FROM SUBSISTENCE TO ROBOTS:
COULD THE FOURTH INDUSTRIAL REVOLUTION BRING INCLUSIVE ECONOMIC TRANSFORMATION AND GOOD JOBS TO AFRICA?

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Abstract

Improving employment opportunities in Africa is particularly salient now and will remain important given the number of young people expected to enter the job market over the next two decades. To what extent could the suite of new technologies known as the Fourth Industrial Revolution (4IR) accelerate economic transformation, leading to the creation of new wage jobs in expanding, higher-productivity sectors? The paper reviews the main productivity issues holding back economic transformation in the agricultural, industrial, and service sectors, and whether 4IR technology adoption could address these. It then asks whether 4IR technology, if adopted, could unlock better job opportunities for Africa's labor force.

The analysis finds that 4IR technology brings opportunities for production cost reduction, productivity and earnings improvement, and the development and introduction of new business lines. Deployment of 4IR technology could lead to new, mostly formal, wage jobs being created, especially in the service sectors, where the technology is complementary to labor, rather than labor saving. Use of digital and 4IR technology could lead to earnings improvements in the informal sector (household farms and businesses), reducing the potential for earning inequality increases associated with skill premia in the formal sector. But the analysis also finds that many of the longstanding obstacles to production upgrading in Africa will affect the pace of 4IR technology adoption – infrastructure and logistics bottlenecks, land tenure rights, difficulties in importing inputs and exporting output, bureaucratic red tape, etc. - if not addressed.

4IR technology, if adopted in Africa, is not likely to bring major job losses. On the contrary, failure to gain access to this technology and deploy it effectively could slow down Africa's efforts to "build back better" and restart transformation. However, 4IR technology is likely to bring only incremental change in the trajectory of employment transformation in terms of the share of employment in the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development. This makes reducing the cost of ICT technology to levels affordable for informal sector operators critical.

Adoption of 4IR technology requires complementary investments in energy, transportation, and ICT infrastructure, and in education, especially at the secondary level. Improvements in the regulatory environment to support new firm entry and access to technology will be needed as well. These issues are not new to Africa, as they already hold back economic growth in many countries, although prior to the COVID-19 global recession, noteworthy progress had been made. Africa's public sector will have to lead this process, in partnership with the private sector, being careful to crowd in, not crowd out, private financing, while at the same time focusing on inclusion of disadvantaged regions and groups.

1. Introduction

During the 21st century, as economies have been buffeted by volatile economic cycles—including the recent COVID-19 pandemic—and by increasingly strong technological winds of change, enhancing employment opportunities has become even more central to development policy discussions. The reasons are obvious: billions of people in the developing world are trying to exit poverty through better jobs that will provide higher incomes for themselves and their families. As the world's youngest continent, with a rapidly growing labor force, improving employment opportunities is especially important in Africa.[2]

After two decades of solid economic growth and improvements in employment opportunities, African countries are back on their heels following disruptions in the global economy and blows to local economies caused by the COVID-19 global pandemic. Before the COVID-19 crisis, many economies in SSA were growing rapidly (Signé, 2020; Jayne et al., 2020), transforming their economies through productivity increases, and offering a larger share of their labor force wage and salary jobs (Fox & Gandhi, 2021; Diao, et al., 2021). Despite this progress, the majority of the African labor force still works informally, in low-productivity activities. One-third of the employed population in Africa lived in extreme poverty in 2018 (ILO, 2019), and the percentage of working poor as share of total employment is even higher in the lowest-income countries.

Employment opportunities depend on the extent of economic transformation and development. Richer countries offer better jobs, and countries get rich by developing productive employment opportunities—the two processes are inextricably linked (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 these enterprises, and enough jobs within them, relative to the supply of labor coming from the population. As a result, youth entering the labor market often end up working in the same types of jobs as their parents—on family farms, in nonfarm self-employment, or in household enterprises (Filmer & Fox, 2014; Fox et al., 2020). The post-Covid-19 economic challenge, to build the economy back better, includes increasing employment opportunities for all Africans.

A key trend occurring in upper income countries, in parallel to developments on the African continent, has been an acceleration of scientific innovation and technological change (Signé, 2022).[3] A group of these new technologies has been labelled as the Fourth Industrial Revolution (4IR) owing to their transformative potential, and because they build on the computing and digital technologies of the Third Industrial Revolution (3IR).[4] It is widely agreed that these next-generation cyber-physical technologies will significantly change production, consumption, trade, the cost of goods and services, and living standards across the globe—more rapidly than previous industrial revolutions, owing to the scope and speed of innovation (Signé, 2022). Although developed in the rich countries, where adoption has been most rapid, the 4IR technology wave has already begun washing up on Africa's shores (Ndung'u and Signé, 2020).

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[2] Throughout this paper, the term "Africa" refers to Sub-Saharan Africa (SSA).

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

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

Innovation is key to economic growth and development.[5] By allowing goods and services to be produced at lower cost, improvement in material welfare is possible. Adoption of technology during the Industrial Age accelerated and sustained economic growth in Western Europe and the U.S., allowing these countries to reach levels of income and welfare unimaginable in previous centuries. Technology adoption in developing countries has helped close the income gap with the post-industrial West, especially in East Asia.

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

Advising on the impact of 4IR on African economic development and the welfare of citizens is a growth industry. In the last two years alone, multiple long reports (150 pages+) have been issued, some of which include a partial analysis of the implications for employment opportunities.[6] These employment analyses have tended to build on previous work done on the employment consequences of 4IR technology adoption in the U.S., especially automation and advanced robotics. Some of the analyses of the U.S have concluded that these technologies have eliminated middle-skill, middle-class jobs and increased inequality (e.g., Frey & Osborne, 2017). Others, such as Acemoglu and Restrepo (2019), argue that it is economic policy as much as technological change that has driven the U.S. result. Analyses of the prospects for Africa are also split on the extent of technological determinism.

Objective and methodology

The objective of this paper is to synthesize the current evidence on the existing and potential benefits of 4IR technology for economic transformation in Africa as well as the constraints to adoption, and to apply this knowledge to analyze the possible effects of the adoption of 4IR technology on future employment opportunities in Africa. Our contribution to the large body of existing literature is: (i) a critical review of this literature, (ii) afocus on the opportunities for and constraints to technology adoption in production units, and the employment opportunities this could produce, and (iii) in discussing employment prospects, a particular emphasis on the informal sector.

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 others, as summarized in the recent Pathwaysfor Prosperity Commission report (PfPC, 2018), we adopt a more holistic and conceptually broader approach than the "counting job losses and gains"

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

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

approach popular in much of the literature to date on potential labor market impacts.[7] 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 can be governed by economic and social policy. As with economic growth itself, technology is not inherently equal or unequal. We focus on the evidence regarding the possible benefits to production units, whether formal or informal, of technology adoption. In organizing and synthesizing the literature, we use the conceptual framework of (i) economic development as economic transformation (within sector productivity gains and structural transformation), with a key role for technology adoption, (ii) technology adoption as a constrained choice of production units; and (iii) desired economic development outcomes as ones which expand people's choices and capabilities to work productively and earn more income, regardless of whether they work formally or informally. Rather than focus on the quantitative range of possible job creations and disruptions, we instead highlight opportunities for and threats to the realization of economic development objectives that the technologies hold. We focus on how public policies could harness the innovative power of 4IR technologies to support improvement of overall employment opportunities (job and earnings) for those currently in the labor market and for those who will enter 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 key issues holding back productivity increases in Africa, thus accelerating economic transformation?
- What are the constraints to technology adoption in production units?
- If adopted by in production units, could 4IR technologies contribute to better employment outcomes – that is, higher earnings, job security, and other improved employment outcomes?
- Will these outcomes be inclusive, or will they contribute to inequality?
- What complementary 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 crisis Africa, 4IR technology has the potential to support countries to regain a positive economic trajectory. 4IR technology brings opportunities for production cost reduction, productivity and earnings improvement, and the development and introduction of new products and business lines. If adopted, 4IR technology could provide new employment opportunities that could prove particularly attractive and accessible to Africa's young labor force. Production technology upgrading could lead to new, often formal, wage jobs being created at a faster rate than the growth of the labor force, reducing the share of informal employment in total employment. It may also enable earnings improvements in the informal sector if policies are put in place to reduce the cost of basic ICT services and reduce producer risk. However, 4IR technology is likely to only bring incremental change in the pre-COVID-19 trajectory

[7] As Korinek and Stiglitz (2021) note, these papers have shown the "vast uncertainty" surrounding the potential employment effects ofthis technology

of employment transformation in terms of speed of the shift from the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development (AU/OECD, 2021; Fox and Gandhi, 2021).

Some sectors will offer more opportunities than others:

- The *services sector* is where the opportunities 4IR technology to accelerate economic transformation and formal wage employment expansion appear greatest. Through the growth of existing firms and new firm entry—especially in sectors such as retail and e-commerce, logistics and transportation, tourism, and business process outsourcing (BPO)—Africa can create new formal sector jobs by expanding service sector exports and meeting the demand in the growing domestic and regional market. However, given the starting place, the share of service sector employment which is informal will decline slowly, and 4IR technology is likely to have a limited impact on informal service sector earnings owing to longstanding obstacles to innovation and productivity (e.g. small margins, insecure working conditions, etc.).
- In the *agricultural sector*, by reducing information frictions which increase risk, 4IR technology could support productivity gains, an increase in farm earnings, and a reduction in rural poverty, as well as bring important environmental benefits, but only if longstanding risks inhibiting technology adoption can be overcome. Technology adoption will not lead to a large expansion of employment, as this sector has been losing its share of employment for years owing to better opportunities elsewhere (structural transformation).
- In the *manufacturing sector*, which has recently expanded its share of output and employment in SSA's LICs and LMICs, 4IR technology may open new opportunities for smaller-scale production for domestic and regional markets. But the sector is not likely to continue increasing its share of employment, because when applied to manufacturing, 4IR technology is labor-saving.
- Substitution of capital for labor— destroying jobs—is less likely in Africa than in rich countries, owing to a higher cost of capital compared to labor, and a lower level of industrialization.

For these gains to be realized, however, some of African economies' enduring challenges to technology adoption by the private sector need to be addressed, including infrastructure and logistics bottlenecks, high cost of finance, land tenure rights, difficulties in importing inputs and exporting output, bureaucratic red tape, etc. Meanwhile 4IR technology brings new challenges, including cyber security and the need for a wider variety of skills. Countries need a comprehensive strategy covering the significant challenges governments will face in the future. Strategies should cover:

- How to revise regulatory frameworks, develop agile governance, improve business environments, and create inclusive policies to encourage technology innovation, importation, and adoption. Key solutions include adopting 4IR technology within the public sector to permit a nimbler regulatory environment, encouraging the development of fintech, including to serve angel and equity investors, and developing cybersecurity frameworks.
- How to reduce gaps in physical and digital infrastructure to spur technology adoption. Solutions will have to involve private finance, with incentives for inclusion of poorer household and more remote and rural areas.

- How to build the skills of the future labor force equitably, in view of the skill-intensive nature of 4IR technology. Given the inadequate learning achievement outcomes of the current educational system and the pressure that past (and in some countries current) high fertility is expected to place on educational infrastructure in the next two decades, skill development and public expenditures will have to focus on increasing access and improving the quality of basic education, including secondary school. This will be the most inclusive strategy. To develop needed high-tech skills, countries should encourage post-secondary educational institutions to work closely with the private sector and to mobilize private financing.

Developing and implementing these strategies is urgent. Apart from Kenya, most LMICs and LICs in SSA have not established the conditions for widespread adoption of the technologies of 3IR, much less 4IR. This issue affects economic opportunities for all.

African states have become increasingly integrated into the global economy, so Africa cannot escape 4IR. The balance between the positive and negative outcomes from 4IR will depend on initial country conditions and policy choices. Poorer households, especially those from rural areas, with limited access to electricity and ICT services, and less access to quality education and training, are at the highest risk of being left behind. The current digital gender divide, driven mostly by access to resources rather than education, could end up disadvantaging women, especially in the informal sector. Widening inequality, especially spatial inequality—an overall risk to economic development and transformation—is therefore a likely outcome in some countries, and will affect employment outcomes. Countries' development strategies need to rise to this challenge.

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

2. Landscape and Conceptual Framework

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

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

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

Can these technologies ignite or accelerate economic and employment transformation in Africa? If so, where, how, and why? To assess these questions, we use the conceptual framework of economic transformation, incorporating the role of technology adoption and employment transformation, how this creates inclusive economic development.

Conceptual framework

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

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

Economic transformation, leading to employment transformation, improves employment opportunities and reduces poverty in developing countries (Fox & Gandhi, 2021). But an inclusive transformation is not inevitable. Labor productivity gains enabled by new technology do not, by themselves, necessarily create more jobs. New jobs are created when (i) productivity gains lower the cost of production, increasing demand and therefore allowing firms to produce more output by hiring more workers, or (ii) new firms enter, producing new items and creating new jobs. In agriculture, for example, sectoral transformation has brought higher incomes but a decline in employment growth in the sector; however, through multiplier effects, these gains have led to higher employment growth in nonfarm sectors (structural transformation) (Timmer, 1988; Jayne et al., 2020). 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 in rich countries and first adopted there, before spreading to less developed countries (Griffith and van Reenen, 2021).[8] In theory, poorer countries can grow rapidly – more rapidly than rich ones – if production units in less developed countries simply adopt new technologies that are used in the production process in rich countries. However, as Verhoogen (2021) has noted, this technological upgrading[9] process has been slow at best in developing 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.[10] Constraints to technology upgrading appear on both the demand side and the supply side (Verhoogen, 2021). These context-specific

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[8] Mobile money as a form of fintech is a notable exception; see discussion below.

[9] Often called "Industrial upgrading" as 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).

[10] This is obviously an over-simplification because the cost is usually fixed and up front, and may have to be financed, while thebenefits will be realized over time, with a degree of uncertainty. Evaluating investment in new technology therefore involves, among other things, using discount rates and probabilities. See Verhoogen, (2021) for a mathematical formulation of the technology adoption decision within the firm.

constraints may lead producers to conclude that technology adoption offers few benefits and too much risk.[11] If these 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 size leading to lack of scale economies making production too costly. The producer could gain scale in export markets, but lacks access these markets owing to trade or informational barriers. On the supply side, a producer may not have access to all the inputs needed to adopt the technology. For example, a producer may face a lack of reliable and affordable energy; tariffs and transport costs may make imported inputs or machinery needed for production unavailable or too expensive; financing may not be available for the capital upgrading, or the skills needed to adopt and use the technology may be lacking. Patent protections may render the technology unaffordable. Relational (long-term) contracts with suppliers, necessary in a context of weak contract enforcement institutions, may inhibit change in production processes. Finally, producers may lack the entrepreneurial skills, or there may be cultural or organizational barriers within firms that inhibit the adoption of a specific technology.[12] All of these constraints may operate to inhibit the adoption of 4IR production technologies in Africa.

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 would 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, this might involve new job creation. Producing product more cheaply or at higher quality would lead to sectoral transformation; starting a new business could lead to structural transformation if labor is reallocated to other sectors.

In either developed or developing countries, the adoption of new technologies that transform production processes or the outputs produced is disruptive. In general, employment opportunities improve over time with transformation, but jobs and occupations are usually gained and lost. Technology that substitutes for labor (e.g. robots) will cause jobs and occupations to be last, while technology which complements labor (e.g. video conferencing technology 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 in Africa and if adopted, could advance economic transformation, but also what kinds of jobs (or job opportunities in the case of self- employment) could be created, what jobs could be lost, and what groups in society might be affected. Ideally, the new jobs will be development-enhancing—meaning, in the words of Sen, that they increase "the capability of people to live the kind of life they have reason to value" (Sen, 2001, p. 53). This development-enhancing technology upgrading can occur within the formal or informal sector. However, as the experience with previous industrial revolutions has shown, the diffusion of technology and the process of employment transformation do not necessarily occur at the same time, and may not initially be development-enhancing for those employed using the new technology.[13]

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[11] Magruder, (2018), makes this point clearly with respect to the adoption of improved inputs in the agricultural sector.

[12] Unions are often blamed for the failure to adopt new technology, but as Atkin, et al., (2017) demonstrate, it is often a failure of management to understand incentives at the shop floor level which inhibits technology upgrading.

[13] Factory technology, as deployed in the 19^{th} century, certainly fits this description.

The policy question for Africa therefore, is (i) how to deploy 4IR technology to raise productivity and aggregate income, and how to have an inclusive 4IR-driven economic and employment transformation. In our review, we focus on whether adoption of 4IR technology in Africa has the potential to (i) reduce the share of informality by growing formal jobs through the creation of new firms and more formal, wage-paying jobs as a share of total employment, and (ii) raise earnings for those employed, regardless of type of job (formal or informal). But before we assess the future, we need to review Africa's starting place in terms of economic and employment transformation.

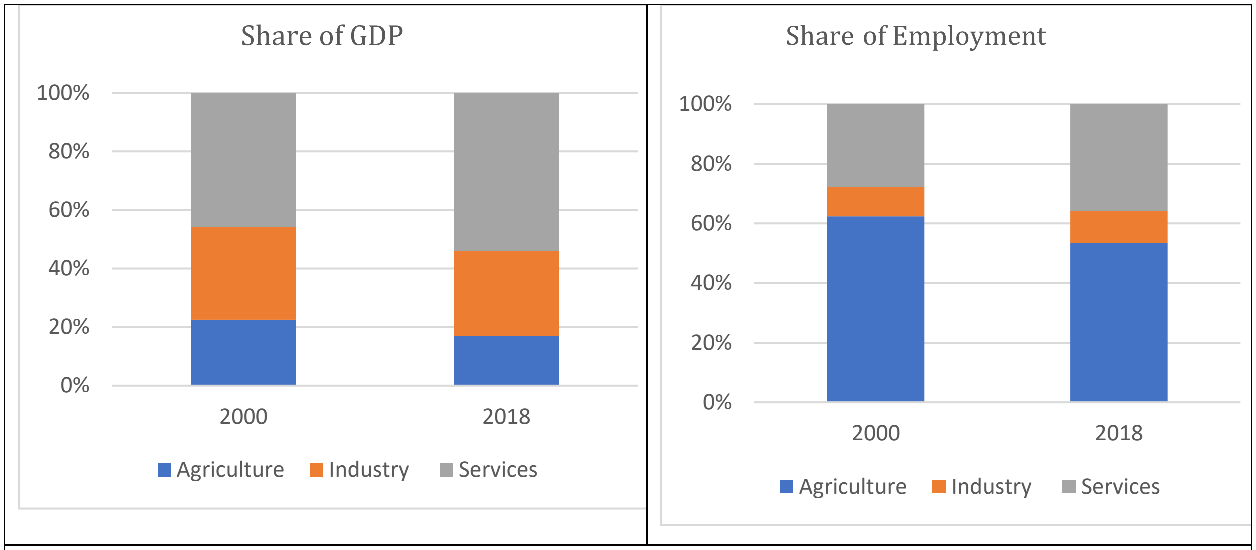
The transformation and employment landscape in Africa

From 2000 until the recent COVID-19 shock, most countries in SSA achieved sustained per capita income growth in (Jayne et al., 2020 based on WDI data). Substantial structural transformation took place, helping to sustain growth. Regionally, agriculture's share of GDP declined by 5 percentage points between 2000 to 2018, while agriculture's share of total employment declined by 9 percentage points.[14] Output and employment in the nonagricultural sectors, especially services, surged. Notably, manufacturing sector output and employment expanded, especially in East Africa (Mensah, 2020), but the sector still only accounts for 5 percent of GDP in the low-income countries (LICs).[15] Trade diversification advanced substantially as well: in 2015, the manufacturing share of total exports reached 50 percent for SSA (Jayne et al., 2020). This number includes South Africa, which has the lowest share of agriculture in output and employment and a high share of manufacturing in output and exports but also reflects growth in regional manufactured goods trade as well.

Within-sector productivity growth was notable as well, especially in agriculture. Region-wide, labor productivity growth averaged almost 2 percent per annum through 2013, driven by both within-sector productivity growth in agriculture (the lowest productivity sector) and structural change (McMillan et al., 2017). In the nonagricultural sectors, productivity growth was lower, primarily because as the share of employment in agriculture decreased, the share of employment in activities with a level of productivity higher than agriculture but lower than the economy-wide average (such as informal retail trade and small-scalemanufacturing) expanded faster than the share of employment in the highest productivity activities (Diao, et al., 2021). Africa's strong growth and productivity performance was driven both by an increase in the capital stock – accounting for about 40 percent of total economic growth – as well as technological change - accounting for about 30 percent, measured by the change in total factor productivity (TFP) (Gazarelli and Limam, 2019).[16] Without continued technological change – mostly driven by 3IR digital technologies, Africa's growth would have been less robust.

[14] All figures in the paper are from World Development Indicator unless otherwise specified.
[15] In classifying countries by income, we use the World Bank classification. See https://datahelpdesk.worldbank.org/knowl-edgebase/articles/906519-world-bank-country-and-lending-groups.
[16] Verhoogen (2021) notes important methodological issues in using TFP as a measure of technological change.

Figure 1: Transformation in Output and Employment, 2000-2018



Source: World Development Indicators

Employment transformation always lags economic transformation. In Africa, this means that despite recent progress in economic transformation, a high level of informal employment, remains in both agriculture and nonagricultural sectors (Fox et al., 2020). The share of informal employment in total employment—including both casual informal wage employment and nonwage household farm and nonfarm production activities—is estimated at 89 percent for Africa as a whole (Table 1).[17] 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).

Table 1: Distribution of 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: Distribution of 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

[17] See ILO (2018) for the international definition of informality.

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

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

But even with a return to the economic growth patterns of the pre-COVID-19 years, the share of employment in nonwage jobs on the continent is not projected to decline substantially over the next 15 years (AUC/OECD, 2021; Fox & Gandhi, 2021) despite the trend of substantial transformation over the past 15 years. While disappointing to some, the prediction rings true, owing to: (i) high projected labor force growth overall, based on past fertility, and (ii) particularly high labor force growth in populous countries with high levels of informality (e.g., DRC, Niger, Nigeria; Fox & Gandhi, 2021). Projected labor force and income per capita growth are well known determinants of informality, with labor force growth having a stronger effect (La Porta & Schleifer, 2013). Within the region, countries such as Ghana, Kenya, and Senegal, with lower projected labor force growth and higher starting incomes, will have an easier time reducing their shares of informal employment. Even so, many households in the region will face challenges in earning a living and improving their material welfare.

These problems are economically and socially complex, and technology is unlikely to be the silver bullet. Nonetheless, it is still worth asking the question of whether 4IR technology can support an inclusive transformation trajectory. In the next section, we use the conceptual 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, starting from the landscape described above. We identify the factors driving the potential impact on economic transformation and employment opportunities. Based on the landscape outlined above, we focus on three key questions:

- Could 4IR technology help production units address key issues holding back productivity increases and economic transformation?
- If so, what are the opportunities and constraints to 4IR technology adoption?

- If adopted, would the technology complement or substitute for labor? Could 4IR technology adoption directly or indirectly contribute to higher earnings, job security, and other improved employment outcomes?

Box1: What is informality?

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

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

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

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

Source: ILO 2018

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

4IR technology has the potential to improve material welfare in Africa through multiple channels: by improving labor productivity throughout the economy; by improving education and health services access and quality; by improving urban management and service delivery through the adoption of smart city technology; and by reducing the cost of consumer goods, raising the real incomes of the population (Signé, 2022). While all channels are important, in this paper we focus on the production channel, as it is the most important for the creation of new and better jobs in the economy. We mostly ignore the role of the public sector as a direct job creator, since employment in this sector tends to expand regardless of technology—it is driven more by demand for publicly-provided services and by resources available. Instead, we examine the constraints that currently exist within private production units[18] and sectors to transformation - the expansion of output, employment, and productivity - and the role 4IR technology could play reducing these constraints and in accelerating the transformation process. In this section, we look for transformation opportunities through technology upgrading within the context of the three major sectors of the economy: agriculture, industry, and services.

3.1 Agriculture

Agriculture is an essential sector in Africa, both today and in 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, agriculture's importance as a share of output and employment has declined substantially, but agricultural commodities and processed agricultural products (e.g., dairy, juices, wine) still account for a significant share of exports and local food supply, an indication of the catalytic role that productivity gains in the agricultural sector have played in boosting structural transformation through downstream and upstream linkages with the rest of the economy (Jayne et al., 2020). For example, in Kenya, agriculture accounts for 26 percent of GDP directly, but an additional 27 percent indirectly through linkages with other sectors (Banga et al., 2020). Throughout Africa, the food system, including agro-processing, is expected to account for up to 40 percent of net new jobs over the next 10 years (Filmer & Fox, 2014; Jayne et al., 2020). A competitive and productive agriculture sector is a key pre-requisite for the expansion of the agro-processing industry

African agriculture faces several challenges. In LICs and LMICs, smallholder family farms (SHF, less than 3 hectares) dominate the sector, and even medium-sized farms (up to 10 hectares) tend to be family owned and operated. Despite recent gains, productivity remains low, reflecting a range of challenges and risks faced by SHFs, including:

(i) limited supply, high price, and uncertain quality of modern inputs, increasing the risk associated with adoption;

(ii) uncertain and limited rainfall and lack of irrigation or other systems of water management;

(iii) declining soil fertility; compounded by

(iv) lack of secure land tenure which deters investment,

[18] When reviewing the energy sector, we include state-owned enterprises as well.

(v) poor roads and missing ICT infrastructure, resulting in high transportation costs, and higher information frictions and marketing transaction costs, and

(vii) low public investment in the sector, especially in research and development (R&D), resulting in limited science-based options tailored to SSA's many microclimates (Jayne et al., 2020).[19]

Meanwhile, migration out of rural areas as well as increased nonfarm employment opportunities are raising the price of seasonal labor for planting, weeding, and harvesting, leading to increased demand for capital (draught animals and tractors). There is some evidence of credit constraints to technology adoption, although perceived risk and lack of information appear to be a much stronger determinants of input use (Magruder, 2018). Crop quality and safety (phytosanitary) infrastructure is also missing or weak, limiting the ability of farmers to participate in high-value export crops GVCs, or even to receive good prices for some of their traditional crops. As a result, aside from specific tropical crops such as cacao and cashews, many countries remain uncompetitive on world markets, and farm earnings are still low in traditional tropical crop production (tea, coffee, cocoa, cotton, oilseeds) and livestock products. Poverty and food insecurity rates are high among SHF households in SSA; constraints on productivity particularly affect women SHF, as they are less likely to have secure land tenure or access to credit.

Most the challenges listed above are not solved directly by technology; they require government interventions through public investment and 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 reduce information frictions. Already, mobile phones are bringing more information to farmers about when and what to plant based on weather forecasts and technical information about crop varieties, building a knowledge-based agricultural community (Fabregas et al., 2019). Ghana-based companies Farmerline and Agrocenta offer farmers mobile and web technology for agricultural advice, weather information, andfinancial tips. Zenvus, a Nigerian startup, measures and analyzes soil data to help farmers apply the right fertilizer and optimally irrigate farms (Signé, 2022). The African Soil Information Service uses remote sensing, providing soil data on an open-source basis, bringing down the cost of soil mapping by 97 percent (PfPC, 2018). If more AI and GPS-coded sensors were used, information could be even further customized, and supply chains could track the progress and quality of crop production in any area. Mobile phone applications have been touted a tool to aid in price discovery and help match farmers and wholesalers, reducing price dispersion and transaction costs (Fabregas et al., 2019; Technopolis, 2019), although evidence to date is that this innovation is not at all transformative (Bergquist and McIntosh, 2020). This suggests that price signals already travel efficiently, and other factors are leading to low farmgate prices.

Insecure land tenure may be the largest contributor to low productivity in African agriculture (Restuccia, 2020). It also impedes labor mobility, reducing structural transformation gains, and in addition is one reason for women's lower agricultural productivity and earnings, so addressing this

[19] The wide variety of microclimates with SSA, each requiring different technologies to improve land productivity, is one reason why there has not been a Green Revolution in Africa. See Jayne, (2020)

issue is important.[20] Land tenure reform is politically and socially complex, and requires both careful design and implementation to have a transformative effect; this is not a technology issue. Once a program has been designed, however, there is some evidence that 4IR technology can support implementation effectively. GPS systems are already being used to register land. Likewise, blockchain is beginning to be used to create a safe repositoryfor land records and to reduce the transaction costs of land rentals and sales; Uganda is one example,but few other countries have followed its lead, in part because of a lack of knowledge and understanding of the technology (Technopolis, 2019).

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, this seasonal employment is low-earning, insecure, 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 provide 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, including expansion in 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 than humans, and help ensure that all farmers' crops are sprayed so that pests cannot return (Technopolis,2019). Drones are currently expensive, however, so their widespread use will require support for the producer organizations that normally organize spraying to introduce this technology (Technopolis, 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 sector could improve farmers' access to credit and weather-based credit insurance (see below); blockchain could also improve the traceability of products, helping establish quality standards and brand identities needed to gain higher prices for Africa's agricultural exports. Use of new biological technologies for the development of micro-climate-specific high-yielding seed varieties could speed up the process of developing the inputs farmers need, tailored to the specific context. Adoption of "precision agriculture," a method of site-specific crop and farming management used to improve farm profitability, efficiency, and sustainability already in use in the U.S. and Europe could further raise productivity by reducing the risk to farmer of investing in more expensive but high yielding technologies.[17] Adoption of new technologies could help create new formal jobs in the upstream and downstream off-farm aspects of the 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

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

land-tenure issues and information frictions, Africa rural areas lack the infrastructure needed to use 4IR technologies. In contrast to the Kenya example above, most of Africa's rural areas, especially in West Africa, are underserved by broadband and mobile phone technology. Only 27 percent of rural adults in Africa have ever used the internet (AUC/OECD, 2021). Many areas, especially in LICs, do not have the electricity supply to power 4IR technology or even basic irrigation systems. In SSA LICs, only 20 percent of the rural population report access to electricity, although solar energy offered through pay-per-use technology (a 4IR technology adaptation) could change this situation quite rapidly. Very few farmers are using the internet, either through fixed broadband or mobile. The situation is better in LMICs, where 50 percent of the rural population has access to electricity.This is one reason why most of the action on adopting 4IR technology in agriculture is taking place inLMICs such as Ghana, Kenya, and Nigeria. However, prior to the COVID-19 crisis, countries such as Ethiopia,Senegal, Ghana, Rwanda, and others had experienced rapid, productivity-led output growth, in part 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 who will be keen to adopt this technology, which could lower the price for other farmers in the area (Jayne et. al, 2018). Thus, a case can be made for technology adoption optimism in the post-COVID-19 era.

In sum, while 4IR technology could reduce information frictions and lower the production and investment risk that pervades the whole crop and livestock value chain, the longstanding productivity constraints faced by African farmers - such as insecure land tenure and missing land sale/rental markets - that have continually held back technology adoption, private investment in the sector, and sector transformation, will likely 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 complementary ICT and energy infrastructure in rural areas. However, increased adaptation and adoption in the agricultural sector could bring needed higher earnings and social benefits, the later 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 below). 4IR will not lead to the creation of formal jobs on the farm in Africa; informal labor and family farms characterize the sector all over the world. But 4IR technology adoption, by raising sector productivity, would speed the process of transformation, and government policy should encourage usage. To the extent that 4IR technologies used in a precision agriculture setting 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 the use of 4IR technology in this sector.

3.2 The Industrial Sectors

The industrial sectors include construction, mining, manufacturing, and utility services (e.g., energy and water supply). Within industry, the manufacturing sector has attracted the most attention in terms of 4IR potential and challenges, but this sector is mostly underdeveloped in the LICs and LMICs of SSA where output and employment shares lag the averages for all LICs and LMICs (Fox & Gandhi, 2021). The lack of an export manufacturing sector is often blamed for the slow employment transformation in SSA, and related high levels of informality (Filmer & Fox, 2014; ACET, 2017). Whether 4IR technology development and adoption in richer countries reduces the potential for

African countries to develop their own manufacturing sector, including competing internationally is a highly relevant issue for SSA development economic policy going forward.

Manufacturing

SSA countries, especially the LICs and LMICs, got a late start in developing a privately-owned manufacturing sector for many reasons, including initial lower human capital and geographical and infrastructural obstacles to exporting. Manufacturing output is highly tradeable so African firms face international competition. In most subsectors manufacturing technology brings returns to scale (Murray, 2017); small domestic markets force African manufacturing firms to export their product with the exception of very heavy or hard to transport items (beverages, building materials). The factors limiting output growth in this sector include the cost of building and maintaining an internationally competitive plant, the costs of inputs such as electricity relative to competitors, and the cost of getting goods to market, especially overseas markets (including information frictions between potential sellers and borrowers). Despite these obstacles, manufacturing's share of output and employment has risen over the past decade in Africa, especially in 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 the manufacturing industry over the last 30 years has not favored late entrants. In part to standardize and improve quality, manufacturing has become more capital-intensive, and the labor share of value added has dropped globally (Rodrik, 2016). 4IR technologies, especially advanced robotics, are accelerating this trend in middle- and upper-income countries, where new manufacturing plants use little labor because robots have an absolute advantage over people in many manufacturing tasks. This global substitution of capital for labor particularly disadvantages developing countries, as their low-paid workers are no longer a source of comparative advantage, and thus have no place in global value chains (Baldwin, 2019). Meanwhile, to compete countries have to import expensive robots made in rich countries (Rodrik, 2018), often using high-cost financing.

In considering the potential role of 4IR technology to spur structural transformation in Africa by expanding output and employment in manufacturing in Africa,- or alternatively, to hinder it - it is instructive to briefly review the experience of automation and advanced robotics in high- income countries as this experience often drives the discussion in developing countries (Kenny, 2019). In the U.S., adoption of advanced robotics in manufacturing processes —including AI and IoT—is widely seen as contributing to middle class job losses and 40 years of steadily rising inequality in wages, incomes and wealth (Kenny, 2019). On the one hand, total jobs in the economy grew during the recent automation period (Arntz et al., 2016; Gaus & Hoxtell, 2019), demonstrating that automation does not necessarily lead to widespread unemployment. But the job loss-job creation effects were not equal across gender, skill level, and region. In particular, the share of medium-skill jobs (those requiring a high school diploma plus experience and/or vocational training), disproportionately held by men and disproportionally located in the U.S.'s industrial heartland in the Northeast and Northern Midwest, fell substantially between 1987 and 2017 (Acemoglu & Restrepo, 2019). Meanwhile, demand increased for highly skilled labor to design, deploy, finance, and maintain robots (contributing to a rise in the wage premium for tertiary education; Acemoglu

& Restrepo, 2019). These labor demand trends are blamed for the widening of earnings inequality.[21]

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

How relevant is the experience of the U.S in adopting 4IR technology to the potential for the sector to play a key role in Africa's transformation? Perhaps not so relevant. It is clear that the type of displacement caused by the automation of manufacturing processes that occurred in the U.S., and to a lesser extent in Europe, will not occur in the LICs and LMICs of Africa because the jobs were never there in the first place. A notable exception is South Africa, which does a mix of assembly and production for the domestic markets as well as regional export; they should be able to hold on to their manufacturing employment owing to logistics advantages relative to potential exporters inside and outside the region. Similarly, countries such as Lesotho and eSwatini, with light-manufacturing export sectors which take advantage of South Africa's logistics and trade preferences such as AGOA, but pay lower wages, may be able to keep manufacturing employment up for a period of up to 10 years (Banga and teVelde, 2018). The critical question is whether 4IR technology, if adopted in Africa's late industrializers, could support transformation through an increased share of manufacturing in output and employment thus creating new formal sector jobs, or whether the technology, whether adopted or not in Africa, would reduce it Africa's manufacturing sector employment.

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 that have been recent growth areas for SSA, including textiles, garments, leather, and furniture, have also been more resistant to automation. If African countries can maintain a labor cost advantage, they could expand output and employment in these sectors, 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 the factory (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 the increased productivity and quality in cutting led to increased orders, creating about 5 percent net new jobs. This is an example where automation reduced the number of jobs per unit of output, but lower unit cost increased product

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

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., they will not be price competitive with labor in Kenya for at least one decade. This leads the authors to predict that the share of manufacturing employment could go up first, before declining.

The pessimists note that factor prices (e.g., low wage labor) matter much less for competitiveness in manufacturing than they did in the past (Baldwin, 2019). In fact, payroll costs in export manufacturing plants in Africa are now a small share of total costs—less than 15 percent, a bit higher in garments (Diao et al., 2021)—so the African advantage of low wages does not hold anymore. Increasing economies of scale in production and increasing quality requirements in transport and distribution are cited more often than labor costs as determining manufacturing plant location (McKinsey, 2019a).[22] This is not an area where Africa excels compared to the rest of the world (World Bank, 2019b). Customs and other border delays for imports and exports are much longer in Africa than in other developing regions, impeding competitiveness (except in South Africa, where the logistics sector is well advanced; AfDB, 2018). All of these factors lead Baldwin (2019), to predict 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 used by their competitors and within global value chains. Diao et al. (2021) compared the capital intensity and the technology used in productive export manufacturing plants in Tanzania and Ethiopia with plants in Vietnam and in the Czech Republic, and found them to be similar, despite vastly different factor endowments and factor prices. They conclude that for an African export manufacturing sector to compete with richer countries, there is no choice but to import the capital-intensive technologies developed in the rich countries. Some have suggested that owing to the spread of global value chains within regional blocs (such as East Asia, Europe, and North America, which have advanced robotic technology and well- developed trade logistics both within the bloc and with the rest of the world), the door to employment transformation through growth in export manufacturing is closing fast for Africa, or may even have already closed (Hallward-Driemeier & Nayyar, 2017; Technopolis, 2019).

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

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

manufacturing jobs in high- skill areas such as programming and maintaining 3D printers. 3D printers could give a boost to Africa's burgeoning design sector. Already, start-up entrepreneurs have set up shop in Nairobi using 3D printers to manufacture items out of waste products based on open-source designs, an example of one potential environmental contribution of 4IR products in manufacturing: less waste (Banga & te Velde, 2018).

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

Owing to the capital intensity and skill-bias of new manufacturing technology, 4IR is unlikely to be the engine for creating vast amounts of new, formal, manufacturing jobs for Africa's labor force even as the technology helps Africa's share of the global manufacturing output remain the same or increase. On the other hand, the employment effect of the diffusion of 4IR technology to the African manufacturing sector 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 African companies will have to start adopting 4IR technology within a decade or so to stay globally competitive. The key question is whether African countries will have the financing and supportive infrastructure that entrepreneurs need for the technology to be profitable. For entrepreneurs and others that are able to develop the required skills—a select group, mostly youth—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 Velde, 2018).

Mining

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

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

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 $.40 per kWh vs. $.10-.20 per kWh from grid-based energy (IFC, 2019). Nigerian electricity users spend three times as much money on back-up generators as they do on grid energy (IFC, 2019). Generators are powered by burning diesel fuel, which emits emissions that are both a health hazard and contribute to climate change. Grid electricity in Africa is still highly dependent on fossil fuels, even though renewable sources are abundant (sun, wind, and hydro; IFC, 2019). The unreliability and cost of energy is frequently cited as one of the top three obstacles to business expansion in SSA (IFC, 2019), and already is an obstacle to the 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 new wage job creation, and increased earnings for enterprises of all sizes. By using IoT and other 4IR technologies (Technopolis, 2019), non-revenue energy use (electricity theft) could be reduced, improving the financial position of electricity distributors. 4IR technology already supports microgrids, energy on demand, and pay-as-you-go schemes for rural villages and towns. Advanced material science is bringing down the cost of key parts of the system, including solar panels and windmills, as well as the batteries needed to store energy for nighttime use or when the wind dies down.

A key issue inhibiting technology adoption is the quality of operational and financial management in legacy state-owned electricity (SOE) companies. Major structural reforms are needed in the sector, involving overhauling the regulatory approaches to SOE monopolies or moving to private sector competitive models. Electricity generation is a sector often cited as most likely to benefit from a private sector, competitive approach (Bond, 2016).

In sum, Africa will need 4IR technologies to transform the industrial sectors, making them more competitive and increasing the range of products made in Africa available to African consumers (as well as lower their prices). These demand and competition pressures will surely encourage technology adoption. However, the prospects for large-scale increased employment and earnings are moderate. While the new jobs created through industrial upgrading are most likely to be formal sector, stable, and higher earning ones, they will also require more skills than jobs in traditional light manufacturing, suggesting that 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 The service sectors

The service sector group is the most heterogeneous, as it includes trade, transportation (air, road, rail; people and freight), hospitality (including tourism), finance, and real estate (sales, rental, and management), professional and administrative services (including ICT), public administration, security, urban services, education, health, social work, arts, entertainment and recreation, personal services (e.g., hairdressing) and domestic services (household chores and care, home security services, etc.).[23] For the most part, service sectors are labor-intensive, but notable exceptions include transportation, ICT, and finance. Service sectors' share of output and employment has grown rapidly throughout Africa. Yet the majority of service sector employment outside of the public sector is informal (Fox & Gandhi, 2021; Diao et al., 2021).

It used to be conventional wisdom that service sectors could not contribute much to economic growth and transformation due to their low potential for productivity improvement.[24] The development and adoption of 3IR and now 4IR technology has changed this picture. For example, containerization and digital trading records have reduced international shipping costs by more than 90 percent since the 1960s, reflecting a huge productivity improvement (Murray, 2017). Wholesale and retail trade in the U.S. has recorded annual productivity growth of 1.3 percent since 1987 (Gollin, 2018), reflecting a number of technological changes including using 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 gained productivity over the last four decades by adopting the technology of barcodes and sensors to manage the process of loading and unloading passengers and freight. The internet has revolutionized tourism, as most activities are now planned online; the occupation of travel agent has almost disappeared in high-income countries (Acemoglu & Restropo, 2019). The healthcare sector has substantially automated by using robots and sensors, as well as modern software to manage complicated supply chains more effectively. 4IR technology, including platforms, is spurring the development of e-commerce, the gig 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).

This cost-lowering, quality-improving technology has also arrived in Africa, but adoption has been limited, resulting in an increasingly segmented services sector. Low-tech informality coexists with

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

[24] 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 the service sector.

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 these exist alongside informal roadside stands, kiosks, and market stalls, sometimes selling the same products (Fox & Sohnesen, 2016). Productivity improvements in domestic freight transportation and logistics are few as of yet, and as a result, outside of South Africa, costs are high and delays are 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 can be found in airports (including air freight) and high-end hospitality, which use all the latest technology to provide the level of service that international and business travelers expect, as well as in the financial sector, where Africa has the highest rate of mobile money adoption in the developing world (66%; AUC/ OECD, 2021).

Service sector output and employment is expected to grow rapidly in Africa, which will result in structural transformation. The project 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 informally supplied services. Demographic dynamics imply that low-tech, informally supplied services will continue to offer employment opportunities for a large share of the labor force, even as formally supplied services also increase their employment share. The business models and employment dynamics in the sectors where formal firms dominate versus where informal firms dominate are quite different, so it makes sense to consider their potential to accelerate transformation by adopting 4IR technologies separately.

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, digital technology supported growth in Africa's service exports at a rate more than six times faster than merchandise exports (Newfarmer et al., 2018). Adoption of 4IR technology could push this process forward even faster, primarily by increasing market access as well as improving product quality.

Research has already identified the importance of ICT for process and product innovation in African firms, especially in services sectors (Houngbonon, et. al, 2021), and this effect is expected to continue. One example of how adoption of 4IR technology solves longstanding market access and development issues is found in the tourism sector. Tourism has been a major source of income growth and jobs at multiple skill levels in Africa, including both customer-facing jobs, which tend to require higher skill levels, and low- and medium-skill jobs in cleaning, transport, maintenance, etc. In Tanzania, tourism accounts for 14 percent of GDP; in South Africa, it creates 36 percent of jobs in the food and beverage sector (Page, 2019). 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 transportation 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 improve the security of the visa and entry process for international travelers if governments adopt the technology. Meanwhile, smartphone-based navigational mapping technology can continue to support both tourists and local transportation. Photos posted online on various platforms (social media and others) 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 this technology adoption and diffusion, 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 a massive globalization of customer-facing services, creating vast new opportunities for decent jobs in developing countries. Africa's lower wages relative to rich countries could once again be a source of comparative advantage. Expansion of the internet has already enabled the business process outsourcing (BPO) export business in non-customer-facing services, including call centers, digital data entry and processing (e.g., insurance claims processing, basic accountancy services), and software development. Africa's share in this market is small, however, compared to BPO powerhouses such as the Philippines and India (PfPC, 2018). It is not clear that this "first-wave" BPO is a growth sector now; much first-wave BPO business could soon be replaced by robots, AI, and IoT technology, and may then go back to rich countries through onshoring. For example, "chatbots" are replacing call center outsourcing (PfPC, 2018). Baldwin (2019) predicts that a "second wave" may emerge, however, more focused on customer-facing skills and enabled by video communications software. Banga et al. (2020) and Baldwin (2019) note that Africa's southern and often landlocked geography, a disadvantage in manufacturing, will not matter for future service exports as no products need to be transported. COVID-19 lockdowns have demonstrated that high-speed broadband technology and conferencing software eliminates the need for everyone to be in same place, so it will be much easier for firms to contract out business services to lower wage economies.

While Baldwin's predictions may hold for Asia, opportunities in Africa could be significantly lower 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 (that is, the cost of living) they are high in USD, especially for workers with post-primary education (Gelb et al., 2020). Thus, service exports based on Africa's other sources of comparative advantage (such as natural resource-based tourism) or designed for a regional market (e.g., Nollywood in Nigeria, which now employs over 1 million people[25]) may have more potential to grow rapidly and create new employment opportunities, while Africa's prospects in the second wave of BPO may be less rosy.

Services for domestic or regional markets show more potential for output and formal wage employment expansion 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

[25] See discussion in Signé, (2022).

trend can be expected to continue. E-commerce operators have had one of the largest employment impacts to date of any internet start-up subsector. For example, Jumia Group, the Nigeria- based e-commerce company, had over 7500 employees in 2020 (AUC/OECD, 2021). Interestingly, larger companies co-exist with small household-based e-commerce operators who sell a limited range of high- volume items such as electronics (Technopolis, 2019). E-commerce operators in Africa face several challenges, including cross-border payments and logistics, but 4IR digital technology is enabling fintech companies and the private logistics sector to become a growth industry, responding to this demand. The expansion of digital currencies based on blockchain technology as a means of payment could ease cross-border payments challenges, allowing an even faster expansion of the e-commerce sector (if such digital currencies are not blocked by central banks). As e-commerce takes off, both through B2B and B2C business models, start-up entrepreneurs are setting up digital platforms linked to brick-and-mortar warehouses, and are contracting with transport providers to provide the services start-ups need. Individually, these companies are not large employers: for example, Kobe360, a well-known Nigerian logistics company, had only 149 employees in 2020, while Twiga foods in Kenya had 275. But through their links with farmers and independent truckers, they both raise and stabilize incomes in both sectors (AUC/OECD, 2021).

In the financial sector, adoption and adaptation of digital technology in Africa (3IR and 4IR) has arguably 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 remains low, at just half the global average for emerging markets (Chironga et al., 2018), households and businesses are still able to save and transact securely. Retail banks will continue to struggle to find consumers given widespread low income levels, the popularity of cash, high fixed costs and thus high fees for small accounts, while Africa is likely to continue to lead the world in terms of digital financial usage per capita (Chironga et al., 2018; Signé, 2022).

Mobile financial services have expanded from savings and payment accounts into credit, insurance, and cross-border remittances, all of which help businesses to survive and, depending on scale, to employ workers. There is significant scope for further improvement and for new applications using 4IR technologies such as blockchain and machine learning. African banks lack information on individuals' credit (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 branches. Digital credit risk management, for example, uses automation, connectivity, and digital delivery and decision- making to allow for faster decisions and superior risk assessment than is possible with current manual processes (Signé, 2022). 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 access to M-pesa accounts, by increasing and protecting women's savings, allowed women to move out of subsistence agriculture and start new non-farm businesses. Women owners of informal businesses in Tanzania who received training on the use of an MFI linked to M-pesa saved almost four times more than the control group used for measuring project impact, and were 16 percent more likely to receive a loan (World Bank, 2019b). In Niger, women who were given access to mobile money savings accounts increased their earnings from their economic activities and their bargaining power in the household (Ahmad et al., 2020). The adoption of uniform national identity systems, often through biometric identification (another 4IR technology), has helped improve system security and functioning and has enabled the system to receive international payments and remittances. Access to mobile money platforms is not equal across Africa. Countries with nimble and enabling regulatory systems such as those in East Africa have seen rapid growth in accounts, and clear benefits. Kenya leads all other countries in SSA in mobile money accounts per capita, while adoption of these financial innovations in Central and Southern Africa remains relatively low (AUC/OECD, 2021).

In sum, 4IR technology could rapidly speed economic transformation and employment growth in the formal service sectors in Africa. Many of these sectors have already shown ample scope and readiness to adapt and adopt new technology, providing many new, higher productivity employment opportunities, and this trend can be expected to continue, speeding the shift of employment out of lower productivity 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 adoption in other sectors. Other 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 labor force participants. While some of Africa's long-standing productivity and innovation constraints (e.g., expensive and high-cost energy) may slow down the technology adoption process 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 activities, selling a broad range of products to 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 they (i) they are convenient, or (ii) they sell items in small quantities, matching the cash flow of their customers (e.g., they sell a few tomatoes, less than a full pack of cigarettes, small quantities of cooking oil or dish soap, etc.). Informal business owners also perform services for household members, including personal services, custom dressmaking/tailoring, and repair of small items. They run small hospitality businesses such as renting out a room in their house (small hotel), or operating a small bar or fast-food restaurant. [26]

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

Individuals and households operating these businesses face a number of challenges. Most start an informal business because of a shortage of wage jobs on offer in the economy, not because of entrepreneurial drive (Fox et al., 2020; Lorenceau, 2021). Very few grow to regularly employ anyone outside the household (Filmer & Fox, 2014). They face high risks, including from competitors who easily enter the sector. Their advertising is word of mouth. The businesses are poorly capitalized. In many cases, informal sellers of goods and services cluster in specific areas so that customers can find them, or they work at home, but others roam the streets looking for customers. Those who operate their business outside of their home often travel long distances, hauling their inventory and equipment (tables, display cases, scales) with them (Chen & Carre, 2020). The urban environments in which they operate mostly 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 which would support their business. Others permit local 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 new 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).

Several studies are optimistic that adoption of 4IR technology would allow a large swath of self-employed, family-employed, and dependent- contractors will be able to raise their earnings and "formalize" (PfPC, 2018; Choi et al., 2020). Some positive examples of technology upgrading in this sector can be cited. Significant earnings gains have already been realized in this sector with the adoption of mobile phones, which provide improved communication with suppliers and customers and 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, and this has raised their earnings (AUC/OECD, 2021). Optimists point to the potential role of digital platforms in connecting service providers and customers, reducing down-time for household business owners and search time for customers. The use of mobile platforms to sell home-made products (such as Etsy in the U.S.) has, in some cases, led to more stable income and more reliable payments. For example, the e-commerce platform Alibaba has helped many family businesses in China connect to the vast domestic and international market by reducing customer discovery and transaction costs. Transportation platforms have made the process of ride-hailing—supplied by informal sector drivers of cars or motorcycles—more efficient, providing a much better service for customers and safer working conditions for drivers (PfPC, 2018). The expansion of e-commerce in Africa has created demand for informal bicycle, motorcycle, and taxi drivers to provide on-demand delivery services for vendors, including food service vendors, creating more and better informal sector jobs in the process.[27] Some observers envisaged that these platforms will be created and used routinely to request and book services delivered in-home by informal service providers such as hairdressers and manicurists, as well as to find a reliable self-employed craftsperson (e.g., plumber or gardener/home repair person).

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

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

Some have argued that 4IR technology is a boon for women working in the informal sector (Choi, et. al., 2020). Women earn less than men in this sector around the world (Chen & Carre, 2020). One issue is mobility. Women often end up working from home owing to the burden of unpaid household responsibilities and/or the hazards of leaving home such as unsafe public transport, workplace harassment, or norms which punish women's mobility. Broadband internet potentially allows 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, an 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 per hour earnings are often very low, below the minimum wage in many countries (Hunt & Samman, 2019).

In fact, all is not a bed of roses for women gig workers. Hunt and Samman (2019) point out that women in Africa are more likely to be present in crowdwork than in activities that utilize platforms to get customers (on-demand work), where earnings tend to be higher. Sadly, women earn less than men in both platform activities and crowdwork. Studies undertaken 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 limited opportunities to learn to drive). Women drivers face additional harassment while doing their work (Siddiqui & Zhou, 2021). Hunt and Machingura (2018) and Siddiqui and Zhou (2021) show that platform technology is reinforcing old discrimination patterns through ratings and review systems.[28] 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 owing to their higher quality. 4IR technology mostly complements, rather than substitutes for labor in these sector, so as African economies grow, wage jobs, mostly formal, can be expected to increase in this sector with technology adoption. Exported services could become a significant, if not large, source of wage and

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

nonwage employment, both through platforms and through 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 is thin on whether employment conditions have improved.

Nonetheless, most employment in the service sector is currently informal, and is likely to remain so, at least in lower-income countries, in part due to the pressure of labor supply—a growing labor force. If inclusion-oriented policies lead to increased private ICT investment and internet usage prices fall substantially, informal service suppliers may start using it to their benefit, setting up websites, for example, and advertising on social media sites such as Facebook. But we do not yet have evidence on the use of internet platforms by informal household businesses in Africa; both positive and negative effects could be envisaged. 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 importantly, is the public sector prepared to help the informal sector make money and keep their businesses going, rather than treating them like a pariah, to be eliminated as part of urban cleanup efforts (see the discussion in Chen & Carre, 2020). These productivity issues are not solved by technology. They reflect are policy decisions that precede even 3IR.

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

4. Key Challenges

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

Challenge 1: Governance - Inadequate regulatory frameworks and business environments

Despite the variation across countries, it is well established that weak governance and Africa's poor regulatory frameworks - which create challenging business environments - currently hinder firm entrance and growth, a prerequisite for economic transformation and for increasing the amount and share of formal wage employment (AfDB, 2018). Africa's excessive red tape and corruption deter both domestic and foreign investment and cost jobs (AfDB, 2018). As a consequence, fewer firms enter and grow, thus creating fewer new formal wage jobs. These regulatory frameworks also inhibit an upgrading of the mechanical and managerial technology needed for African firms to remain competitive in a globalized economy, including adaption and adoption of 4IR technology (Choi et al., 2020; AUC/OECD, 2021). Unfortunately, policymakers and economic stakeholders too often have an insufficient awareness of the importance of industrial upgrading through technology adoption for economic growth and job creation (AUC/ OECD, 2021). Furthermore, governments often do not have the skills to respond to 4IR regulatory and investment challenges.

The business legal environment (regulations and implementation) does not sufficiently encourage importation of 4IR technology, in 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. and Foreign Direct Investment (FDI) is increasingly important for gaining access to 4IR technologies. However, despite recent increases, FDI in Africa remains low, at around $46 billion in 2018, and little of this FDI is directed towards the ICT sector or the adaption and adoption of 4IR technology (UNCTAD, 2019).

One important area for public policy focus is enabling financial sector deepening. Governments regulate contracts and payments systems, but these regulations usually do not permit the use of blockchains for financial transactions without the intermediation of a third party, or for customs documentation or healthcare records (The Law Library of Congress, 2018). Legislation to develop a single digital identity for residents is also needed in about half of African countries, in order to enable mobile finance 2.0 and blockchain-based transactions (Signé, 2022).

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

Governments need to focus on the business environment for farmers as well. Adoption of technology in the agricultural sector, desperately needed to raise earnings and productivity, is primarily inhibited by risk, created among other things 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 in order to encourage productivity-enhancing technology to be adopted. It can also invest in the development and dissemination of this technology through publicly-financed agricultural research.

4IR brings new challenges to public sector regulators, such as insuring cybersecurity. Cybersecurity is crucial at the individual, corporate, leadership, and systems level. Cybersecurity will take on unprecedented importance as cyber-warfare expands, and the increasing interconnection of systems and the importance of data provides new targets for attack. Capitalizing on 4IR requires effective cybersecurity to protect critical infrastructure, digital data systems, and ensure the sustainability of the firms creating jobs. With any digital infrastructure development, governments must implement legislation to protect the data and privacy of their citizens and critical infrastructure to avoid disrupting firms with cyberattacks, as it could impact jobs. A lack of awareness of the potential value of public sector information dissemination around issues such as cyber security compounds the problem. Similarly, governments are scrambling to effectively regulate drones to avoid interference with aircraft as their use is growing (Technopolis, 2019).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Equipping rural areas and towns with affordable internet access will provide enormous resources for participation in the digital economy. ICT infrastructure in small cities and towns can allow these places to act as "transmission hubs" that will serve rural areas (AU/OECD, 2021). This will strengthen connections between rural and urban areas and drive rural transformation. As much as possible, private investment should be encouraged for this effort, as public finance will be in short supply owing to its decimation during the COVID-19 shock and response. Alliances and partnerships between public and private actors can help provide cost-effective solutions to allow access in less densely populated rural areas (Chakravorti & Chaturvedi, 2019; AU/OECD, 2021, PfPC, 2019). For urban informal sector operators and digital start-ups, extending Commons within a spectrum-sharing environment would help expand access while keeping prices down.[29]

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

Proactive strategies promoting inclusion will be critical. For example, aggregating demand from public buyers seeking to reach marginalized communities can help make broadband more affordable and ensure inclusion; if government and NGO programs aggregated their demand, this would guarantee a market and could encourage network expansion (PfPC, 2019). Governments should restructure taxes so they are not discriminatory and should provide incentives to firms that prioritize underserved communities (BC, 2019). Universal service funds, sourced from ICT industry taxation, can be used to provide ICT services to those who otherwise could not afford them (BC,

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

2019). The Pathways for Prosperity Commission (PfPC), however, recommends against their use because of a history of poor transparency and unknowledgeable, uninformed program managers. Instead, governments should encourage or require the ICT industry to raise the cost of services in more prosperous areas (usually cities), in order to subsidize the loss of revenue among poorer communities. Subsidies could also be directed toward funding free Wi-Fi zones (PfPC, 2019).

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

Challenge 3: Inclusive skill development for technology adoption

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

One overarching recommendation often found in reports on 4IR and developing countries to counter the loss of comparative advantage is to raise the skill level of the labor force up to the needs of 4IR technologies, especially in the post-secondary STEM skill areas (Naude, 2017; Technopolis, 2019; AU/ OECD, 2021). This recommendation deserves further scrutiny. Post-secondary STEM skill development, especially engineering, is very expensive compared with social sciences or humanities (or even secondary education) and as a result, despite a major expansion of post-secondary education, the supply of technically-trained graduates in these fields in Africa has not increased very much. More importantly, despite a rapid expansion of educational access, African countries still need to expand infrastructure at the primary and secondary levels in the years to come owing to past high fertility, which every year expands the need for places at all levels just to maintain current progress. The quality of basic education is an issue as well. This means that with limited resources, African countries face tough spending tradeoffs. Expanding expensive post-secondary education could leave few resources available for needed improvements in the primary and secondary system which will develop most of the future labor force, especially those who will make a living in the informal sector, trying to use 4IR technology to raise earnings. This trade-off is often ignored in discussions on the future of work and 4IR technology, which tend to focus on the demand for post-secondary skills in formal firms. We explore this trade-off in more detail below.

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

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

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

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

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

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

In sum, Africa needs improvements in quality at all levels of education to deliver the skills that will be demanded and rewarded in tomorrow's economy. These skills needs are much broader than digital skills or engineering. 4IR innovations will require the African labor force and students (young people) to develop a broader and more diverse skillset that can add value to new systems of production, marketing, selling, and service. To achieve this, quality basic education needs to be available to all, and both cognitive learning outcomes and socio-emotional skills need to be prioritized and delivered in a cost-effective manner.

Solution 3: Inclusively increase human capital

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

Africa's higher education system, which will be responsible for training the high-skill labor to complement 4IR technology, has expanded rapidly owing to increased demand, but needs a quality upgrade and needs to incorporate new financing models. Engaging with private sector technology leaders will be key to meeting both challenges. If public educational institutions worked with industry to reform curricula and pursue work-based learning opportunities, they could help higher education graduates attain the range of skills they need to succeed at a variety of tasks—technical, cognitive, and socioemotional – and provide skilled labor 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 areas such as data science, digital marketing, artificial intelligence, coding, and app development. Another example is Kenya's Ajira Digital Program, which has reportedly enabled over 630,000 youths to have access to online jobs (Ajira Digital, 2020).

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

The need for a comprehensive strategy

While the challenges presented above are complex, they are not insurmountable. Efforts to conscientiously shape public policy guiding technological growth to maximize benefits and minimize rewards will be crucial for success in 4IR. A critical assessment of the literature shows that what is missing, beyond the specific deficits highlighted, is a comprehensive, effective, and implementable strategy that will address the various challenges faced by governments (AUC/OECD, 2021; Signé, 2022; PfPC, 2019). Several important dimensions of the necessary strategies stand out.

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

- African governments need *strategies to increase new technology adoption and foster innovation in the private sector* to maximize growth, transformation, and inclusion. Wider access to technology increases the potential for job creation, but throughout Africa, firm-level access to technology remains limited. Governments should approach this challenge from three angles: fostering innovation; facilitating technology adoption (including 4IR technologies); and increasing access to finance.

- *Strategy development and implementation 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, including the private sector, civil society, and external partners in an open policymaking process.

- The successful implementation of such a strategy will also require *evidence-based policy making*, with experimentation, economic evaluation of the use of public funds, and impact studies, to guide better project choice and ensure follow-through to final delivery (Signé, 2018).

Many of these observations on the needed strategic approach to economic transformation are not new, as African governments are already awash in plans and strategies (Pritchett et al., 2010). What governments can do is to revisit existing strategies from the perspective of the need for technology innovation and adoption. Priorities can be re-assessed and renewed, focusing on local context including looking both for opportunities for quick wins (e.g., expansive of access to mobile telephones, internet, and fintech; reform of tariff structures to support technology importation; increased public-private partnerships in post-secondary education), and initiatives that need to start now in order to bear fruit in the medium term (e.g. expansion of energy infrastructure and reform of legacy service delivery; education system reform to build 21st century skills).

5. Conclusion

4IR technology has the potential to support countries in transforming their economies and their employment opportunities. 4IR technology brings opportunities for production cost reduction, productivity and earnings improvement, and the development and introduction of new business lines, providing a wealth of new opportunities that should prove particularly attractive and accessible to Africa's young labor force. Deployment of 4IR technology could accelerate needed economic transformation through new, often formal, wage jobs being created at a faster rate than the growth of the labor force, and earnings improvements in the informal sector.

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 only bring incremental change in the trajectory of employment transformation, in terms of shift from the informal to the formal sector, as this trajectory has been already set by past demographic change and current level of economic development (Fox and Gandhi, 2021; AU/OECD, 2021).

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

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