is not an area where Africa excels compared to the rest of the world (World Bank 2019b). Except in South Africa, where the logistics sector is well-advanced (AfDB 2018) customs and other border delays for imports and exports are much longer in Africa than in other developing regions, impeding competitiveness. That is why Baldwin (2019) predicts that manufacturing's share of employment in Africa will go down.

The problem for Africa is that in order to be competitive and attract investment, late industrializers must adopt the technologies their competitors use and join GVCs. Comparing the capital intensity and the technology used in productive export manufacturing plants in Tanzania and Ethiopia with plants in Vietnam and the Czech Republic, Diao et al. (2021) found them to be similar despite vastly different factor endowments and factor prices. They conclude that if African export manufacturers to compete with those in richer countries, they have no choice but to import the capital-intensive technologies developed in rich countries. Some have suggested that owing to the spread of GVCs 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), for Africa the door to employment transformation through growth in exports is closing fast, or may even have closed already (Hallward-Driemeier & Nayyar 2017; Technopolis et al. 2019).

4IR technology makes it cheaper to customize production, which is disrupting the economies of agglomeration that have held back the development of competitive manufacturing sectors 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 like 3D printing reduce the need for scale. Thus 4IR technologies could make manufacturing more democratic, and more profitable in smaller land-locked countries. Medium and even small enterprises will be able to enter the market, set up shop in African cities far from international ports, and supply a wide variety of industrial and consumer goods without delay or transport costs, and without needing to invest heavily in machinery to produce specific parts. This is likely to decrease costs of production, increase productivity, increase demand for products, enable new firms to enter markets, decrease the cost of trade, and bring more companies into GVCs in Africa. These impacts will spread to the labor market, where there could be an increase in manufacturing jobs in high-skill areas like programming and maintaining 3D printers. 3D printers could also give a boost to Africa's burgeoning design sector. Already, entrepreneurs have set up shop in Nairobi using 3D printers to manufacture items out of waste products based on open-source designs—an example of one 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. Financing capital investment is cheaper in Asia and the West than in Africa, where capital markets are less developed (Technopolis et al. 2019; The Economist 2020). While 3D printers are cheaper than a whole

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[20]Hallward-Driemeier and Nayyar (2017) have found that services embodied in traded goods account for one-third of the value of manufactured exports in OECD countries—a major reason why shop floor wages matter less and less for manufacturing competitiveness.

manufacturing plant, they still require investment in imported machinery and continued reliance on imported inputs. Deloitte (2016) reports that the cost of 3D printing machines has reduced their adoption in markets like South Africa, even though it has a large supply of workers with digital skills. In countries open to foreign direct investment (FDI), multinational 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 high skills to operate, such as knowing how to work with computer-assisted design platforms (CAD). To be able to create or modify products that respond to needs in Africa markets, even more sophisticated CAD skills are required. 3D printing is an area where partnerships between higher education and private industry to set up technology hubs could speed adoption of advanced technology (see skills discussion below).

Given the capital intensity, reduction of labor, and skill bias of its manufacturing technology, 4IR is unlikely to create vast amounts of new, formal, manufacturing jobs in Africa, even though the technology can help Africa to retain or increase its share of global manufacturing output. On the other hand, the diffusion of 4IR technology to African manufacturing is not likely to be job-destroying, as it was in the U.S. The global diffusion of 4IR technology in manufacturing probably means that to stay globally competitive African companies will have to start adopting 4IR technology within a decade or so. But will African countries have in place the financing and supportive infrastructure that entrepreneurs need for the technology to be profitable? For entrepreneurs and others who can acquire the skills required—a select group, mostly young—some higher-earning employment opportunities should be available in small-scale production for local or regional markets. Finally, 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 high-level digital skills (Banga & te Velde2018).

Mining

While the sector is not a large employer, the share of mining jobs in SSA is larger than in similar countries in other regions because it has large mineral reserves, a large proportion of which is still unexploited (Fox & Gandhi 2021). For instance, 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 exporting minerals in Africa has shot up over the past 10 years, so that only a handful of SSA countries are not mineral exporters (Chuhan-Pole et al. 2017). Mining operations create jobs indirectly in surrounding communities, through backward and forward links, and revenue from mining leases supports public administration and service provision, which also create jobs.

Wage jobs with formal mining enterprises—mostly foreign—are well paid in Africa, though informal artisanal mining tends not to pay well (Chuhan-Pole et al. 2017). Mining is physically difficult and often dangerous due to work accidents and exposure to dust and toxins (Stewart, 2019). Around the world, 4IR technology—robots and sensors—is already being used in mining, 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 the jobs that remain (Gaus & Hoxtell 2019; Technopolis et al. 2019). In Africa 4IR technology is mostly being adopted by large multinational mining companies; Africa's dangerous informal artisanal mining industry is not likely to be affected.

Global demand for rare earth minerals offers new opportunities for Africa if more mineral reserves can be identified and profitably exploited. 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 $0.40 per kWh vs. $0.10–0.20 per kWh from grid-based energy (IFC 2019). Nigerian electricity users spend three times as much on back-up generators as on grid energy (IFC 2019). Generators are powered by burning diesel fuel, which emits emissions that are both a health hazard and a contributor to climate change. Grid electricity in Africa still depends heavily on fossil fuels, even though renewable sources like sun, wind, and hydro are abundant (IFC 2019). The cost of energy and its unreliability are often cited among the top three obstacles to business expansion in SSA (IFC 2019) and is already an obstacle to adoption of 4IR technologies in many sectors.

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 creation of new wage jobs and increased earnings for enterprises of all sizes. By using IoT and other 4IR technologies (Technopolis et al. 2019), non-revenue energy use (electricity theft) could be reduced, which would improve 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, e.g., solar panels, windmills, and the batteries needed to store energy for nighttime use or when the wind dies down.

One major factor deterring adoption of technology is the quality of operational and financial management in legacy state-owned enterprises (SOEs). Major structural reforms are needed in the electricity sector in order to overhaul regulation of SOE monopolies or move to competitive private sector models. Generation of electricity is often cited as most likely to benefit from a private sector approach (Bond 2016).

In sum, Africa will need 4IR technologies to transform industrial sectors, make them more competitive, broaden the range of products made in Africa for local consumers, and lower their prices. But although these demand and competition pressures will surely encourage technology adoption, the prospects for large-scale increases in employment and earnings in the sector, with or without, are moderate. While the new jobs created through industrial upgrading are most likely to be formal, stable, and higher-earning, they will also require more skills than do jobs in traditional light manufacturing; in other words, this part of the transformation might not be inclusive. Not considered in this section are the employment implications for the service side of manufacturing—marketing and sales, which could gain employment share if manufacturing output as a share of GDP grows. In the next section, we turn to the opportunities and challenges of 4IR technology in services.

3.3 Services

Services is the most heterogeneous sector; it covers 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.).[21] For the most part, providing services is labor-intensive, but among notable exceptions are transportation, ICT, and finance. The share of services in output and employment has grown rapidly throughout Africa, yet beyond the public sector, most jobs in services are informal (Fox & Gandhi 2021; Diao et al. 2021).

It used to be conventional wisdom that services could not contribute much to economic growth and transformation because their potential for productivity improvement was low.[22] 3IR and now 4IR technology

[21] Nearly half of employment in services is in publicly owned and operated production units, e.g., public administration, education, and health and social services. This paper does not look at adoption of 4IR technology in these units. For a discussion of opportunities and challenges within the public sector, see Signé (2022).

[22] W. Baumol's famous question—"How do you increase the productivity of a string quartet?"—is still sometimes used to characterize the purported lower growth and productivity potential of services.

has changed this picture. For example, containerization and digital trading records have reduced international shipping costs by more than 90 percent since the 1960s—a huge productivity improvement (Murray 2017). Since 1987 wholesale and retail trade in the U.S. has recorded annual productivity growth of 1.3 percent (Gollin, 2018), reflecting technological changes that include using computers and 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 & Hoxtell 2019). The air transport sector became more productive over the last four decades by adopting barcode and sensor technology to manage the loading and unloading of passengers and freight. The Internet has revolutionized tourism because most activities are now planned online; in high-income countries the occupation of travel agent has almost disappeared (Acemoglu & Restropo 2019). The healthcare sector has substantially automated by using robots, sensors, and modern software to manage complicated supply chains more effectively. 4IR technology, including platforms, is spurring the development of e-commerce, the gig service 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).

Such 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 digital technology but also informal roadside stands, kiosks, and market stalls, which sometimes sell the same products (Fox & Sohnesen 2016). Productivity improvements in domestic freight transportation and logistics have been few; as a result, other than in South Africa, costs are high and delays frequent (McKinsey 2019a; 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 are airports (including air freight) and high-end hospitality, which use all the latest technology to provide the level of service that international and business travelers expect, and the financial sector, where Africa has the highest rate of mobile money adoption in the developing world (66 percent; AUC/ OECD 2021).

Service sector output and employment are expected to grow rapidly in Africa, which will result in structural transformation as the share of employment in formal jobs grows. The projected growth reflects both increased demand as incomes rise and ease of entry into service sectors for Africa’s growing labor force, especially in the case of informal services. Demographic dynamics imply that low-tech, informal services will continue to offer employment opportunities for a large share of the labor force, even as formal services also increase their employment share. The business models and employment dynamics in the sectors where formal firms dominate are quite different from those in sectors where informal firms dominate, so it makes sense to consider separately the potential of the two groups to adopt 4IR technologies.

Services primarily provided by formal firms

Several authors consider 4IR technology adoption crucial for the expansion of the formally-supplied African service sectors, permitting exports to grow, bringing higher-earning, more productive jobs. 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, thanks to digital technology in Africa service exports grew more than six times faster than merchandise exports (Newfarmer et al. 2018). 4IR technology could push this process forward even faster, primarily by increasing market access and improving product quality.

The importance of ICT for process and product innovation in African firms, especially in services, has already been recognized (Houngbonon et al. 2021), and is expected to continue. One example of how 4IR technology can solve longstanding market access and development issues is tourism: In Africa tourism has been a major source of income growth and jobs at different skill levels, from customer-facing jobs, which tend to require higher skills to low- and medium-skill jobs in cleaning, transport, and maintenance. In Tanzania, tourism accounts for 14 percent of GDP; in South Africa, it creates 36 percent of food and beverage jobs (Page 2019). Consumer spending on tourism in Africa is projected to double between 2015 and 2030 (Signé 2020); 4IR technology could push this growth even higher, to the benefit of large, formal African businesses. In countries with adequate Internet coverage, the cloud, AI, and blockchain may be able to further facilitate travelers' access to transportation or other services upon arrival. For example, the international expansion of Uber and the development of local ride-hailing transportation platforms provide a safer environment for international passengers seeking land transport options. 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 further make the visa and entry process for international travelers more secure if governments adopt the technology. Meanwhile, smartphone-based navigational mapping can continue to support transportation for both tourists and residents. Photos posted online on social media and other platforms can attract travelers to Africa's unique geological and historical sights. The large number of international firms already operating tourism-related businesses will likely drive adoption and diffusion of this technology, as well as create an organized interest group pressuring governments to reduce regulatory hurdles while increasing Internet security (similar to the process with digital technology and banking in Africa).

Baldwin (2019) argues that 4IR technology, which has drastically reduced the cost of face-to-face communication, will enable extensive 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) 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 like the Philippines and India (PfPC 2018). It is not clear that this "first-wave" BPO is a growth sector today; much first-wave BPO business could soon be replaced by robots, AI, and IoT technology, and may then revert 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, that is more focused on customer-facing skills and enabled by video communications software. Banga et al. (2020) and Baldwin (2019) note that Africa's often landlocked geography in the south, which is a disadvantage for manufacturing, will not matter for future service exports because 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 the 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 owing to the lack of complementary factors needed to make these businesses profitable. One issue is skills. 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*."

Most of Africa is at a skill disadvantage compared with Asia. While African wages are low in PPP terms (the cost of living) they are high in U.S. dollars, 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[23]) may have more potential to grow fast and create new employment opportunities, while the continent's prospects in the second wave of BPO may be less rosy.

Services for domestic or regional markets show more potential for expansion of output and formal wage employment through technology adoption. 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-

[23] See discussion in Signé 2022.

commerce operators have had one of the largest employment impacts to date of any Internet start-up subsector. For example, in 2020 Jumia Group, the Nigeria- based e-commerce company, had over 7,500 employees (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 must deal with problems like cross-border payments and logistics, but 4IR digital technology is enabling fintech companies and the private logistics sector to become a growth industry. The expansion of digital currencies based on blockchain technology as a means of payment could ease the difficulties of cross-border payments, allowing an even faster expansion of e-commerce sector—if such digital currencies are not blocked by central banks. As e-commerce takes off, through both B2B and B2C business models, entrepreneurs are setting up digital platforms linked to brick-and-mortar warehouses and contracting with transport providers for the services start-ups need. Individually, these companies are not large employers: For example, in 2020 Kobe360, a well-known Nigerian logistics company, had only 149 employees, and Twiga foods in Kenya had 275. But through their links with farmers and independent truckers, they helped raise and stabilize incomes (AUC/OECD 2021).

In the financial sector, arguably in Africa adoption and adaptation of digital technology (3IR and 4IR) has directly and indirectly raised output and productivity the most while also providing innumerable opportunities for improved employment outcomes. 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, while Africa's retail banking penetration is low, just half the global average for emerging markets (Chironga et al. 2018), households and businesses can still save and transact securely. Retail banks will continue to struggle to find consumers given the prevalence of low incomes, the popularity of cash, high fixed costs, and thus high fees for small accounts, so that Africa is likely to continue to lead the world in 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. African banks lack information on the credit of individuals (Chironga et al. 2018). 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 bank branches. Digital credit risk management, for example, uses automation, connectivity, and digital delivery and decision-making to allow for faster decisions and risk assessment that is superior to current manual processes (Signé 2022). Advanced analytics and machine learning can further 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. Studies have documented the positive impact of fintech services on the performance and growth of micro, small, and medium (MSM) enterprises throughout Africa (Signé 2022). Enhanced use of 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.

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, by increasing and protecting women's savings, access to M-Pesa accounts allowed women to move out of subsistence agriculture and start were trained to access microfinance services 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 had access to mobile money savings accounts increased their earnings from economic activities and their bargaining power in the household (Ahmad et al. 2020). Uniform national identity systems, often based on biometric identification (another 4IR technology), has helped improve system security and functioning and has enabled the mobile money 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, but adoption of these financial innovations in Central and Southern Africa remains relatively low (AUC/OECD 2021).

In sum, 4IR technology could rapidly speed economic transformation and employment growth in formal service sectors in Africa. Many of these sectors have already shown ample scope and readiness to adopt new technology, providing many new, higher productivity employment opportunities; this trend can be expected to continue, speeding the shift of employment out of less productive sectors. Some service 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, supporting technology adoption by other sectors. Some sectors, such as wholesale and retail trade, can be expected to expand employment as rapidly as output, creating formal employment opportunities for Africa's moderately-skilled workers. In these people-facing sectors, technology makes labor more productive but does not eliminate the need for humans. While some of Africa's long-standing productivity and innovation constraints (e.g., expensive and high-cost energy) may slow the adoption of technology in some countries, the owners and managers of African domestic and international formal firms have already demonstrated the potential to work around these constraints to expand their businesses and profits.

Services mostly provided by household enterprises and self-employment

Provision of informal services by self-employed people and household enterprises is the fastest- growing employment category in Africa today (Fox & Gandhi 2021). Over half of informal businesses engage in retail trading, selling a broad range of products almost exclusively 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. They are patronized because (1) they are convenient, or (2) they sell in small quantities, matching the cash flow of their customers (e.g., a few tomatoes, less than a full pack of cigarettes, small quantities of cooking oil or dish soap). Informal businesses also perform services for individuals, such as custom tailoring, dressmaking, and repair of small items. They run small hospitality businesses, such as renting out a room or operating a small bar or fast-food restaurant. [24]

Most individuals and households start an informal business not because of entrepreneurial drive but because of a shortage of wage jobs in the economy (Fox et al. 2020; Lorenceau 2021). Very few grow enough to employ anyone outside the household (Filmer & Fox 2014). They face high risks from competitors, who can easily enter the sector. Their advertising is word of mouth. The businesses are poorly capitalized. Often informal sellers of goods and services cluster in specific areas so that customers can find them easily or they work at home, but others roam the streets looking for customers. Those who operate a business outside of their home often travel long distances, hauling inventory and equipment, such as tables, display cases, and scales (Chen & Carre 2020). The urban environments where they operate usually do little to support these businesses; many city governments actually undermine their productivity directly by denying them access to spaces in which to work and municipal services that could support their business; others permit police to harass business operators (Filmer & Fox 2014; Chen & Carre 2020). Under these circumstances, any investment, especially in new machinery, is risky. As a result, their use of technology is extremely limited. In urban areas many have a mobile phone to connect with customers or suppliers and use mobile money, although access in rural areas and small towns is lower (AU/OECD, 2021). Use of the Internet is rare (AU/OECD, 2021), despite evidence that when a community gets access to high-speed Internet, the probability that a household operates an informal service business goes up (Houngbonon et al. 2021).

[24] For a detailed description and analysis of this sector in SSA, see chapter 5 of Filmer & Fox (2014).

Several studies suggest that adoption of 4IR technology would allow many self-employed, family-employed, and dependent contractors to raise their earnings and "formalize" (PfPC 2018; Choi et al. 2020). Significant earnings gains have already been realized in this sector with the adoption of mobile phones, which improved communication between suppliers and customers and provide access to finance (Choi et al. 2020). The expansion of mobile phone technology has allowed people, mostly women, to leave subsistence agriculture and start businesses, which has raised their earnings (AUC/OECD, 2021). Optimists point to the experience throughout the world of digital platforms in connecting service providers and customers, reducing downtime for owners of household businesses and search time for customers. The use of mobile platforms, like Etsy in the U.S., to sell home-made products has in some cases led to more stable income and more reliable payments. For example, by reducing customer discovery and transaction costs, the e-commerce platform Alibaba has helped many family businesses in China to connect to the vast domestic and international markets. Transportation platforms have made the process of ride-hailing—supplied by informal-sector drivers of cars or motorcycles—more efficient, providing much better service for customers and safer working conditions for drivers (PfPC 2018). The expansion of e-commerce in Africa has created demand for bicycle, motorcycle, and taxi drivers to provide on-demand delivery services for vendors, including food service vendors, in the process creating more and better informal jobs.[25] Some observers envisage these platforms as being used routinely to request and book services delivered in-home by informal service providers, such as hairdressers and manicurists, and to find a reliable self-employed craftsperson (e.g., plumber, gardener, home repair person).

However, aside from improving the productivity of on-demand drivers, the promise of 4IR technology seems elusive given the reality of African non-farm informal sectors. Because the business models in these sectors are simple, attempts to "formalize" them as a steppingstone to business growth and stability have had limited success (Bruhn & McKenzie 2014). In fact, many interventions confuse cause and effect. The issue is not whether informal businesses pay taxes or register the business; in most cases their earnings are low enough to slide under the floor for paying taxes, and in any case local authorities often require them to pay taxes, fees, or bribes (Filmer & Fox 2014). The issue is how these businesses can reduce their precarity enough to make it feasible for them to adopt new technologies to improve productivity. Thus, the issues are the business model and the environment in which they operate.

Some have argued that 4IR technology is a boon for women working in the informal sector (Choi, et. al., 2020). Around the world women working informally earn less than men (Chen & Carre 2020). One issue is mobility. Women often have to work from home because they have of unpaid household responsibilities or it is hazardous for them to leave home because of, e.g., unsafe public transport, workplace harassment, or norms that punish women's mobility. Broadband Internet could allow women to balance paid and unpaid work by taking on services activities on a flexible schedule (see citations in Hunt & Samman, 2019, section 3). But first, they need access to the Internet, another area where women are quite a bit behind men (Bailur 2020).

In any case, the growth of women in crowdwork is a work-around for the mobility constraints holding women in business back, not a solution. Crowdwork earnings are often very low, below the minimum wage in many countries (Hunt & Samman, 2019). Hunt and Samman (2019) point out that women in Africa are more likely to be in crowdwork than in activities that use platforms to get customers (on-demand work), where earnings tend to be higher. Sadly, women earn less than men in both on-demand activities and crowdwork. Studies to measure the impact of COVID-19 on work revealed that for women, the burden of childcare reduced their competitiveness in online platform work as they had fewer hours available so were limited in the jobs they could compete for (Siddiqui & Zhou, 2021). Meanwhile, in the on-demand economy, patterns of occupational segregation persist; men still dominate the transport sector, for example—perhaps because women have few opportunities to learn to drive. Women drivers face additional harassment while doing the work (Siddiqui &

[25] Most drivers are required to register their vehicle with the local municipality (if they own it; if not, the owner should do so). Because they also must have a drivers' license, they are not completely informal (unregulated by the state). However, these drivers rarely have a business license or a separate bank account for the business , so they would not be considered formal.

Zhou 2021). Hunt and Machingura (2018) and Siddiqui and Zhou (2021) show that platform technology reinforces old discrimination patterns through ratings and review systems.[26] Chen and Carre (2020) document the isolation often felt by informal home-based workers, which leaves them vulnerable to exploitation. These examples confirm once again that 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 because of their higher quality. 4IR technology mostly complements, rather than substitutes for labor in these sectors, so as African economies grow, wage jobs, mostly formal, can be expected to increase with technology adoption. Exported services could become a significant, if not large, source of both wage and nonwage employment, whether through platforms or contracts between formal firms. Domestic retail trade is likely to be a major source of future formal employment as business gradually shifts away from informal traders. Decreasing informality in some occupations and sectors could improve jobs on the intensive margin (earnings, income stability, and safety) for those remaining informal. 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 in Africa seems to be an improvement over previous employment relationships, but for home-based workers the evidence on whether employment conditions have improved is thin.

Nonetheless, most employment in services is currently informal and likely to remain so, at least in lower-income countries, in part due to the pressure of labor supply—a growing labor force. If inclusion-oriented policies lead to increased private ICT investment and falling prices for Internet usage, informal service suppliers may start to benefit from using ICT, setting up websites, for example, and advertising on social media sites like Facebook. But we do not yet have evidence on the use of Internet platforms by informal household businesses in Africa; effects could be both positive and negative. Would an electronic record of transactions simply lead to higher taxes? Or could it also lead to access to a more secure income and an improved safety net? Most important: Is the public sector prepared to help the informal sector make money and keep their businesses going, rather than treating them like pariahs to be eliminated as part of urban cleanup efforts (see the discussion in Chen & Carre 2020). These productivity issues are not solved by technology. They reflect policy decisions—some made even before 3IR.

As with agriculture and manufacturing, technology adoption in services will depend on access to and the price of complementary inputs (energy, transportation, and ICT services), as well as supportive regulation that encourages new business to enter and more productive businesses to expand. These constitute direct challenges to Africa's governments. Africa's new country governments, which are poor, may struggle to meet this challenge. Cultures and ways of working in the public sector may have to change, and prioritizing government initiatives and investments to deal with the challenges is essential. We turn to this topic in the next section.

[26] Siddiqui & Zhou (2021) cite the case of a Kenyan woman who adopted a male name for her on-line identity to avoid this type of discrimination.

4. The main challenges and the way forward

One common theme was present throughout the discussion so far: In order for the private sector to undertake the needed investments to bring the potential transformative economic development and employment opportunities of 4IR technology to Africa, public policies and investments must provide a supportive enabling environment. Many authors have discussed in general the challenges confronting governments wishing to harness the potential of productive technologies like those of 4IR to create quality jobs (AUC/OECD 2021; Choi et al. 2020; Calderon et al. 2019). 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. The COVID-19 pandemic substantially increased the strength of those barriers. The shift in donor aid flows and public spending toward health and social protection and the suspension of education and training have drastically complicated the ability of governments to direct resources to enabling investment to improve employment opportunities. The difficulties are heightened in lower-income countries, where there are shortages of essential infrastructure and public resources are scarce. It is therefore important to understand how difficult it can be for governments to create an environment that will induce 4IR technology adoption in order to positively impact employment and economic growth trajectories, and to explore options for surmounting the difficulties.

Challenge 1: Governance: Inadequate regulation and unsupportive business environments

Despite variations between countries, it is well established that weak governance and Africa's poor regulatory structures currently deter firm entrance and growth, which are a prerequisite for economic transformation and for increasing the amount and share of formal wage employment (AfDB 2018). Africa's excessive red tape and corruption discourage both domestic and foreign investment, at the cost of jobs (AfDB 2018). As a consequence, because fewer firms enter and grow, fewer new formal wage jobs are created. Poor regulation also inhibits upgrading of the mechanical and managerial technology needed for African firms to remain competitive in a globalized economy (Choi et al. 2020; AUC/OECD 2021). Unfortunately, too often policymakers and economic stakeholders are not aware of the importance of industrial upgrading through technology if there is to be economic growth and job creation (AUC/ OECD 2021). Often, too, governments do not have the skills to respond effectively to 4IR regulatory and investment challenges.

The legal environment for business (regulations and implementation) does not sufficiently encourage importation of 4IR technology in the form of inputs or capital goods. 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, but despite recent increases, FDI in Africa is low—it was only about $46 billion in 2018, and little of it was directed to the ICT sector or the adaption and adoption of 4IR technology (UNCTAD 2019).

One important public policy focus for African countries is to enable financial sector deepening. Governments regulate contracts and payments systems, but the 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 establish 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).

Access to finance is one of the biggest challenges for high-tech companies, not only for acquiring technology but also for scaling operations. 4IR technology is expensive, and the high fixed costs must be financed. Limited access to finance is a major obstacle to firm entrance, survival, and growth, especially for young entrepreneurs: It complicates 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 the 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 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 limits this option.

Governments also need to focus on the business environment for farmers. Adoption of technology in the agricultural sector, which is desperately needed to raise earnings and productivity, is primarily inhibited by risk, created in part by weather cycles exacerbated by climate change, information frictions, and insecure land tenure. The public sector cannot eliminate weather risk, but it can adopt policies and programs to reduce information frictions and land tenure insecurity so that adopting productivity-enhancing technology is encouraged. It can also invest in the development and dissemination of this technology through publicly-financed agricultural research.

4IR raises new issues for public sector regulators, such as ensuring cybersecurity. Cybersecurity is crucial at the individual, corporate, leadership, and systems levels. 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 and digital data systems, and to ensure the sustainability of the firms creating jobs. With any digital infrastructure development, governments must pass laws to protect the data and privacy of their citizens and put in place critical infrastructure to avoid disrupting firms with cyberattacks, which could impact jobs. Governments are not yet really aware of how important it is to keep the public informed about such issues as cyber security, which compounds the problem. Similarly, governments are scrambling to effectively regulate drones to avoid interference with aircraft as their use is growing (Technopolis, 2019).

Way forward 1: Upgrade regulatory institutions, improve business environments, and create inclusive policies.

Regulatory frameworks must be restructured if innovation policies are to be effective (Oyelaran-Oyeyinka 2014) and to capitalize on the 4IR technology to ensure that quality jobs are created (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. Ease of doing business depends on reforming government legislation, regulatory policies, and implementation, including service provision. Reforms should aim to facilitate the legal process of creating a business, obtaining licenses, and registering intellectual property so that firms can enter the market faster and more efficiently (Signé 2020).

It is also important that standards, rules, and regulations be firm-friendly for both domestic and foreign investors, especially in terms of protecting intellectual property ownership (Deutch 2005; IFC 2016). Increasing FDI has enormous potential to accelerate firm digital transformation and innovation. Beyond the skill and technology transfers that come 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 adoption of 4IR technology in Africa. Public policy should encourage development of new sources of finance for 4IR technology adoption—domestic and foreign—by encouraging web-based platforms to bring together entrepreneurs and investors, including equity-based and early-angel investors. Regulators should encourage the broader use of blockchain technologies in areas like trade credit because these technologies remove the need for an intermediary, which reduces financing costs (Technopolis et al. 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. Digitalizing tax collection could also 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 program, increased funding for R&D, and is proactively encouraging the further development of M-Pesa and other fintech solutions.

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 and it can also facilitate the emergence of private sector networks to address business information asymmetry.

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, such as 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 protection of the privacy rights of citizens (AUC/OECD 2021). Other recommendations include establishing a cybersecurity agency dedicated to firms and citizens as well as national intelligence and defense or other internal government agencies; creating a service to accredit service for providers; and adopting an emergency response plan for cyber-attacks on firms (Fadia et al. 2020).

Tax reforms, including incentives to encourage investment and employment, technology adaptation and adoption, and incentives for R&D, are also widely recognized as tools to encourage innovation, quality job creation, and social inclusion (World Bank 2019b; Choi et al. 2020; PwC 2010; AUC/OECD 2021; Armstrong et al. 2018; Millington 2017). Rwanda, Cameroon, South Africa, and numerous other African countries use a variety of tax incentives (among them 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, e.g., investment amounts and number of jobs created (KPMG 2017). However, sometimes there is no follow-up once the investment is complete so the effectiveness of employment tax incentives is unknown, and probably limited (Ebrahim et al. 2017).

South Africa may be using incentives effectively: It introduced the R&D tax incentive in November 2006, along with other measures to stimulate private sector R&D. It has demonstrated how tax incentives can be part of broad institutional support for innovation and R&D: The incentive is overseen by the Department of Science and Technology, which also manages a variety of relevant programs and agencies, 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 innovation that could be commercialized (Naudé 2017). For tax incentive mechanisms to be effective, however, corruption and clientelism must be minimized—as they must also be in public and private governance.

Finally, in the context of the African Continental Free Trade Area, which aims to create a single market for 55 African nations, governments should also accelerate cooperation to remove roaming fees at the continental level and successfully harmonize or integrate payment systems and cross-border payment mechanisms so that intra-African trade, especially e-commerce and trade in services can accelerate (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, such as electricity, the Internet backbone, fixed broadband, mobile telecommunications, communication satellites, network infrastructure, data centers, and cloud computing.

Expanding electricity and transport infrastructure, and, more recently, ICT infrastructure, is one of the biggest challenges for 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 in Africa electricity is more expensive than in 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 because of 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, especially in electricity, dates back to the colonial period; its effects 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 social benefits that are high enough to exceed the cost (AU/ OECD 2021), many countries are still behind 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). Although since 2010 access to mobile phones in Africa has expanded faster than anywhere else in the world, too many households, especially in rural areas, still do not have access to mobile telephone connections or mobile Internet (Leke & Signé 2019), mainly because mobile phone and Internet connectivity are so expensive. The high cost is in large part due to import tariffs on infrastructure materials, failure to encourage competition, failure to require low-priced minimum packages, and the common practice of governments imposing inconsistent fees and unequal taxation on ITC firms (BC 2019). In U.S. dollars, the average price for a low-usage package in Africa is below the average for all developing countries, but in purchasing power parity or as a percentage of GNI the price is quite high. On average, users pay 8.25 percent of their monthly incomes to purchase 1GB of mobile data, compared with the UN Broadband Commission target of 2 percent (Latif Dahir and Kazeem 2018). Notably, less than 20 percent of Africans can afford 1GB of mobile data account (AU/OECD, 2021).

Way forward 2: Increase access to technology and close the gap in physical and digital infrastructure, especially in sectors with potential for high-quality jobs.

Closing the physical and digital infrastructure gap to address employment will require African leaders to act boldly to capitalize on 4IR innovations. 4IR 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 and informal businesses can become more productive. Some studies suggest that priority be given to fixed broadband penetration and electricity, which are more closely linked to accelerating job growth than mobile Internet access (Calderon et al. 2019). However, other observers suggest that Africa could leapfrog over fixed-line broadband and simply adopt 5G infrastructure, including free public Wi-Fi in urban areas (Technopolis et al. 2019).

Equipping rural areas and towns with affordable Internet access will provide enormous resources for participation in the digital economy. ICT infrastructure in small cities and towns would allow these places to act as transmission hubs to 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 in this effort should be encouraged: The COVID-19 shock and response have decimated public finance. Alliances between public and private actors can help provide cost-effective solutions to allow access in less densely populated areas (Chakravorti & Chaturvedi 2019; AU/OECD 2021; PfPC 2019). For urban informal operators and digital start-ups, extending Commons within a spectrum-sharing environment would help expand access while keeping prices down.[27]

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

To influence the market and foster competition between ICT firms, the government can auction off spectrum licenses to encourage new players to enter the market (AU/OECD 2021; PfPC 2019). A variety of solutions have been offered to the problem of broadband affordability, among them expanding the spectrum/broadband, increasing competition between 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 by only providing high-usage, high-cost bundles and thus excluding lower-income users.

Proactive strategies to promote 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; government and nongovernment programs aggregating their demand would guarantee a market and could encourage network expansion (PfPC 2019). Governments should restructure taxes so they are not discriminatory and also provide incentives to firms that prioritize underserved communities (BC 2019). Universal service funds, sourced from ICT industry taxes, 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 uninformed program managers. Instead, governments should encourage or require the ICT industry to raise the cost of services in cities and other more prosperous areas in order to subsidize the loss of revenue in 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, especially women within these households, will require government programs, nudges, and regulation. Ultimately, ensuring access and protection for all will unlock extensive opportunities for workers and entrepreneurs to participate in a competitive marketplace.

Challenge 3: Inclusive skill development for technology adoption

Unlike the technologies of 1IR and 2IR—which 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 not consumer-facing are being eliminated around the world by digital and 4IR technology, which for many tasks has an absolute advantage over humans, especially for tasks that are routine, physically demanding, or dangerous. As Rodrik (2018) and other have noted, this reduces the comparative advantage in a globalized economy of African countries, whose workforce is low-wage but less skilled.

One overarching recommendation to counter the loss of comparative advantage that is often found in reports on 4IR and developing countries is to raise the skill level of the labor force up to meet the needs of 4IR technologies, especially in 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, the humanities, or even secondary education; as a result, despite a major expansion of post-secondary education, the supply of technically-trained graduates in STEM fields in Africa has not increased very much. More importantly, despite a rapid expansion of educational access, African countries still need to expand primary and secondary infrastructure owing to 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.

Thus, with resources limited, 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, from which will emerge most of the future labor force, especially those who will make a living in the informal sector. 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 recently catching up somewhat, Africa's youth trail their counterparts in other regions in educational achievement, a situation that is expected to persist (AUC/ OECD 2021). Primary and secondary (basic) 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, too many students in African countries leave school without having mastered the skills 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 had minimum proficiency in mathematics (Arias et al. 2019).

Skills deficiencies in basic education minimize the region's transformational potential (Choi et al. 2020) and reduce the inclusiveness of economic growth. Informal operators as well as low-skilled labor in the formal sector rely on the basic education system to build the skills they need for productivity and earnings to grow. 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 use this information effectively (Fabregas et al. 2019). This requires that they be literate and have basic cognitive and problem-solving skills. Many proposals for ways to increase job mobility and ensure the labor force remains productive and in demand over their lifetime call for "lifelong learning systems" and more on-the-job training (World Bank 2019a). But skills beget skills: Children need first to learn how to learn early in their education; otherwise, life-long learning cannot be a reality (World Bank 2018). Furthermore, development of technical, vocational, and other higher-order skills must build on a foundation of basic cognitive skills (World Bank 2018).

Post-secondary education systems are also struggling. Except in South Africa, the quality of education in African universities is low. Tests in Kenya and Ghana found 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 few and their quality is low (Arias et al. 2019). In Africa there is currently a misalignment between the skills taught in post-secondary education and the skills the job market demands. Already, employers in medium and large firms in SSA, especially exporters, report that inadequate technical education can limit firm growth (although not as much as other factors, such as energy supply and costs; 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 local labor markets, and face no pressure or incentives to improve the relevance of their curriculums. 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).

In Africa technical and vocational education training (TVET) programs generally fail to deliver value for money (Arias 2019). Curricula and teaching methods in Africa seem to be stuck in the mid-20th century, when a narrow set of vocational skills was adequate for a lifetime of work. TVET systems are not well linked 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 tends to be two to six times more expensive than general secondary education, raising questions about sector expansion given the need for more students to complete general secondary school (Fox 2019). A study in Egypt concluded that TVET graduates depressed their lifetime earnings by attending these institutions (Krafft2018); similar results were found in Kenya (Hamory Hicks et al. 2016).

Building the skills high-tech sectors need is expensive, and Africa does not have the necessary financial resources. In SSA, countries are already spending about 4.5 percent of their GDP on education, both public and private, although the systems do not meet current needs (Arias et al. 2019). Of the 4.5 percent, 1 percent already goes to higher education. The African Union suggests that member countries spend 1 percent of GDP on building 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, social protection, and infrastructure. In LICs and poorer LMICs, expansion of post-secondary education to cover even 25 percent of new entrants by 2035 or 2040 seems unlikely (Technopolis et al.2019; Arias et al. 2019).

Africa is often faulted for having limited entrepreneurship skills (Technopolis 2019). Starting and growing firms that use 4IR technology is critical to economic transformation, expanding opportunities for wage employment, and enhancing productivity. Experience with entrepreneurship education and training in Africa has been lackluster. While secondary and tertiary entrepreneurship education programs seem to be successful at encouraging the mindsets and skills closely tied to entrepreneurship—such as self-confidence, leadership, creativity, ability to deal with risks, motivation, resilience, and self-efficacy (see Valerio et al. 2014; AfDB et al. 2017), a recent evaluation of several African programs concluded that students who completed a 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 also matters: In countries with a poor business environment, the outcomes of entrepreneurship education are worse (Valerio et al. 2014).

In sum, Africa needs better quality education at all levels if it is to deliver the skills that will be rewarded in tomorrow's economy. The skill needs are much broader than digital skills or engineering. 4IR innovations will require African workers and students (young people) to have more diverse skill sets that can add value to new systems of production, marketing, selling, and service. To achieve this, quality basic education needs to be available to all, and both cognitive learning outcomes and socioemotional skills need to be prioritized and delivered cost-effectively.

Way forward 3: Inclusively increase human capital.

Countries will need to deal realistically with their skill deficits, not just to take advantage of 4IR opportunities but also to avoid stalling their transformations completely. Closing the skills gaps will require continued investment in basic education and a search for new financing models to support continuous upgrading of post-primary education. In African LMICs and LICs, both equity and productivity concerns imply that public spending should give priority to improving the quality of basic education. Countries will not benefit from 4IR technology if skills development programming and public spending are mostly directed to 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).

Higher education—which will be responsible for training the high-skill workers needed to complement 4IR technology—has expanded rapidly in response to increased demand but needs a quality upgrade and new financing models. To meet both challenges, engaging with private sector technology leaders will be crucial. If public educational institutions worked with industry to reform curricula and pursue work-based learning opportunities, they could help higher education graduates attain the skills they need to succeed at a variety of tasks—technical, cognitive, and socioemotional—and prepare workers whose skills are better suited to industry's needs. To develop the necessary post-secondary STEM and digital skills, countries should try to combine public and private financing and service provision. For 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 such areas as data science, digital marketing, artificial intelligence, coding, and app development. Another example is Kenya's Ajira Digital Program, which has reportedly made it possible for more than 630,000 youths to have access to online jobs (Ajira Digital 2020).

Education strategies at all levels need to focus more on building socioemotional skills (Arias et al. 2019; World Bank 2018). Adults in OECD countries value building problem-solving and teamwork-related skills in children, such as tolerance, responsibility, and independence; African adults are much more concerned to promote value hard work and obedience, reflecting different cultures, history, and life challenges (Arias et al. 2019). The socioemotional skills valued in OECD countries are associated not only with successful entrepreneurship but also with higher earnings and greater mobility; incorporating development of these skills into African education curricula 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 after-school programs, that build these skills (Fox and Gandhi 2021). This is another challenge for reformers of education in Africa.

The need for a comprehensive strategy

While the challenges identified are complex, they are not insurmountable. Efforts to conscientiously shape public policies guiding technological growth to maximize benefits and minimize costs will be crucial for success in 4IR. 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 challenges for governments (AUC/OECD 2021; Signé 2022; PfPC 2019). Several important strategic dimensions stand out.

- *Strategies should be based on a whole-of-government approach*. Rather than having a single ministry or body dedicated to the task, government bodies should be agile to accelerate multi-stakeholder collaboration, engaging various ministries, agencies, and national- and sub-national governments. A comprehensive strategy should cover, among other areas, industrial development, agriculture, education, employment, youth, trade, technology, finance, infrastructure, and cybersecurity.

- *To maximize growth, transformation, and inclusion, African public strategies to stimulate adoption of new technologies and foster private sector innovation*. Wider access to technology increases the potential for job creation, but throughout Africa, relatively few firms have been able to access technology. Governments should approach this challenge from three perspectives: fostering innovation; facilitating technology adoption; and increasing access to finance.

- *Strategy development and application should be inclusive*. 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 that brings the private sector, civil society, and external partners into an open policymaking process.

- *Strategies will only be successful if policymaking is evidence-based*, and supported by experimentation, economic evaluation of the use of public funds, and impact studies to guide better project choice and ensure follow-through to completion (Signé 2018).

Many recommendations for the strategic approach to economic transformation are not new; African governments are already awash in plans and strategies (Pritchett et al., 2010). What governments can do is to review their chosen strategies from the perspective of the need for technology innovation. Priorities can be re-assessed and renewed, focusing on the local context to look for:

- Opportunities for quick wins, such as expanding access to mobile telephones, Internet, and fintech; reforming tariff structures to support technology imports; and increased public-private partnerships in post-secondary education; and
- Initiatives that need to be launched immediately so that they will bear fruit in the medium term; examples are expansion of energy infrastructure, streamlining legacy service delivery, and reforming the education system to build 21st century skills.

5. Conclusion

4IR technology has the potential to support countries as they transform their economies and expand their employment opportunities. New technologies bring opportunities for firms to reduce production costs, improve productivity and earnings, and introduce new business lines, all of which will provide a wealth of new opportunities that will prove particularly attractive and accessible to Africa's young labor force. Deploying 4IR technology could accelerate needed economic transformation by creating new, often formal, wage jobs faster than the rate at which the labor force is growing, and improve earnings improvements in the informal sector.

While we see potential in 4IR technologies to support the resumption and possible acceleration of the pre-COVID-19 economic transformation trajectory, 4IR technology is likely to bring only incremental change in the trajectory of employment transformation, in terms of a shift from the informal to the formal sector because the trajectory had already been set by past demographic change and current economic development (Fox and Gandhi 2021; AU/OECD 2021).

Africa cannot escape 4IR because African states have become increasingly integrated into the global economy. But constraints on production-unit adoption of technology are plentiful. Some are longstanding, like many in the agricultural sector, and some are new, such as cybersecurity concerns. Economic policy needs to prioritize reducing these constraints–through land reform, infrastructure construction, regulatory reform, and reforms in education. The balance between positive and negative outcomes from 4IR will depend on policy choices.

Annex 1 | Landscape of selected 4IR technologies

Technology	Definition and Purpose
Additive manufacturing (3D printing)	Produces objects through computer- aided, layer-by-layer addition of materials, resulting in a much more customizable process than traditional (subtractive) manufacturing.
Advanced materialsscience	Optimizes the use of raw materials and develops new sustainable materials for use inbatteries, electronics, water filtration, etc.
Artificial intelligence(AI)	AI refers to the ability of machines, computers, or computer-controlled robots to perform operations analogous to human intelligence, such as processing information, recognizing complex patterns, drawing conclusions, and making decisions.
Automation (robotics)	Design, construction, and use ofmachines to execute tasks automatically, with speed and precision.
Big data	Extremely large data sets thatcan be computationally analysed to reveal otherwise hidden patterns and trends; an underlying requirement for many other 41R technologies. Supports better informed decisions.
Blockchain (distributed ledgertechnology)	Creation and exchange of digital records without a trusted centralized agent. It includes a suite of computing services that support digital recording of transactions through a process that is distributed across computing systems over the Internet using cryptography.
Cloud computing	On-demand, remote availabilityof computer system resources such as software, infrastructure, platforms, data storage, and computing power to users over the internet. Reduces computing costs.
Drones/autonomousvehicles	AI is used to move remotely with minimal or no human input. These tools have a wide range of applications, from collecting information to transporting people and goods.
High-speed, high- bandwidth Internet(including SG *technology)*	Massively increases the speed of wireless networks, extending internet access.

The Internet of Things(IoT)	Network of devices, machines, animals, or people with sensorsthat have unique identifiers and can 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).
Nanotechnology	Microscopic materials and service robots. Nanobots can serve welfare-enhancing purposes (e.g., deliver drugs torepair cellular damage) or welfare-diminishing purposes (enhance chemical weapons and explosives).
Quantum computers	Exponential increase in computing power by manipulating information based on quantum bits rather than digitally.

References

Acemoglu, D., and P. Restrepo. 2019. "Automation and New Tasks: How Technology Displaces and Reinstates Labor." *Journal of Economic Perspectives* 33(2): 3–30. https://doi.org/10.1257/jep.33.2.3

ACET (African Center for Economic Transformation. 2017. *African Transformation Report 2017: Agriculture Powering Africa's Economic Transformation.* https://acetforafrica.org/acet/wp-content/uploads/publications/2017/10/ATR17-full-report.pdf

AfDB et al. (African Development Bank Group, OECD Development Center, and United Nations Development Program). 2017. *Entrepreneurship and Industrialization: African Economic Outlook 2017: Special Theme: Entrepreneurship and Industrialization*. https://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/AEO_2017_Report_Full_English.pdf

AfDB (African Development Bank). 2018. *African Economic Outlook 2018*. https://www.icafrica.org/fileadmin/documents/Knowledge/GENERAL_INFRA/AfricanEconomicOutlook2018.pdf

Agyei-Holmes, A., N. Buehren, M. Goldstein, R. Osei, I. Osei-Akoto, and C. Udry. 2020. "The Effects of Land Title Registration on Tenure Security, Investment and the Allocation of Productive Resources : Evidence from Ghana," Policy Research Working Paper Series 9376, World Bank, Washington, DC.

Ajira Digital. 2020. *The Future Works Online.* https://ajiradigital.go.ke/about_ajira.

Altonji, J. G., and S. D. Zimmerman. 2017. "The Costs of and Net Returns to College Major." NBER Working Paper No. 23029. National Bureau of Economic Research, Cambridge, MA. https://doi.org/10.3386/w23029.

Arias, O., D. K. Evans, and I. Santos. 2019. *The Skills Balancing Act in Sub-Saharan Africa: Investing in Skills for Productivity, Inclusivity, and Adaptability*. Africa Development Forum Series World Bank. https://documents1.worldbank.org/curated/en/558991560840574354/pdf/The-Skills-Balancing-Act-in-Sub-Saharan-Africa-Investing-in-Skills-for-Productivity-Inclusivity-and-Adaptability.pdf.

Armstrong, K., J. Burley, M. Parmelee, S. Santifort, and J. W. van Fleet. 2018. *Preparing Tomorrow's Workforce for the Fourth Industrial Revolution.* Deloitte Global and The Global Business Coalition for Education. https://www2.deloitte.com/content/dam/Deloitte/global/Documents/About-Deloitte/gx-preparing-tomorrow-workforce-for-4IR.pdf.

Arntz, M., T. Gregory, and U. Zierahn. 2016. "The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis." OECD Social, Employment, and Migration Working Paper No. 189. OECD, Paris. https://doi.org/10.1787/5jlz9h56dvq7-en.

Assegaf, Z., D. Cherepakha, A. Matambo, and J. Weydringer. 2017. *Africa: Mapping New Opportunities for Sourcing.* McKinsey & Company. https://www.mckinsey.com/featured-insights/middle-east-and-africa/africa-mapping-new-opportunities-for-sourcing.

Atkin, D., A. Chaudhry, S. Chaudry, A. K. Khandelwal, T. Raza, and E. Verhoogen. 2017. "On the Origins and Development of Pakistan's Soccer-ball Cluster." *World Bank Economic Review* 30 (S1), S34–S41. https://doi.org/10.1093/wber/lhw015.

AU/OECD (African Union and OECD Development Centre) 2021. *Africa's development dynamics 2021: Digital transformation for quality jobs*. AUC, Addis Ababa/OECD. https://doi.org/10.1787/0a5c9314-en

Bailur, S. 2020. *Female Livelihoods in the Gig Economy*. Caribou Digital. https://medium.com/caribou-digital/female-livelihoods-in-the-gig-economy-tensions-and-opportunities-f14982b6aaad.

Baldwin, R. 2019. *The Globotics Upheaval: Globalization, Robotics, and the Future of Work*. New York: Oxford University Press.

Banga, K., A. Ruiz Rodriguez, and D.W. te Velde 2020. "Digitally Enabled Economic Transformation and Poverty: Evidence from Kenya and Cambodia." Supporting Economic Transformation. https://set.odi.org/wp-content/uploads/2020/09/DEET-and-poverty-reduction_final-2.pdf

Banga, K., and D. W. te Velde. (2018). "Digitalisation and the Future of Manufacturing in Africa." Supporting Economic Transformation. https://set.odi.org/wp-content/uploads/2018/03/SET_Digitalisation-and-future-of-African-manufacturing_Final.pdf.

Bergquist, L.F., and C. McIntosh 2020. "Search Cost, Intermediation, and Trade: Experimental Evidence from Ugandan Agricultural Markets." ATAI Working Paper, July 2021. https://www.atai-research.org/search-cost-intermediation-and-trade-experimental-evidence-from-ugandan-agricultural-markets/.

Bond, J. 2016. "Infrastructure in Africa." *Global Journal of Emerging Market Economies* 8(3), 309–33. https://doi.org/10.1177/0974910116677788.

Broadband Commission for Sustainable Development. 2019. *Connecting Africa through Broadband: A Strategy for Doubling Connectivity by 2021 and Reaching Universal Access by 2030*. https://www.broadbandcommission.org/Documents/working-groups/DigitalMoonshotforAfrica_Report.pdf.

Broadberry, S., and L. Gardner. 2021. "Economic Growth in Sub-Saharan Africa, 1885–2008: Evidence from Eight Countries. *Explorations in Economic History* 82. https://doi.org/10.1016/j.eeh.2021.101424.

Broadman, H. (2016). How to stimulate innovation by Africa's private sector. International Finance Corporation. https://www.ifc.org/wps/wcm/connect/bc4c6990-ca52-4e3f-9544-bbaf488bf450/EMCompass+Note+8+Innovation+Prospects+Africa+9-8.pdf?MOD=AJPERES&CVID=lsuODpE

Bruhn, M., and D. McKenzie. 2014. "Entry Regulation and the Formalization of Microenterprises in Developing Countries." *The World Bank Research Observer* 29(2): 186–201. https://doi.org/10.1093/wbro/lku002.

Calabrese, L., K. Sen, D. W. te Velde, C. Ubabukoh, and S. Wiggins. 2020. *Innovation and Economic Transformation in Low-income Countries: A New Body of Evidence*. Overseas Development Institute. https://www.researchgate.net/profile/Chisom-Ubabukoh/publication/339567650_Innovation_and_economic_transformation_in_low-income_countries_a_new_body_of_evidence/links/5e594181299bf1bdb8442a64/Innovation-and-economic-transformation-in-low-income-countries-a-new-body-of-evidence.pdf

Calderon, C. , G. Kambou , V. Korman, M. Kubota, and C. C. Canales. 2019. *Africa's Pulse, No. 19*: *An Analysis of Issues Shaping Africa's Economic Future.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1421-1.

Chakravorti, B. and R. S. Chaturvedi. 2019. "Research: How Technology Could Promote Growth in 6 African Countries." *Harvard Business Review.* https://hbr.org/2019/12/research-how-technology-could-promote-growth-in-6-african-countries.

Chen, M., and F. Carre, Eds. 2020. *The Informal Economy Revisited.* Routledge, Taylor and Francis. https://library.oapen.org/handle/20.500.12657/39924.

Chironga, M., L. Cunha, H. DeGrandis, and M. Kuyoro. 2018, February. *Roaring to Life: Growth and Innovation in African Retail Banking*. McKinsey & Company. =https://www.mckinsey.com/~/media/mckinsey/industries/financial%20services/our%20insights/african%20retail%20bankings%20next%20growth%20frontier/roaring-to-life-growth-and-innovation-in-african-retail-banking-web-final.ashx

Choi, J., M.A. Dutz, and Z. Usman, Eds. 2020. *The Future of Work in Africa: Harnessing the Potential of Digital Technologies for all*. Africa Development Forum, World Bank, Washington, DC. http://hdl.handle.net/10986/32124.

Chuhan-Pole, P., A. L. Dabalen, and B. C. Land. 2017. *Mining in Africa: Are Local Communities Better Off?* Africa Development Forum, World Bank, Washington, DC. https://doi.org/10.1596/978-1-4648-0819-7

Deloite. 2016. *Industry 4.0: Is Africa Ready for Digital Transformation?* https://www2.deloitte.com/content/dam/Deloitte/za/Documents/manufacturing/za-Africa-industry-4.0-report-April14.pdf

Deutch, John. 2005. *What Should the Government Do to Encourage Technical Change in the Energy Sector?* MIT Joint Program on the Science and Policy of Global Change. http://web.mit.edu/globalchange/www/MITJPSPGC_Rpt120.pdf.

Diao, X., M. Ellis, M. McMillan, and D. Rodrik. 2021. "Africa's Manufacturing Puzzle: Evidence from Tanzanian and Ethiopian Firms." NBER Working Paper No. 28344. National Bureau of Economic Research, Cambridge, MA. http://www.nber.org/papers/w28344.

Fabregas, R., M. Kremer, and F. Schilbach. 2019. "Realizing the Potential of Digital Development: The Case of Agricultural Advice." *Science,*366(6471). https://doi.org/10.1126/science.aay3038.

Fadia, A., M. Nayfeh, and J. Noble. 2020. *Follow the Leaders: How Governments Can Combat Intensifying Cybersecurity Risks.* McKinsey & Company. https://www.mckinsey.com/industries/public-and-social-sector/our-insights/follow-the-leaders-how-governments-can-combat-intensifying-cybersecurity-risks.

Fofack, H. 2020. "Making the AfCFTA Work for 'The Africa We Want."' Working Paper, Africa Growth Initiative at Brookings. .https://www.brookings.edu/wp-content/uploads/ 2020/12/20.12.28-AfCFTA_Fofack.pdf

Filmer, D., and L. Fox. 2014. *Youth Employment in Sub-Saharan Africa*. World Bank. http://hdl.handle.net/10986/16608.

Fox, L. 2019. “Economic Participation of Rural Youth: What Matters?” IFAD Research Series 46. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3521170.

Fox, L., and D. Gandhi. 2021. “Youth Employment in Africa: Progress and Prospects.” Africa Growth Initiative Working Paper No. 28, Brookings Institution, Washington, DC.

Fox, L., P. Mader, J. Sumberg, J. Flynn, and M. Oosterom. 2020. *Africa’s “Youth Employment”’ Crisis Is Actually a ‘”Missing Jobs’” Crisis.* Brooke Shearer Series No. 9, Brookings Institution, Washington, DC.

Fox, L., L.W. Senbet, and W. Simbanegavi. 2016. “Youth Employment in Sub-Saharan Africa: Challenges, Constraints, and Opportunities.” *Journal of African Economies,* 25(1): 3-15.

Fox, L., and T. P. Sohnesen. 2016. “Household Enterprises and Poverty Reduction in Sub-Saharan Africa.” *Development Policy Review* 342: 197–221. https://doi.org/10.1111/dpr.12152.

Fox, L., and A. Thomas. 2016. “A Diagnostic of Youth Employment Challenges in Sub-Saharan Africa.” *Journal of African Economies* 25(1): 16-36.

Frey, C. B., and M. Osborne. 2017. “The Future of Employment: How Susceptible Are Jobs to Computerization?” Oxford Martin School Working Paper, Oxford University. https://www.oxfordmartin.ox.ac.uk/downloads/academic/future-of-employment.pdf.

Fuglie, K., M. Gautam, A. Goyal, and W. F. Maloney. 2020. *Harvesting Prosperity: Technology and Productivity Growth in Africa*. World Bank, Washington, DC.

Gaus, A., and W. Hoxtell, 2019. “Automation and the Future of Work in Sub-Saharan Africa.” Global Public Policy Institute, Konrad-Adenauer-Stiftung. https://www.gppi.net/2019/04/24/ automation-and-the-future-of-work-in-sub-saharan-africa.

Gelb, A., V. Ramachandran, C. J.Meyer, D. Wadhwa, and K. Navis. 2020. “Can Sub-Saharan Africa Be a Manufacturing Destination? Labor Costs, Price Levels, and the role of Industrial Policy.” *Journal of Industry, Competition and Trade* 20: 335–57.

Gollin, D. (2018). “Structural Transformation without Industrialization.” Background paper, Series 2. Pathways for Prosperity Commission. https://pathwayscommission.bsg.ox.ac.uk/Doug-Gollin-Paper.

Griffith, R., and J. Van Reenen. 2021. "Product Market Competition, Creative Destruction and Innovation," IFS Working Paper W21/43, Institute for Fiscal Studies. https://ideas.repec.org/p/ifs/ifsewp/21-43.html.

Hallward-Driemeier, M., and G. Nayyar. 2017. *Trouble in the Making? The Future of Manufacturing-led Development*. World Bank, Washington, DC.

Hamory Hicks, J., M. Kremer, I. Mbiti, and E. Miguel. 2016. *Evaluating the Impact of Vocational Education Vouchers on Out-of-school Youth in Kenya* (3ie Impact Evaluation Report 37). International Initiative for Impact Evaluation, New Delhi.

Hjort, J., and J. Poulsen. 2017. "The Arrival of Fast Internet and Employment in Africa." NBER Working Paper No. 23582. National Bureau of Economic Research, Cambridge, MA

Houngbonon, G.V., J. Mensah, and N. Traore. 2021. "The Effects of Entrepreneurship in Africa" Photocopy.

Hunt, A.. and F. Machingura. 2016. *A Good Gig? The Rise of On-demand Domestic Work*. London: Overseas Development Institute.

Hunt, A., and E. Samman. 2019. *Gender and the Gig Economy: Critical Steps for Evidence-based Policy*. London: Overseas Development Institute.

ILO (International Labour Organization). 2016. *Non-standard Employment Around the World: Understanding Challenges, Shaping Prospects*. Geneva: International Labour Office. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_534326.pdf.

——. 2018. *Women and Men in the Informal Economy: A Statistical Picture (*3rd ed). Geneva: International Labour Office. https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_626831.pdf.

——. 2019. *The Working Poor or How a Job Is no Guarantee of Decent Living Conditions*. Geneva: International Labour Office. https://ilo.org/wcmsp5/groups/public/---dgreports/---stat/documents/publication/wcms_696387.pdf

——. 2021a. *ILOSTAT* [Online database]. http://www.ilo.org/global/statistics-and-databases/lang--en/index.htm.

——. 2021b. *Measuring Decent Work*. https://www.ilo.org/integration/themes/mdw/lang--en/index.htm.

——. 2019. *The Dirty Footprint of the Broken Grid: The Impacts of Fossil Fuel Back-up Generators in Developing Countries*. Washington, DC: IFC.

Jayne, T.S., L. Fox, K. Fuglie and A. Adelaja. 2020. *Agricultural Productivity Growth, Resilience, and Economic Transformation in Sub-Saharan Africa: Implications for USAID*. USAID, BIFAD, and Association of Public & Land-Grant Universities. https://www.usaid.gov/sites/default/files/documents/BIFAD_Agricultural_Productivity_Growth_Resilience_and_Economic_Transformation_in_SSA_Final_Report_4.20.21_2_2.pdf.

Kenny, C. 2019. *Automation and AI: Implications for African Development Prospects?* Center for Global Development. https://www.cgdev.org/publication/automation-and-ai-implications-african-development-prospects.

Khady, K. 2019. Funding program to promote innovative entrepreneurship in Tunisia. *https://concoursn.com/funding-program-to-promote-innovative-entrepreneurship-in-tunisia/*

Korinek, A. andn J. E. Stiglitz. 2021. "Artificial Intelligence, Globalization, and Strategies for Economic Development." NBER Working Paper No. 28453. Camgridge, MA: National Bureau of Economic Research. https://www.nber.org/papers/w28453.

KPMG. 2017. *Investing in Africa: A Guide to Tax / Incentives in Africa*. https://assets.kpmg/content/dam/kpmg/ng/pdf/tax/ng-incentives-in-africa.pdf.

Krafft, C. 2018. “”Is School the Best Route to Skills? Returns to Vocational School and Vocational Skills in Egypt.” *The Journal of Development Studies* 54(7): 1100–20.

Law Library of Congress. 2018. *Regulation of Cryptocurrency Around the World.* Global Legal Research Center. https://www.loc.gov/law/help/cryptocurrency/cryptocurrency-world-survey.pdf .

La Porta, R., and A. Shleifer. 2014. » Informality and Development. *Journal of Economic Perspectives* 28(3): 109-26. https://www.aeaweb.org/articles?id=10.1257/jep.28.3.109

Latif Dahir, A., and Y. Kazeem. 2018. *Tunisia's 'Startup Act' Could Show Other African Governments How to Support Tech Ecosystems*. Quartz. https://qz.com/africa/1252113/tunisia-startup-act-to-boost-african-tech-ecosystem-and-innovation/.

Leke, A., and L. Signé. 2019. *Spotlighting Opportunities for Business in Africa and Strategies to Succeed in the World's Next Big Growth Market*. Washington, DC: Brookings Institution. https://www.brookings.edu/research/spotlighting-opportunities-for-business-in-africa-and-strategies-to-succeed-in-the-worlds-next-big-growth-market/.

Lippolis, N. 2019. “Making Sense of New Technologies and Jobs in Developing Countries.” Background Paper Series No. 13. Oxford, UK: Pathways for Prosperity Commission.

Lorenceau, A., J. Rim, and T. Savitki. 2021. “Youth Aspirations and the Reality of Jobs in Africa.” OECD Development Policy Papers, No.38. Paris: OECD Publishing. https://doi.org/10.1787/2d089001-en.

Magruder, J. R. 2018. “An Assessment of Experimental Evidence on Agricultural Technology Adoption in Developing Countries.” *Annual Review of Resource Economics* 2018 (10): 299–316.

Mail and Guardian. 2020, May 29). “5G Technology Is the Future.” https://mg.co.za/special-reports/2020-05-29-5g-technology-is-the-future/.

McKinsey Global Institute. 2019a. *Globalization in Transition: The Future of Trade and Value Chains.* https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Innovation/Globalization%20in%20transition%20The%20future%20of%20trade%20and%20value%20chains/MGI-Globalization%20in%20transition-The-future-of-trade-and-value-chains-Full-report.pdf.

——. 2019b *The Future of Work in South Africa: Digitisation, Productivity and Job Creation.* https://www.mckinsey.com/~/media/mckinsey/featured%20insights/middle%20east%20and%20africa/the%20future%20of%20work%20in%20south%20africa%20digitisation%20productivity%20and%20job%20creation/the-future-of-work-in-south-africa.ashx

McMillan, M., D. Rodrik, and C. Sepúlveda. 2017. “Structural Change, Fundamentals, and Growth: A Framework and Case Studies.” Policy Research Working Paper No. 8041, World Bank. http://hdl.handle.net/10986/26481.

Mensah, E. 2020. “Is Sub-Saharan Africa Deindustrializing?” MERIT Working Paper No 2020-045. Maastricht University and United Nations University. https://econpapers.repec.org/RePEc:unm:unumer:2020045.

Millington, K. A. 2017. *How Changes in Technology and Automation Will Affect the Labour Market in Africa.* K4D Helpdesk Report. Institute of Development Studies. https://gsdrc.org/wp-content/uploads/2017/10/Impact-of-automation-on-jobs-in-Africa.pdf.

Murray, S. 2017. “New Technologies Create Opportunities,” WIDER Working Paper 2017/156. United Nations University World Institute for Development Economics Research. https://www.wider.unu.edu/sites/default/files/Publications/Working-paper/PDF/ wp2017-156.pdf.

Naudé, W. 2017. “Entrepreneurship, Education, and the Fourth Industrial Revolution in Africa.” IZA Discussion Paper Series No. 10855. Institute of Labor Economics. https://www.iza.org/publications/dp/10855/entrepreneurship-education-and-the-fourth-industrial-revolution-in-afric.

Newfarmer, R., J. Page, and F. Tarp. 2018. *Industries without Smokestacks: Industrialization in Africa Reconsidered*. WIDER Studies in Development Economics*.* Oxford University Press.

Ndung’u, N,, and L. Signé. 2020. *The Fourth Industrial Revolution and Digitization Will Transform Africa into a Global Powerhouse*. Washington, DC: Brookings Institution. https://www.brookings.edu/research/the-fourth-industrial-revolution-and-digitization-will-transform-africa-into-a-global-powerhouse/.

OECD Development Centre. 2018. *Better Policies for Better Youth Livelihoods: A Guidance Note for Development Practitioners.* EU-OECD Youth Inclusion Project. https://www.oecd.org/dev/inclusivesocietiesanddevelopment/Guidance_Note_2018.pdf.

Oyelaran-Oyeyinka, B. 2014. “The State and Innovation Policy in Africa. *African Journal of Science, Technology, Innovation and Development* 6(5): 481–96. https://doi.org/10.1080/20421338.2014.983731.

Page, J. 2019. *How Industries without Smokestacks Can Address Africa’s Youth Unemployment Crisis*. Brookings Institution. https://www.brookings.edu/research/how-industries-without-smokestacks-can-address-africas-youth-unemployment-crisis/.

PfPC (Pathways for Prosperity Commission). 2018. *Charting Pathways for Inclusive Growth*. Oxford University Press. https://pathwayscommission.bsg.ox.ac.uk/sites/default/files/2019-11/charting-pathways-report.pdf

Pritchett, L., M. Woolcock, and M. Andrews. 2010. “Capability Traps? The Mechanisms of Persistent Implementation Failure.” Center for Global Development Working Paper No. 234. https://www.cgdev.org/sites/default/files/1424651_file_Pritchett_Capability_FINAL.pdf.

PwC (PricewaterhouseCoopers). 2010. *Innovation: Government's Many Roles in fostering innovation*. www.pwc.com/gx/en/technology/pdf/how-governments-foster-innovation-2010.pdf.

Ramaphosa, C. 2020. *A national strategy for harnessing the Fourth Industrial Revolution: The case of South Africa*. Brookings Institution. https://www.brookings.edu/blog/africa-in-focus/2020/01/10/a-national-strategy-for-harnessing-the-fourth-industrial-revolution-the-case-of-south-africa/.

Restuccia, D. 2020, March. ”The Impact of Land Institutions and Misallocation on Agricultural Productivity.” *NBER Reporter.* https://www.nber.org/reporter/2020number1/impact-land-institutions-and-misallocation-agricultural-productivity.

Robb, G., and A. Paelo. 2020. “Competitive Dynamics of Telecommunications Markets in South Africa, Tanzania, Zambia, and Zimbabwe.” WIDER Working Paper 2020/83. United Nations University World Institute for Development Economics Research. https://doi.org/10.35188/UNU-WIDER/2020/840-5.

Rockefeller Foundation. (2018, June 6). “African Development Bank launches coding for employment program: Unleashing Africa’s next generation of digital innovators [Press release].” https://www.rockefellerfoundation.org/news/african-development-bank-launches-coding-employment-program-unleashing-africas-next-generation-digital-+innovators/.

Rodrik, D. 2016. “Premature deindustrialization.” *Journal of Economic Growth*, 21:1-33.

——. 2018. “New Technologies, Global Value Chains, and the Developing Economies.” Background Paper Series No. 1. Pathways for Prosperity Commission.

Schwab, K. 2016. *The Fourth Industrial Revolution*. New York: Crown Business.

Schwab, K., and N. Davis. (2018). *Shaping the Fourth Industrial Revolution*. Cologny, Switzerland : World Economic Forum.

Sen, A. 2009. *The Idea of Justice*. Cambridge, MA: Belknap Press, Harvard University.

Siddiqui , Z., and Y. Zhou (2021). “How the Platform Economy Sets Women Up to Fail.” *Rest of the World*, September, 2021. https://restofworld.org/2021/global-gig-workers-how-platforms-set-women-up-to-fail/

Signé, L. 2018, December 13. “Korea-Africa Relations Hold Enormous Trade, Development and Investment Potential. *The Hill*. https://thehill.com/opinion/international/420770-korea-africa-relations-hold-enormous-trade-development-and-investment-potential.

——. 2020. “Tech Investment Is Crucial to Unlock Africa’s Potential in a Post-coronavirus World.” *MIT Technology Review*. https://insights.techreview.com/tech-investment-is-crucial-to-unlock-africas-potential-in-a-post-coronavirus-world.

——. 2022. *Africa’s Fourth Industrial Revolution*. Cambridge: Cambridge University Press. Forthcoming.

Signé, L., M. Esposito, and S. Khagram. 2020. “The New Urgency of Global Tech Governance. *Project Syndicate*. https://www.project-syndicate.org/commentary/global-tech-governance-data-standards-and-rules-after-covid-by-landry-signe-et-al-2020-09.

Signé, L., N. Davis, M. Esposito, and S. Khagram. 2020, September 29. “Future-ready Leaders for the Fourth Industrial Revolution.” *HRD Connect*. https://www.hrdconnect.com/2020/09/29/future-ready-leadership-for-the-fourth-industrial-revolution/.

Signé, L., S. Khagram, and A. Lashitew. 2020. “The ‘Great Reset’ Requires Agile Governance.” *MIT Technology Review.* https://insights.techreview.com/the-great-reset-requires-agile-governance/.

Stewart, A. G. 2019. “Mining Is Bad for Health: A Voyage of Discovery.” *Environmental Geochemical Health* 42: 1153–65. https://doi.org/10.1007/s10653-019-00367-7.

Suri, T., and W. Jack. 2016. “The Long-run Poverty and Gender Impacts of Mobile Money.” *Science*, 354(6317): 1288–92. https://doi.org/10.1126/science.aah5309.

Suri, T., and C. Urdry. 2022. “Agricultural Technology in Africa.” *Journal of Economic Perspectives* 36:1: 33–56.

Technopolis, Research ICT Africa, and Tambourine Innovation Ventures. 2019. *Study on unlocking the potential of the Fourth Industrial Revolution in Africa*. https://4irpotential.africa/.

The Economist. 2020. ”Why Interest Rates Are so High in Africa. “.https://www.economist.com/finance-and-economics/2020/05/21/why-interest-rates-are-so-high-in-africa

Theunissen, I. 2015, November 26. “E-agriculture: How ICT Is Taking Farming into the Future.” *IT News Africa.* https://www.itnewsafrica.com/2015/11/e-agriculture-how-ict-is-taking-farming-into-the-future/.

Timmer, C. P. 1988. “The Agricultural Transformation.” In Chenery, H. & Srinivasan, T. N. (Eds), *Handbook of Development Economics* Vol. 1: 275–331. Amsterdam: Elsevier

UNCTAD (United Nations Conference on Trade and Development). 2017. *Trade and Development Report 2017: Beyond Austerity: Towards a Global New Deal.* United Nations Trade and Development Agency. https://unctad.org/system/files/official-document/tdr2017_en.pdf.

——. 2019, June 12. “Foreign Direct Investment to Africa Defies Global Slump, Rises 11%.” https://unctad.org/news/foreign-direct-investment-africa-defies-global-slump-rises-11.

Valerio, A., B. Parton, and A. Robb. 2014. *Entrepreneurship Education and Training Programs Around the World: Dimensions for Success*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-0202-7.

Verhoogen, E. 2021. “Firm-Level Upgrading in Developing Countries.” NBER Working Paper 29461, National Bureau of Economic Research. 1. https://www.nber.org/papers/w29461

World Bank. 2006. *World Development Report 2006: Equity and Development*. Washington, DC: World Bank.

——. 2018. *World Development Report 2018: Learning to Realize Education’s Promise*. Washington, DC: World Bank.

——. 2019a. *World Development Report 2019: The Changing Nature of Work.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1328-3.

——. 2019b. *Africa’s Pulse, No. 20: An Analysis of Issues Shaping Africa’s future.* Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1509-6,

——. 2020. *World Development Indicators*. Washington, DC World Bank. https://databank.worldbank.org/source/world-development-indicators.

Africa Growth Initiative
at BROOKINGS

1775 Massachusetts Ave. NW
Washington, D.C. 20036
brookings.edu/africagrowth