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# Economic Transformation in the *Fourth Industrial Revolution*

Insights From African Manufacturing and Guidance for Policymakers

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# Executive Summary

In the coming years and decades, African governments must navigate the challenge of driving job-rich economic transformation in the context of disruptive global technological change. Recent and ongoing technological breakthroughs are heralding a fourth industrial revolution (4IR). The 4IR refers to "the marriage of physical assets and advanced digital technologies [...] that communicate, analyse, and act upon information, enabling organisations, consumers, and society to be more flexible and responsive and make more intelligent data-driven decisions" (Deloitte, 2020).

4IR technologies are beginning to permeate manufacturing around the world, with the potential to automate more complex production processes while also drastically improving customisation, waste reduction and production cost. The number of industrial robots installed globally grew from 0.5 million in 2000 to 3 million by 2020. These robots are evolving, with rapid advancements in processing power and machine learning leading to increased autonomy, versatility and connectedness. The integration of wireless sensor networks is enabling machinery, components and final products to generate large amounts of data, which – with the help of big-data analysis, cloud computing and artificial intelligence (AI) – are enabling productivity-enhancing innovations such as predictive maintenance, process and task optimisation, user-led product design and automated waste reduction. 3D printing is increasingly used in producing prototypes and component parts, for example in the automotive, footwear and plastics industries.

There are growing concerns among African policymakers that manufacturing will no longer absorb low-skill labour at scale and that low-cost labour is becoming less of an advantage in the early stages of building competitive manufacturing sectors. As such, the fear is that manufacturing can no longer be the main engine of economic transformation. On the other hand, many policymakers wonder whether African economies can bypass the traditional economic-transformation route, skipping the manufacturing stage and leapfrogging directly into digitally enabled services in the 4IR economy. However, the existing empirical evidence on the impact of 4IR technologies on employment and skills is both scarce and ambiguous, more so in developing countries in general, and especially in Africa.

In this context, this publication aims to equip African policymakers with the conceptual frameworks, empirical insights and policy tools needed to drive economic transformation amid technological disruption. It does so on the basis of a global literature review and first-hand evidence on the impact of new technologies on strategic industries in three African countries. This paper provides:

- A framework for thinking about the threats and opportunities posed by disruptive manufacturing technologies for economic transformation, job creation and investment in Africa.

- Firm-level, on-the-ground insights into the “what”, “why” and “how” of technology adoption in key industrial sectors on the continent.

- Recommendations for the design of smart industrial policies to drive inclusive economic transformation in the context of rapid technological change.

The study is based on a global literature review and 33 in-depth interviews with manufacturers and other ecosystem stakeholders in the automotive, textile and apparel (T&A), and food and beverage (F&B) industries in South Africa, Kenya and Ghana.

## Key Messages

**Pursue the Window of Opportunity to Develop Labour-Intensive Manufacturing Sectors Through Smart Industrial Policies**

Over the next decade, African economies can capitalise on a window of opportunity to create jobs in some labour-intensive manufacturing activities. The comparative advantage of cheap labour will remain relevant for some time, but only in some subsectors, such as the sewing of garments, the final assembly of cars and certain food-processing activities. A window of opportunity exists to drive labour-intensive manufacturing growth through industrial policies aimed at these subsectors. But to be globally competitive in the medium to long term, governments will need to upskill their countries' workforces, and develop better digital infrastructure, research-and-development (R&D) capabilities and technology-related services to create jobs in the context of the 4IR.

### Prepare to Upgrade Your Manufacturing Sectors Into 4IR Technologies, but Don't Skip the 3IR: Build a Strong Industrial Base First

In the 4IR era, manufacturing will continue to be a core driver of economic transformation and a requirement for building a competitive and resilient economy. It will continue to create the biggest learning and upgrading opportunities within global and regional value chains, even greater positive spillovers into other economic sectors than before and increasingly high-quality jobs. Building or maintaining a globally competitive economy will increasingly require embracing 4IR technologies. In some sectors – such as large-scale beverage production – the use of advanced technologies is already widespread. In others, 4IR technologies are gradually being adopted and leading to productivity and efficiency gains. African manufacturing sectors will need to embrace 4IR technologies to keep up.

But an economy cannot jump into the 4IR without a strong industrial base. The 4IR builds on third-industrial-revolution (3IR) technologies, engineering and organisational capabilities, and is primarily about integrating and connecting existing 3IR technologies into a "smart factory". For example, recent innovations in smart robotics would not have been possible without earlier advances in software programming and basic robotics, both of which in turn were built on previous innovations in electric machinery and assembly-line organisation. As such, while it is conceptually practical to discuss these industrial revolutions as distinct periods, it is more accurate to view industrial technological change as a continuous evolutionary transition. These industrial capabilities emerge via learning-by-doing when firms engage in industrial activities in a supportive and competitive environment. Policies can foster the growth of competitive industrial capabilities through the entry, emergence and growth of manufacturing firms that become increasingly competitive. This is the foundation for entering and thriving in the 4IR.

African governments should adopt smart industrial policies to foster the development of competitive industries using the most appropriate technologies before moving on to more advanced emerging technologies. Industrial policies should focus on fixing market failures, providing the public goods necessary for market development, and actively fostering foreign and domestic investment to spur the growth of industrial ecosystems. In the face of scarce resources, smart industrial policies require a careful selection of sectors with the highest potential for success.

Policy has a central role to play in building an ecosystem that fosters the adoption, absorption, adaptation and innovation of 4IR technologies in manufacturing. African governments should foster technology adoption and technological learning in manufacturing through policies that help alleviate the constraints to technology adoption.

These policies should also foster technology-related services such as system integration, software engineering, data analytics and machine maintenance, which are expected to drive job-creation opportunities in the future.

At the firm level, policies can foster advanced technological capabilities by helping firms achieve the economies of scale that make technology adoption viable, generating demand for technology-related services through targeted subsidies, providing R&D grants and tax incentives, and providing information and training on available technologies. At the ecosystem level, policy interventions include technology R&D and incubation, public procurement to create demand for technology-intensive activities, the strengthening of key infrastructure such as internet, electricity and data centres, data localisation to spur local data storage and processing services, 4IR skills development and concessional financing for technology adoption.

**Moving Into the 4IR Does Not Necessarily Mean Losing Jobs**

The net effect of 4IR-technology adoption in African manufacturing on the number of jobs appears to be neutral or positive. 4IR technologies are not primarily about replacing human labour with machine work; rather, they are about adding a digital layer to existing manufacturing technologies to enable increased production efficiency, scale, quality and versatility, among other things. Firms at the forefront of technology adoption tend to be (i) growing thanks to productivity gains and, as a result, hiring more people and (ii) retraining most employees whose tasks have been automated and moving them to other operations such as sales and distribution or machine operation and maintenance.

### Foster the New Skills Needed in 4IR Manufacturing

Technology adoption is fundamentally changing the skills profile of manufacturing labour in Africa and globally. Increasingly automated production lines require fewer manual workers and more engineering and IT graduates. Factories are also hiring more young people familiar with digital technology. The "servicification" of manufacturing is beginning to emerge at a small scale, especially in Kenya and South Africa, where locally owned system integrators have emerged to support manufacturers in 4IR technology installation and integration, data collection and processing, and proprietary software- and hardware-technology development. This means that some jobs are leaving the factory and moving into outsourced service firms. African governments should foster the development of 4IR skills in close collaboration with manufacturers and technology leaders, including through public-private training institutes, technology- and skills-transfer agreements with international firms and training incentives for local manufacturers.

### Manage the Transition of Labour Into 4IR Jobs and Tasks

This shift in the skills profile of manufacturing will continue to create a need for new skills while also causing labour-market disruption and adjustment costs. Policies are also needed to manage these labour-market shifts through re-skilling and upskilling displaced workers, improving the job-search process and expanding social-protection measures.

Active labour-market policies can improve the functioning of the labour market and its outcomes. In the context of the 4IR, policymakers should focus on re-skilling and upskilling of displaced workers, as well as on improving the job-search process. Policy interventions include job-search assistance, subsidised employment programmes, retrain-and-retain incentive schemes to reduce technology-induced lay-offs, and reskilling support for laid-off workers.

Social-protection measures typically provide a source of income for workers who have lost their jobs as a result of technological changes. They can also provide a cushion for workers as they transition to new employment opportunities. Policy tools include the establishment of unemployment insurance or social safety nets. The 4IR and its adjustment costs will increase the need for such social measures.

Finally, effective delivery and coordination mechanisms will be key. From the establishment of a Chief Scientist's Office that identifies frontier technologies and their application in industrial activities to international partnerships with global technology leaders, new forms of public policy and public-private partnerships with coordinated support from different government agencies are needed to deliver the policies required to embrace and manage automation effectively.

# Case-Study Findings

Chapter 4 presents detailed findings from firm and other stakeholder interviews in the automotive, textile and garment, and food and beverage industries of South Africa, Ghana and Kenya.

### TECHNOLOGY-ADOPTION TRENDS

Africa's most advanced manufacturing sectors are simultaneously still consolidating 3IR technologies while beginning to venture into 4IR technologies. The automotive, beverage and textiles sectors all boast mature 3IR-technology adoption, with most processes automated and digital product design and production-management systems in place. The apparel sector is mixed: several tasks have recently gone from being manual to automated, such as the cutting and spreading of fabrics. Sewing is still mostly manual as the dexterity required cannot yet be replaced by machines in a cost-effective manner.

In terms of 4IR technologies, several interviewed firms had recently installed cameras and sensors that generate data for quality monitoring throughout the supply chain, from inputs (for example, ingredients for F&Bs) to production processes (for example, to verify that correct parts have been assembled in the automotive industry) and end-products (for example, radio-frequency identification (RFID) tags on garments to improve supply-chain efficiency and transparency, and to optimise stock management). Especially in the automotive and beverage sectors, sensors on machinery are also increasingly being used to generate real-time data and enable predictive machine-maintenance planning, energy-use optimisation and new after-sale services (such as predictive maintenance of cars). 3D printing is increasingly used for prototype production by numerous firms in the apparel and automotive industries and, to a lesser extent, to produce and replace parts in the automotive and beverage industries.

## FACTORS AFFECTING TECHNOLOGY ADOPTION IN AFRICA

The key drivers of technology adoption are volume (i.e., production scale), standardisation, energy efficiency and waste reduction, new materials and labour replacement. Ultimately, these increase the return on technology investment, productivity, efficiency, sustainability and compliance with global value-chain standards. Global value-chain lead firms or headquarters are key drivers of technology-adoption decisions in African original equipment manufacturers (OEMs) or supplier plants. Across the three sectors – automotive, T&A and F&B – firms' decisions to invest in new technologies are driven by efforts to achieve (i) production volumes, which create economies of scale and make productivity-enhancing automation viable, (ii) process and quality standardisation, (iii) energy efficiency and waste reduction, (iv) optimised supply-chain and stock management, (v) new materials (for example, lighter materials trigger the adoption of laser-welding robots) and finally (vi) wage-bill reduction. Labour replacement was mentioned as a relatively minor driver of technology adoption compared to other factors such as volume and standardisation.

In Africa's automotive industries, production scale is the key constraint on further technology adoption. This is an observed bottleneck in the other sectors too but to a far lesser degree. Beyond volume, skills are the most mentioned bottleneck to technology adoption. Firms in all three sectors are constrained by (i) the high cost of training new staff or retraining existing staff to effectively use new technologies, including the absence of locally available trainers, (ii) the shortage of mechatronic[1] and software engineers, and (iii) the shortage of technology-related and soft skills that local graduates bring. Other commonly cited bottlenecks include (i) the cost and availability of finance for capital investments in new production technologies, (ii) the cost and reliability of electricity, which makes highly automated production processes risky and costly, (iii) the lack of locally available machinery-servicing facilities and spare parts, and (iv) the availability, cost and quality of digital infrastructure such as 5G connectivity and data centres.

## LABOUR-MARKET IMPACTS

The impact of 4IR-technology adoption on employment is mixed. In the automotive and beverage industries, it appears that the most significant labour-replacing automation has already taken place, and the leading African operations are already highly automated and capital intensive[2]. In those sectors currently experiencing an automation drive, there is some labour displacement, but there does not appear to be a significant negative net effect on employment, even at the plant level. The firms at the forefront of technology adoption in these sectors are harnessing productivity gains and therefore tend to be growing, expanding their operations and hiring more people. Significant manufacturing tasks in some sectors (for example sewing, or loading and offloading) will remain labour intensive for some time.

In line with the global evidence, technology adoption is fundamentally changing the skills profile of manufacturing labour in Kenya, Ghana and South Africa. Manufacturing is becoming more skill-intensive. Increasingly automated production lines require fewer manual workers and more people with university-level engineering and IT competencies. Numerous factories are also hiring more young people familiar with digital technology, with the average age of production-line labour dropping drastically. This is stimulating youth employment, but older, less digitally literate employees are facing job displacement.

The servicification of manufacturing is beginning to emerge at a small scale, especially in Kenya and South Africa. There is significant job-creation and value-addition potential in manufacturing-related services in the three countries studied, including in the export market. This is particularly the case in Kenya and South Africa, where a number of locally owned system-integrator firms have emerged to support manufacturers in the installation and integration of 4IR technologies, the collection and processing of data from new devices, and in some cases even the development of proprietary software and hardware technologies.

02

# Introduction

In the coming years and decades, African governments must navigate the challenge of driving job-rich economic transformation in the context of disruptive global technological change. This study aims to provide evidence-based insights on the impact of technologies on strategic sectors in African countries and equip African policymakers with the conceptual frameworks, empirical insights and policy tools needed to craft effective economic-transformation strategies and policies in the context of the fourth industrial revolution (4IR).

## Setting the Scene

**Technologies associated with the third industrial revolution (3IR) began disrupting manufacturing and its job-creation potential in the mid-20th century.**

From as early as the 1950s, new digital manufacturing technologies such as electronic manufacturing machinery, basic industrial robotics, digital analytics and computer-aided design (CAD) have been automating tasks previously undertaken by humans in manufacturing processes. As with preceding industrial revolutions, the adoption of these technologies not only replaced existing jobs but also created new ones that generally required a higher level of skills. These new jobs came from the creation of entirely new products (for example, personal electronics) and services (such as software development) as well as new tasks required within manufacturing processes (for example, machine operation, maintenance and process-flow design). In addition, at the aggregate economy level, new technologies tended to increase productivity, which lowered the relative cost of existing goods like personal computers, therefore freeing up households' disposable income to spend on either more of the same or more of other goods and services. This increase in aggregate demand led to new opportunities for companies to grow, creating more jobs.

**The 4IR, still in its infancy, is beginning to permeate manufacturing around the world.**

Over the past two decades, the number of industrial robots installed globally grew exponentially, from 0.5 million in 2000 to 3 million by 2020. Robots are evolving, with rapid advancements in processing power and machine learning leading to increased autonomy, versatility and connectedness. With the integration of wireless sensor networks, component parts, machinery and final products are beginning to generate vast amounts of data. That information is being processed in unprecedented ways using big-data analysis, cloud computing and artificial intelligence (AI), giving rise to productivity-enhancing innovations such as predictive maintenance, process and task optimisation, user-led product design and automated waste reduction. 3D-printing (or "additive manufacturing") is increasingly used in producing prototypes and component parts, such as in the automotive, footwear and plastics industries. This has the potential to drastically improve customisation, waste reduction and the cost of production, while also allowing complex production processes to be increasingly automated.

**The effects of the 4IR on labour are not well understood.**

While research on the labour effects of 4IR technologies is growing, existing evidence is mainly speculative, anecdotal and focused on the most advanced economies. A number of studies have focused on identifying the impact of technologies on the labour market by assessing the probability of automation of occupations, using labour-force surveys and determining the level of routine tasks – i.e., tasks which are easy to codify, programme and can be performed by computers. These studies suggest an ambiguous effect on labour, producing wildly different estimates on the proportion of existing jobs at risk of automation, with calculations ranging from 9 per cent to 47 per cent in respect of jobs in the US and UK. Few studies have paid attention to the system-level impacts on jobs, including the indirect creation of new jobs, and the level of adoption of these technologies at the firm level. What is clear is that, as with previous industrial revolutions, the skills composition of manufacturing labour will change. What is unprecedented in the current industrial revolution is the speed of innovation which will lead to drastic changes in skills composition and business models in manufacturing.

Firms and industrial activities will create fewer low-skill and repetitive tasks to be performed by humans and will increase demand for more complex, higher-skill tasks. As such there is, and will continue to be, a labour-displacing effect and a need for new skills.

**In the current policy discourse in Africa, there is a mix of anxiety and hype around the implications of the 4IR for job creation and economic transformation, with a dearth of empirical evidence.**

In the current policy discourse in Africa, there is an anxiety that manufacturing will no longer absorb low-skill labour at scale as it did in the early stages of economic transformation in today's industrialised economies. In addition, as manufacturing becomes more capital-, knowledge- and technology-intensive, African policymakers worry that their economies' cheap labour is rapidly losing its relevance in building competitive manufacturing sectors. The United Nations Industrial Development Organisation (UNIDO) noted in 2020 that "for firms in developing countries – especially those participating in global value chains (GVCs) – threats from supply chain reorganisation, delocalisation of production and onshoring are a common fear". As such, the worry is that manufacturing can no longer be the main engine of economic transformation.

**On the other hand, many policymakers are wondering whether African economies can bypass the traditional economic-transformation journey from agriculture to manufacturing to services and leapfrog directly into digitally enabled services in the 4IR economy.**

However, most of the debate is currently hypothetical, with little evidence on how these labour-saving and disruptive technologies impact African countries' labour markets and development paths. Therefore, it is critical to improve the current understanding of the impacts of technologies on the labour market and help policymakers understand the technological revolution and prepare for it with more evidence-based research.

This paper aims to infuse the policy discourse with an evidence-based approach that recognises both the threats and opportunities of 4IR technologies for job creation and economic transformation in Africa.

To this end, the study provides on-the-ground, firm-level insights and perspectives on trends in technology adoption, the drivers of and constraints to that adoption, and its impacts on production, employment and skills.

# Methodology and Scope

### METHODOLOGY

**The study consisted of an extensive literature review and 33 semi-structured interviews.**

The literature review studied the existing theory and evidence on the adoption of 4IR manufacturing both in Africa and globally, as well as their impact on production and employment. This included academic papers, industry reports, policy documents and others. The study team carried out 33 semi-structured interviews with some of the most technologically advanced medium-sized and large firms as well as other relevant actors working across the focus sectors and countries, including:

- **Textiles and apparel.** Nine medium-sized and large companies, including large exporters such as DTRT Dignity and United Aryan EPZ; medium-sized firms supplying the local market such as Sixteen47 and Omega Apparels; textile mills Thika Cloth Mills and Gelvenor Africa; clothing retailer Woolworths; and outdoor-clothing brand and manufacturer K-Way.

- **Automotive.** Ten interviews covering four assembly plants (Isuzu East Africa, Japan Motors, Universal Motors Limited and one confidential interviewee), four component manufacturers (Africa Battery Manufacturers, Supreme Spring, Tool and Die, Pipe Manufacturers), one industry association and one industry expert.

- **Food and beverage.** Seven interviews in Ghana and Kenya with large international or indigenous companies with well-established and technologically advanced plants. In Ghana, this included FanMilk, a producer of flavoured milk drinks and ice-creams, Ghanian farm-to-factory chocolate manufacturers Niche Cocoa, Accra Brewery Limited (a subsidiary of ABInBev) and Equatorial Coca-Cola Bottling Company in Ghana. In Kenya, interviews were carried out with fast-moving consumer-goods giant Bidco Africa, fruit-juice producer Bidcoro and Coca-Cola Kenya.

- **Technology-related services.** Four interviews with system integrators that provide services or technologies to manufacturing firms such as hardware and software installation, training, technology advisory, and bespoke hardware and software solutions. These included Schneider Electric (Kenya – regional HQ), KAD Controls (Kenya), IMEX Solutions (Kenya) and Jendamark (South Africa).

- **Other ecosystem actors.** Three interviews with the Kenya Association of Manufacturers, the Ghana Association of Industries and LMI Holdings, a diversified group that provides shipping and logistics services to manufacturing firms in Ghana.

## SCOPE

### Technologies

The study focuses on the core software, hardware and infrastructure technologies and applications defining the 4IR, which are expected to fundamentally change manufacturing as well as services and lead to potential automation and changes in firms' labour and skill structures.

### Sectors

The study focuses on the automotive, textiles and apparel (T&A) and food and beverage (F&B) industries, with a minor focus on technology-related services supporting these manufacturing sectors. The selection of these sectors was based on three criteria:

- Sectors identified by the literature as the most exposed to automation (such as the automotive industry).

- Sectors that are tradable and important for the early stages of structural transformation of African economies (for example, T&A and F&B).

- Sectors in which technology adoption presents considerable opportunities for new job creation as opposed to job substitution (such as technology-related services).

Within these sectors, the study focuses on medium and large firms operating at or near their country's technological frontier.

### Countries

The study focuses on Ghana, Kenya and South Africa. The selection of the countries was based on four main criteria:

- **Regional champions.** Potential regional economic-transformation frontrunners whose development would have (or is already having) a catalytic effect on broader economic development in the region.

- **Industrial base.** Economies with a significant existing manufacturing base, which is a precondition for entry into the 4IR.

- **Technological advancement.** As the 4IR is still nascent not just in Africa but globally, we selected economies with a relatively high level of technological development in manufacturing, that is those with the highest chance of demonstrating the first signs of 4IR-technology adoption in manufacturing.

- **Firm access and data availability.** We selected countries in which our research team had high chances of gaining access to rich information through firms and other stakeholder interviews, given our existing networks.

**The study has some key limitations.**

First, not all firms contacted in the three sectors were able or willing to take part in interviews and, of those that were, not all were able or willing to host a factory visit by the study team. This naturally limited the depth and breadth of information available. Second, data available on technology adoption are generally sparse and highly variable across sectors and countries. Third, the study had to limit its focus to three sectors and three countries owing to time and resource constraints. Insights and lessons from these case studies are likely to be transferable to other manufacturing sectors in low- and middle-income country (LMIC) contexts, but there is a limit to this transferability as every sector and country comes with significant idiosyncratic factors.

## Structure of the Report

The remainder of this paper is organised as follows:

**Chapter 3** presents the study's analytical framework and a review of the relevant global evidence. This guides the study's empirical research as well as aiming to provide a framework for policymakers to think about the impact of disruptive technologies on economic-transformation prospects and their implications for industrial strategies. This includes (i) a mapping of disruptive manufacturing technologies, (ii) a discussion of the potential ecosystem- and firm-level factors affecting technology adoption in manufacturing, and (iii) a discussion of the potential – in terms of both threats and opportunities – of technology adoption on production and employment in Africa.

**Chapter 4** presents three sector case studies on the automotive industry, T&A and F&B from the three focus countries of South Africa, Kenya and Ghana. These case studies provide on-the-ground insights into the adoption of disruptive technologies in key economic sectors, specifically:

- Which automation and 4IR technologies are being adopted and how (in which part of the value chain or production process, and for which tasks)?
- What are the drivers of adoption and constraints hindering adoption?
- How has technology adoption affected production in the firm?
- How has technology adoption affected the quantity and skill level of employees hired by firms?
- What are the expected future trends with regards to the above?

**Chapter 5** turns to the question of policymaking for job-rich economic transformation in the context of the 4IR. It first discusses the implications of technological disruption on economic-development pathways in Africa. Based on the empirical insights from the three sector case studies, it then presents recommendations for adapting industrial policies and strategies to the context of disruptive technological change. These consist of policy tools to embrace automation by developing industrial and advanced technological capabilities at the firm and ecosystem levels and manage automation by reducing the labour-adjustment costs of technological change protecting workers.

03

# Technological Disruption and African Manufacturing

A range of technologies is disrupting global manufacturing with profound implications for the future of industrial development in Africa. In this chapter, we discuss the key characteristics of new technologies disrupting manufacturing worldwide, the current state of technology adoption in manufacturing, how these technologies are impacting manufacturing production, investment and employment, and what factors drive or curtail their adoption.

## The Technologies Disrupting Manufacturing

Technological progress has historically been a core driver of economic development because it enables transformative productivity growth. The past three centuries have seen a series of industrial revolutions in which technological breakthroughs radically transformed modes of production, consumption and service delivery. Between the late 1700s and early 1800s, the invention and rapid expansion of steam engines as well as innovations in ironmaking and mechanical tools enabled mechanised factory production, triggering the first Industrial Revolution (1IR). Between the late 1800s and early 1900s, the advent of electric power, expansion of the railways, use of petroleum and innovations in industrial organisation (including the assembly line and mass production) constituted the second industrial revolution (2IR). Starting in the 1960s, the development of semiconductors, personal computers and the internet led to the third industrial revolution (3IR) (World Economic Forum (WEF), 2016; United Nations Development Programme, 2020). During the 3IR, industrial robots and sensors entered factories and manufacturing businesses began using software to manage business operations, globalised supply chains, manufacturing processes, and the design of new products and machines.

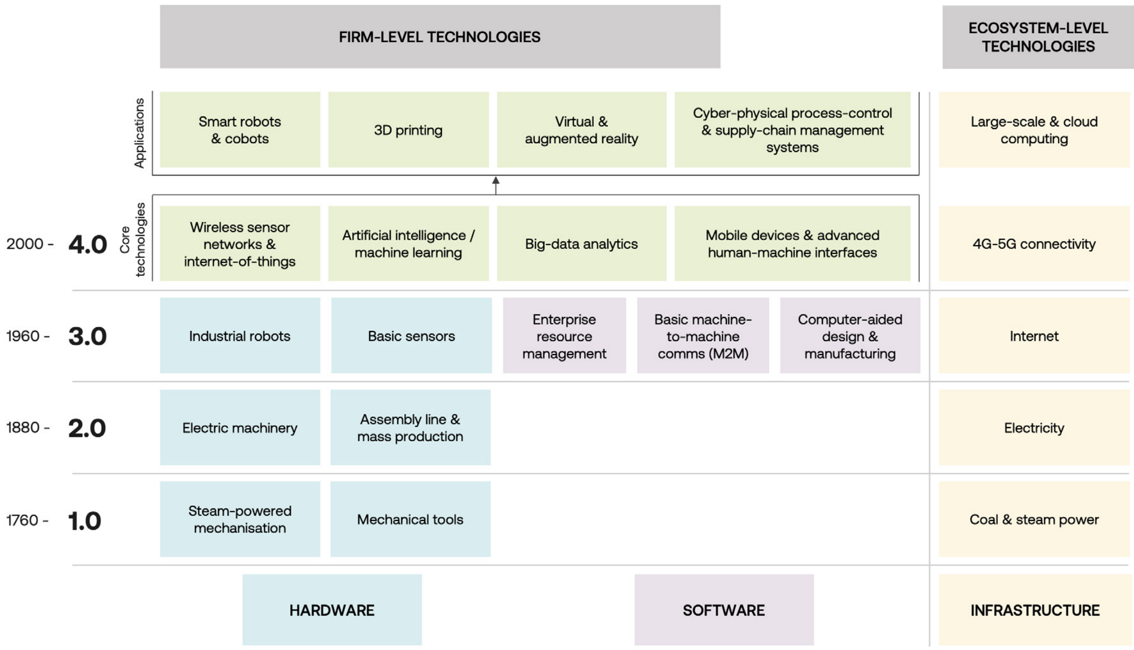
Recent and ongoing technological breakthroughs are heralding a fourth industrial revolution (4IR). The 4IR refers to “the marriage of physical assets and advanced digital technologies […] that communicate, analyse, and act upon information, enabling organisations, consumers, and society to be more flexible and responsive and make more intelligent data-driven decisions" (Deloitte, 2020). New 4IR technologies are expected to fundamentally transform manufacturing sectors. Some of the technologies expected to be most disruptive are AI, big data, the internet of things (IoT) and connected devices, text, image and voice processing, robotics, 3D printing and modelling, cloud computing and biotechnology (WEF, 2020).

While it is conceptually practical to discuss these industrial revolutions as distinct periods, it is more accurate to view industrial technological change as a continuous evolutionary transition. The hallmark technologies of the 4IR have generally evolved and emerged from the same engineering and organisational principles of previous revolutions. For instance, the automation of production processes can be traced back to the 1800s, while the adoption of robots goes back at least to the 1960s (Andreoni and Anzolin, 2019). New technologies build on earlier technologies. For example, the development of smart robots required earlier advances in software programming and basic robots, both of which in turn are built on previous innovations in electric machinery and assembly-line organisation.

Figure 1 illustrates the key 4IR technologies disrupting manufacturing, as well as the earlier technologies they are built on. The 4IR is often described as a blurring of physical and digital worlds, and the breakthroughs defining the 4IR result from combinations of advanced hardware, software and connectivity. This study focuses on four enablers and four applications in the 4IR. The enablers constitute the technological building blocks needed for the four new applications. The applications, which use combinations of these building blocks, describe how manufacturing enterprises are applying new software-hardware-connectivity combinations to transform production processes. As will be evident in the sector case studies presented in Chapter 4, technologies from different technological revolutions often operate simultaneously in practice.

FIGURE 1

# Disruptive hardware, software and infrastructure technologies in manufacturing[3]




Source: Authors

While this study focuses on manufacturing, it should be noted that 4IR technologies are also expected to have a pervasive impact on non-manufacturing sectors. For example, smart sensors and big-data analytics are expected to enable productivity gains in agriculture while AI, virtual and augmented reality (VR and AR), and big data are expected to usher in a revolution in personalised, optimised and remote services, including via the so-called metaverse.

## CORE 4IR TECHNOLOGIES

### Artificial Intelligence and Machine Learning

AI and machine learning[4] are increasingly enabling machines to perform actions such as reading, writing, speaking and recognising patterns. These new abilities are expected to make machines increasingly autonomous, versatile and responsive to new information (Korinek, 2019). Given the pace of AI innovation, these skills are expected to allow computers and robots to replace human labour in a range of repetitive manual work as well as analytical tasks (Korniek and Stiglitz, 2021). At the same time, more advanced and responsive software and hardware tools are likely to be able to work in ever greater synergy with humans, with more advanced understanding and responsiveness to human input.

### Wireless Sensor Networks and Internet of Things

The Internet of Things (IoT) refers to the interconnectedness of physical objects equipped with sensors, software and network connectivity. This allows these objects to collect and exchange data, to communicate and coordinate with each other, and to be controlled remotely. The IoT is expected to offer ever more detailed, real-time visibility to manufacturing processes, enabling effective monitoring and improvement at the machine, factory and supply-chain levels.

Wireless sensor networks (WSNs) are one of the key technologies that enable the IoT. WSNs are networks of small, low-power devices equipped with sensors, processors and wireless-communication capabilities. These devices work together to sense and collect data from the physical environment and transmit those data to a central online repository. WSNs are increasingly used in manufacturing to monitor production processes and collect real-time data. For instance, a WSN might be used to monitor the temperature and humidity in a factory or to track the movement of materials and products. These data can be used to improve process efficiency and quality, and to identify and troubleshoot problems as they arise.

### Big-Data Analytics

Big-data analytics are defined as the process of analysing large and complex datasets with higher velocity and granularity to uncover patterns, correlations and trends to enhance decision-making. Manufacturers can use big-data analytics to make more informed, evidence-based decisions, for instance to optimise production lines, reduce waste or improve product quality. Big-data analytics are enabled by a range of technologies including (i) distributed file systems and databases designed to handle large volumes of data and support fast read-and-write access, (ii) cloud-computing and data-processing technologies designed to distribute data-processing tasks across a cluster of computers, (iii) advanced data-visualisation tools, and (iv) machine-learning algorithms that automatically identify patterns and trends and make data-based predictions.

### Large-Scale and Cloud Computing

Cloud computing refers to the delivery of computing resources, such as data storage, processing power and networking which take place over the internet on a pay-as-you-go basis. This allows organisations to access and use these resources on demand, rather than having to purchase and maintain their own hardware and infrastructure. It also enables them to scale their computing resources up or down as needed without the need to purchase and maintain additional hardware. This can be particularly useful for big-data analytics as the amount of data being processed can vary significantly over time.

### 4G and 5G Connectivity

The aforementioned technologies require rapid internet connectivity to process vast amounts of data across distributed systems such as cloud computing and WSNs. 4G and 5G connectivity allows improved communication and collaboration, enhanced automation and control, and improved monitoring and maintenance in smart manufacturing systems.

## APPLICATIONS

### Smart Robots and Cobots

Smart robots are robots that are equipped with sensors, processors and other technologies that enable them to perform tasks that require a high degree of intelligence, adaptability and flexibility. These tasks can include interacting with people, working in unstructured environments and making decisions based on incomplete or changing information. Smart robots are often used for tasks that are difficult or dangerous for humans to perform, such as working in hazardous environments or handling dangerous materials. They are also used in applications where they can improve efficiency and productivity, such as by performing repetitive tasks or handling materials in a warehouse. Cobots, short for collaborative robots, are a type of smart robot designed to work alongside humans in a shared workspace. Cobots are typically smaller and less expensive than other industrial robots, and typically assist human workers with tasks such as assembly, material handling or testing. Cobots are designed to work safely alongside humans and are equipped with built-in safety features.

**3D Printing**

Manufacturers in several subsectors have begun using 3D printing for the production of prototypes and some components. It allows for faster delivery speeds and higher levels of product customisation. As 3D-printing technology improves, 3D printing will increasingly disrupt current production processes, for instance in the automotive components, plastics and footwear sectors, among others. This could represent a significant advantage for LMICs.

**Virtual and Augmented Reality**

VR creates immersive, computer-generated environments and AR enhances real-world environments with digital content. VR and AR are beginning to be used in advanced manufacturing to (i) train workers in immersive training environments, (ii) design and prototype new products, processes and systems, (iii) create immersive inspection environments allowing workers to more easily identify and address quality issues, and (iv) assist workers in performance maintenance and repair tasks by providing them with real-time guidance and instructions as they work or by allowing remote experts to work with local workers in real time. VR and AR technologies use portable display devices like smartphones, tablets and head-mounted displays, sensors that track the user's position, processors that process and render digital content in real time, input devices such as controllers or gloves, and connectivity systems such as WiFi or Bluetooth. AI and big-data analytics are sometimes used to develop and improve the performance of industrial AR and VR systems.

**Cyber-Physical Process-Control and Supply-Chain Management Systems**
A cyber-physical process-control system (CPPCS) is used to control and coordinate manufacturing processes in real time. A CPPCS typically consists of several interconnected components including sensors that gather data from the physical environment, actuators that control the physical process, for example by adjusting valves or motors, and computing systems that process and analyse data to help human operators make decisions. The main goal of a CPPCS is to improve the efficiency, quality and flexibility of manufacturing processes by providing real-time data and control capabilities. For example, a CPPCS might be used to monitor the performance of a production line and adjust the operation based on factors such as quality, efficiency and demand. Typically, sensors are used to monitor and collect data from the manufacturing process, such as information about temperature, pressure, flow rates and task completion or quality. Advanced CPPCS solutions then use AI algorithms and big-data analysis to understand these data in order to (i) predict maintenance requirements, (ii) identify defects, and (iii) identify opportunities to improve efficiency or reduce waste.

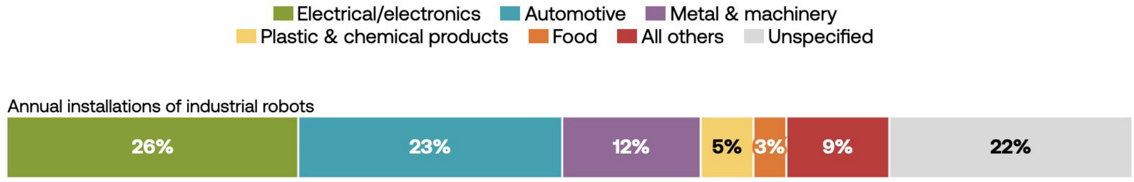
Cyber-physical supply-chain management systems (CPSCMS) are systems that use digital technologies, such as sensors, computing systems and communication networks, to optimise and coordinate the flow of goods and materials in a supply chain. CPSCMS use WSNs to collect and transmit data from the supply chain in real time and AI algorithms and big-data analysis to analyse these data. As a result, CPSCMS enable data-based decision-making to improve the efficiency, flexibility and transparency of supply-chain operations. Similar to CPSCMS, digital-supply networks (DSN) rely on communication, data and blockchain technologies to enable real-time communication and collaboration between supply-chain partners and to provide visibility and transparency in the supply chain.

## The State of 4IR-Technology Adoption in Manufacturing

The rate of 4IR-technology adoption in global manufacturing value chains is accelerating, as demonstrated by exponential growth in industrial robot installations and in the AI market. According to the International Federation of Robots (IFR), the number of installed industrial robots globally has grown exponentially, from around 0.5 million in 2000 to 1 million in 2014 and more than 3 million by 2020. In 2020 alone, 384,000 new industrial robots were installed globally. The electronics and automotive industries have the highest rates of robot installation, representing a share of more than 50 per cent in 2019 (see Figure 2). The size of the AI market in manufacturing is also growing rapidly. In 2019, manufacturers worldwide are estimated to have invested $9.5 billion in AI and global revenues from AI are projected to reach $31.2 billion in 2025, a near 20-fold increase from 2018 ($1.62 billion) (World Manufacturing Foundation, 2020). Manufacturing is also the second-biggest investor in AI after financial services (WFM, 2020).

FIGURE 2

## Annual global installations of industrial robots by customer industry




Source: International Federation of Robots

UNIDO (2020) shows that the capabilities to produce and export 4IR technologies are highly concentrated, with ten economies accounting for more than 91 per cent of all global patents and 70 per cent of exports in advanced digital technologies. These economies are also responsible for nearly half of all imports of these technologies. Another 40 economies actively engage with these technologies, though with less intensity (UNIDO, 2020). The rest of the world shows very little or no activity in the global creation or use of these technologies (UNIDO, 2020).

## The Factors Affecting Technology Adoption in Manufacturing

Several factors drive or inhibit the adoption of new technologies in the manufacturing sector. These factors vary, depending on the country and manufacturing subsector, and carry different weights in different contexts. As a result, the drivers and bottlenecks discussed below are neither exclusive nor fully present in all sectors considered, but they have been widely discussed in the literature – especially in recent contributions on technology adoption – and constitute a first set of hypotheses to test in our case studies. We categorise the factors affecting technology adoption in manufacturing into two main layers: i) ecosystem factors and ii) firm-level factors.

FIGURE 3

# Principal factors affecting technology adoption in manufacturing

| ECOSYSTEM FACTORS | FIRM-LEVEL FACTORS |
|---|---|
| Availability of technologies | Scale/volume |
| Relative costs of labour v robots | Industrial & technological capabilities |
| Skills | Flexibility & proximity to demand |
| Infrastructure | Operational & resource efficiency |
| Access to finance | Quality & standardisation |
| Tech-related services | Ergonomics & safety |
| Regulation and policy incentives | |

Source: Authors

## ECOSYSTEM FACTORS

### Availability of Technologies

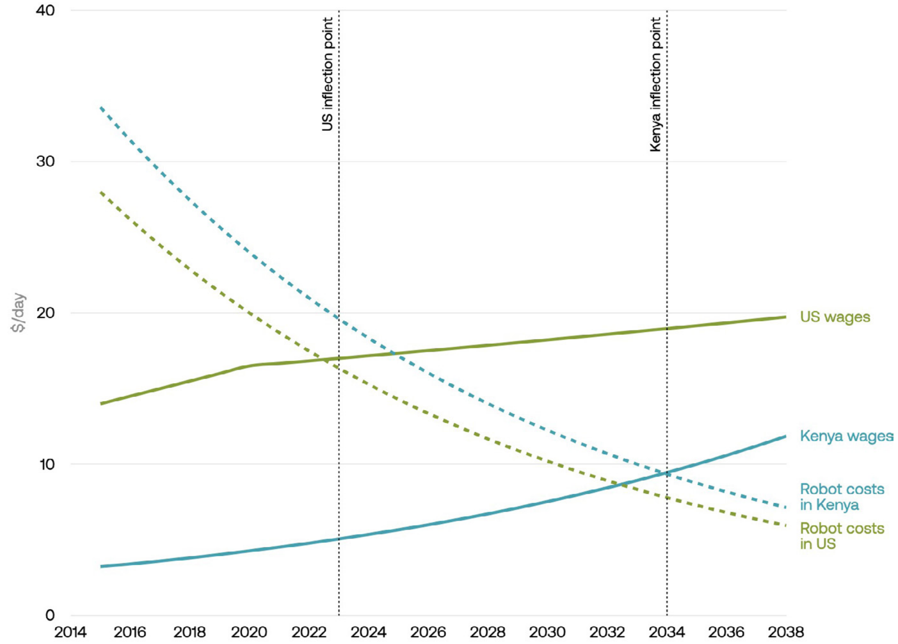
The first fundamental factor affecting technology adoption is market availability of automation technology. For example, the food industry is characterised by highly diverse, irregular-shaped and delicate products. As a result, automation technology for some products and processes is simply not yet available.

### Cost of Labour-Saving Technologies Versus Cost of Labour

Technology adoption carries an initial capital-investment cost as well as ongoing operational costs; taken together, these can be compared to continuous wage costs. Generally, a rise in labour costs and a fall in the cost of robots and other labour-saving technologies could accelerate the adoption of automation. Figure 4 compares the hourly operating costs of robots with hourly wages in the US and Kenya in the furniture sector. The figure shows an inflection point in 2023 where a steep decline in the hourly operating costs of robots will fall below US wages in the furniture sector, and firms may then choose to adopt labour-replacing robots (Banga and Te Velde, 2018). In Kenya, however, the inflection point is not expected before 2034, more than a decade later because wages are lower, while robot-operating costs will be higher in Kenya. More generally, despite a steady decrease in the cost of new technologies like robots and software, this still constitutes a major impediment for small- and medium-sized enterprises (SMEs) – especially but not exclusively in emerging economies. Since technology adoption is an investment that requires a strong business case, the benefits of new technologies may be not enough to induce adoption if the price is too high – also considering that emerging countries are mainly importers and not producers of such technologies. For example, several studies find that, compared with large enterprises, SMEs have a lower level of Industry 4.0 implementation due to financing constraints and other issues (Pech and Vrchota, 2020; Ingaldi and Ulewicz, 2019; Benitez et al, 2021; Agostini and Nosella, 2020).

FIGURE 4

# Falling robot costs, rising labour costs – the case of furniture manufacturing




Source: Adapted from Banga and Te Velde (2018)

### Skills

As discussed above, 4IR technologies are more likely to create jobs that demand new technical, analytic and cognitive abilities. Advanced technologies require (i) a higher share of science, technology, engineering and maths (STEM) graduates, (ii) human-machine interaction skills, (iii) an ability to learn new skills and adapt to new tasks, and (iv) complex collaboration skills (Banga and Te Velde, 2018). Therefore, the availability of these skills in the local workforce can either be a driver or a barrier to technology adoption.

### Infrastructure

Firms need certain physical infrastructure such as electricity and internet access to successfully operate new technologies. Reliable and affordable electricity is a basic necessity for any technology adoption in manufacturing. Access to high-speed affordable internet access is vital to 4IR manufacturing. In addition, 4IR technologies usually need an already established substantial digital infrastructure to enable adoption. Developing countries face significant challenges in providing these necessary infrastructures. The infrastructures are too risky and financially infeasible to be supplied by private businesses. The effective integration of advanced digital production technologies requires infrastructure such as affordable and high-quality electricity and reliable, high-speed connectivity. While this infrastructure may not be a factor in a developed country, it can be critical in a developing country. Lack of technology-related services, given that most technology providers are in Europe, the US and Japan, and difficulties accessing spare parts, maintenance and system-integration services locally, are challenges that many developing countries face.

### Access to Finance

Technology adoption often requires a large upfront capital investment that many firms need to finance with debt or equity.

### Policy and Regulation

Technology adoption can be influenced by policy interventions such as a ban on certain materials or government-led safety requirements (Caldwell, 2013; KPMG, 2014). Such policies may foster the introduction of new technologies, especially in areas such as quality monitoring, traceability and product life-cycle management. Liere-Netheler et al (2018) also find that the imposition of new legal frameworks or regulation on environment or sustainability standards by the government drives the adoption of new technologies.

## FIRM-LEVEL FACTORS

### Scale/Volume

Production volumes are crucial to justify investment in new technologies. Manufacturing sectors in general, and especially those at the core of this study – automotive, T&A and F&Bs – are closely linked to mass-production dynamics, such as high volumes that can foster productivity increases. Historically, such industries have tended to adopt new technologies when these assure higher productivity through faster and more reliable production cycles. Conversely, without sufficient production volumes, the business case for medium- to long-term capital investments is often weak. Sometimes, firms are “forced” to adopt new technologies if they want to produce specific parts for a customer, yet this is problematic since it brings diseconomies of scale and impedes productivity increases. Related to this, the seasonality of some food sectors is also a barrier to adoption.

### Industrial and Technological Capabilities

Technology adoption does not take place in a vacuum; rather, it is a process that strongly depends on firm-level capabilities – both at the production and at the organisational levels – among other factors. The new industrial technologies are most likely technically demanding and analytical, especially in STEM. This implies that businesses need to develop a broad array of conventional and new capabilities required for absorbing, deploying and embedding them effectively in existing production organisations (Bogliacino and Codagnone, 2019). UNIDO (2020) defines three types of capability: investment, technological and production. Investment and technological capabilities refer to the “resources, skills and technological knowledge needed by firms to adopt and use equipment and technology, expand output and employment, and further upgrade their technological competence and business activities” while production capabilities refer to “production experience, learning by doing and behavioural and entrepreneurial factors” (UNIDO, 2020).

### Flexibility and Proximity to Demand

In the coming decades, 4IR manufacturing is expected to enable increased customisation to specific customers’ preferences. With cheap labour becoming a less important driver of plant location, industrial multinationals are expected to increasingly relocate plants closer to final consumers. This "reshoring" would be enabled by automation technology and would further reinforce the adoption of automation as the major demand centres for technology-intensive manufactured goods are high-wage economies. However, so far there is little empirical evidence that reshoring is happening at scale or indeed that flexibility is a direct driver for the adoption of new technologies.

### Operational and Resource Efficiency

Companies often introduce 4IR technologies to increase efficiency. For instance, sensor technologies can monitor and report on worker productivity, monitor and optimise energy use, and inform decisions about optimal raw material used to reduce waste. Therefore, without replacing human labour, new technologies can increase the efficiency of the production line. Aside from reducing input costs, an additional rationale for improving resource efficiency and waste for many firms is to achieve greater environmental sustainability standards.

### Quality Standardisation

Manufacturing sectors have been increasingly characterised by higher standards, which can address very different elements. For example, quality encompasses a broad range of factors, from hygiene and health standards in the F&B sectors to new/lighter materials in the automotive sector that require specific technologies to be pressed/welded. The importance of complying with such standards forces firms to adopt new machines, to implement new processes and to upgrade their workforce.

### Ergonomics and Worker Safety

Both from the consumer side and from firms downstream of the value chain, there is increasing pressure to ensure full safety for workers acting in the production process. For example, the food industry presents elevated worker-safety risks due to the risk of animal-human disease transmission and injury. As a result, many countries have passed strict labour-safety standards that drive the adoption of automated production processes to decrease the amount of direct human-animal contact.

# The Impact of 4IR-Technology Adoption on Manufacturing

The adoption of 4IR technologies has important implications for manufacturing production, investment and employment outcomes, with each of these is discussed below, raising questions such as whether these technologies will slow down lower-income countries' (LICs) economic catch-up or whether they will provide an opportunity to leapfrog and bridge the productivity and knowledge gap with HICs. Technological advancement is impacting all sectors of the economy, but the threat of automation in LMICs is more of a concern within the manufacturing sector, considering the historical role that this sector has played in structural transformation.

## IMPACT ON PRODUCTION

The adoption of 4IR technologies is expected to fundamentally transform production through improvements in productivity, quality and standardisation, sustainability, flexibility and employee safety.

### Productivity

4IR technologies generally enable faster, more flexible, and more efficient production processes at higher quality and lower costs and with fewer errors, ultimately improving productivity (Rubmann et al, 2015). While this is true in most cases, Acemoglu and Restrepo (2019) argue that some technologies simply replace jobs without significantly increasing firm productivity.

### Quality and Standardisation

Several applications of 4IR technologies are aimed at improving product quality and standardisation. For example, automation enables the reduction or elimination of human error while cyber-physical production control systems using a range of sensors are able to identify and help address quality issues in real time. For example, a Chinese company, Baowu, expected the adoption of the Alibaba Cloud ET Industrial Brain, powered by AI, edge computing and augmented reality, to reduce the factory's nonconforming product rate by 28 per cent (UNIDO, 2020).

**Sustainability**
4IR technologies can improve environmental sustainability. For example, cyber-physical production control systems use sensors to monitor and optimise energy and raw material efficiency, thus reducing the environmental footprint per unit of output and reducing waste. In another example, cyber-physical supply-chain management systems can be used to increase supply-chain traceability, allowing retailers and consumers to make more environmentally conscious buying decisions.

**Flexibility**
While in the past industrial automation tended to lead to less production flexibility, higher output rates and increasing vertical integration (Morroni, 1992; Alcorta, 1995; Upton, 1995),[5] the scenario is likely to be different within the 4IR smart factory with technologies that are designed to make existing production systems adaptive, flexible and reconfigurable (Vancza et al, 2011). This is expected to allow manufacturers to eventually leverage 4IR technologies to produce a wider range of products, including personally customised goods, using the same production line.

**Employee Safety**
With advances in industrial robotics and other automation technologies, the most dangerous tasks can increasingly be performed by machines, consequently reducing human exposure. This was the case, for example, with a series of cobots that Mahindra & Mahindra Ltd. recently installed in its engine and vehicle manufacturing plants (UNIDO, 2020).

## IMPACT ON INVESTMENT

Technological upgrading has tended to have a positive impact on investment, with manufacturing sectors in developing countries often seeing technological improvements because of foreign-direct-investment (FDI) inflows (Bas and El Mallakh, 2019). Technological spillover effects from FDI result in productivity gains for domestic firms when foreign firms are linked vertically. However, the effect is sometimes negative when foreign firms are present in horizontal value chains as they are likely to attract local specialist workers to the detriment of local firms (Le and Pomfret, 2011). Higher income countries tend to see greater levels of FDI in high- or medium-technology manufacturing, whereas developing countries have seen a greater proportion of FDI flowing into low-technology manufacturing sectors (UNIDO, 2015). New technology will attract strategic asset-seeking FDI (Dunning, 1993).

This is not surprising; individual firms invest abroad because of a number of factors such as human capabilities (labour-force skills, education levels and so on), business environment (market development, market size, financial services etc.), infrastructure (energy, ICT, logistics etc.), production costs (especially wages) and investment policies (for example, tax incentives). Therefore, LICs whose main comparative advantage is relatively cheaper labour tend to attract labour intensive, lower-technology FDI, whereas more developed countries with a lower cost of capital tend to attract more capital-intensive, higher-technology FDI.

The emergence of 4IR technologies may result in shifts in investment decision-making processes. Labour-reducing technologies such as robotics and AI could replace labour-intensive processes, negating one of the major comparative advantages of LICs, with a potential to reshore manufacturing activities back to HICs. While firm-level decisions may, in the short term, not promote reshoring of existing manufacturing capabilities due to inertia, cost issues and other factors (UNCTAD, 2022), in the long term such a process may occur, particularly where most manual labour can be cost-efficiently automated (ILO, 2020).

There have so far been only limited cases of manufacturing reshoring, with 5.9 per cent of 2,500 European firms having reshored while 16.9 per cent have offshored (Banga and Te Velde, 2018; UNIDO, 2019). On the other hand, the International Labour Organisation (ILO) (2020b) has found evidence that, while reshoring is still relatively uncommon, there is a positive link between the adoption of 4IR technologies in HICs and reshoring. This means that unless LICs rapidly adopt new technologies in the manufacturing sector, they may see an eventual decline in manufacturing FDI.

### IMPACT ON EMPLOYMENT

The adoption of new technologies in manufacturing creates threats, opportunities and ambiguous effects on job creation in developing countries.

FIGURE 5

## Mapping the labour-displacement and reinstatement effects of 4IR technologies

| | | | | |
|---|---|---|---|---|
| 4IR TECHNOLOGY APPLICATIONS | **Smart robots & cobots** – robotisation of routine tasks using increasingly re-programmable and autonomous robots & cobots, enabled by AI, IoT & big data | **3D printing** (with CAD/CAM) enables highly customisable products & automated production including using new raw materials | **VR & AR-enabled remote services** such as machine maintenance & metaverse experiences | **Cyber-physical process-control & supply-chain management systems** enabled by sensor networks, big data, IoT & AI |
| DISPLACEMENT EFFECT | Advanced robots can carry out more manual tasks, leading to decreased low- and medium-skill labour demand per unit of output | Very few jobs likely to be replaced in foreseeable future as 3D printing is not used in mass production except for some very specific products | The tradability of more services (i.e. remotely delivered business, health, creative services) might displace some local service providers | Some low- and medium-skill factory & supply-chain management jobs likely to be replaced by automated decision-making |
| | 4IR manufacturing requires more advanced infrastructure and stronger technological capabilities to remain (or become) competitive – potentially leading to less manufacturing foreign direct investment in low-income countries and fewer jobs created | | | |
| REINSTATEMENT EFFECT | Increased demand for medium- and high-skill mechatronic engineers, data analysts, software engineers, system integrators etc | New medium- and high-skill jobs in 3D design, mechatronic engineering, system integration, materials development & sourcing etc | Conversely, the tradability of services means that low-income countries can compete globally with lower-cost services, creating jobs at all skill levels | New medium- and high-skill jobs in IoT installation, data analysis, AI development & data-based decision-making |
| | 4IR technologies enable firms to increase efficiency and productivity, driving growth and job creation in those firms | | | |

Source: Authors

### Impact on Net Job Creation

The policy discourse in LMICs is often marked by a fear that a rapid automation of manufacturing will delay and even stall the economic-convergence process, increasing the income gap with HICs. It is feared that rapid automation occasioned by 4IR technologies will replace manufacturing labour as automated production systems become cheaper and better than the equivalent manual labour. This presents a double threat for the traditional manufacturing development pathway: first, developing countries may lose their key comparative advantage in the early stages of transformation – cheap, unskilled labour (Rodrik, 2018); second, even where they do manage to develop a productive and competitive manufacturing sector, its job propensity may be reduced, leading to the same, highly unequal "jobless growth" that characterises economies driven by service sectors (Korinek and Stiglitz, 2021). In addition, as discussed above, the declining cost of robots may induce labour-intensive firms in developing countries to reshore back to developing countries.

However, beyond speculation and anecdotal evidence, there is little firm evidence to support this conclusion (UNIDO, 2020). Theoretically, there are two competing arguments on the effects of robots and automation on employment: the displacement effect and the reinstatement effect. The displacement effect means that automation, advances in AI and industrial robots replace tasks previously performed by labour, displacing millions of workers and reducing the share of labour in production. On the other hand, the reinstatement effect means that automation and robots increase productivity, market demand and scale of production (Acemoglu and Restrepo, 2018; Aghion et al, 2020). This creates new labour demand for non-automated tasks, creating new employment and increasing the labour share in value-added. The net impact of automation and robots on employment therefore depends on the balance of the displacement and reinstatement effects, which is an empirical question. Therefore, the impact of automation on employment can be positive, negative or neutral.

Current evidence suggests that robotisation and other automation technologies have an ambiguous net effect on the quantity of jobs. A growing body of research attempts to explore the possible impact of technologies on the future of work and to identify the net impact of 4IR technologies and automation on jobs. Numerous quantitative empirical studies find a positive or neutral net impact of industrial robots and other automation technologies on employment (Dauth et al, 2021; Graetz and Michaels, 2018; Hirvonen et al, 2022; Adachi et al, 2022; Dekle, 2020; Dottori, 2020). Some of these studies observe job losses in the manufacturing sector that are offset by gains in the business-services sector, with a neutral net impact on job creation (Dauth et al 2021; Dottori, 2020), hinting towards changes in the types of jobs created and the potential growth of services linked to manufacturing. Using the same methodology, another set of research finds negative impact of industrial robots on employment and wages (Acemoglu and Restrepo, 2020; Acemoglu, Lelarge, and Restrepo, 2020); Borjas and Freeman, 2019). Another body of research uses a speculative methodology to examine the share of routine-based occupations and tasks and their risk of automation. These studies, which focused on OECD countries, produced estimates on the number of jobs at risk of being replaced by machines that range widely from 9 per cent (Arntz et al, 2016; Nadelkoska and Quintini, 2018) to 47 per cent (Frey and Osborne, 2013).

While some automation technologies make manufacturing workers redundant, 4IR technologies are also expected to generate demand for a new set of manufacturing-related services that will create jobs. With the increasing knowledge-intensity of hardware and software technologies used in 4IR manufacturing, industrial firms are expected to rely increasingly on services in areas such as mechatronic engineering, data science, software development, data processing and others focusing on machine-worker collaboration. According to UNIDO (2020), the proportion of knowledge-intensive business services in manufacturing production has grown significantly over the last one-to-two decades across countries in different income groups. Currently, these services represent 4.3 per cent of manufacturing production in developing countries, 7.5 per cent in upper-middle income countries and 9.7 per cent in HICs. As the servicification of manufacturing continues, UNIDO (2020) contends, developing countries “probably need to aim for higher knowledge intensity in production than in the current advanced economies”.

On the other hand, the policy discourse is influenced by a hope that LMICs can leapfrog into the 4IR, gaining competitive advantage over other countries whose production systems are based on increasingly outdated infrastructure, technologies, skills and firm capabilities. For instance, a WEF (2018) report projected that a new division of work between humans and machines would result in more than 130 million new roles by 2022. This fuels a belief that LIC workforces can be absorbed directly into new emerging digitally traded services in digital technology and the creative industries, among others. However, the leapfrog hypothesis is called into question by evidence showing that new technological revolutions tend to build on past technological infrastructure and capabilities. The existing evidence suggests that firms in non-industrialised countries will struggle to leapfrog into using new technologies without a certain level of development in the manufacturing ecosystem, including transferable technological and managerial capabilities, competitive basic enabling infrastructure such as energy, transport and internet, and the adoption of 3IR technologies (Hallward-Driemeier and Nayyar, 2017). This is not least because one of the major aspects of the 4IR is the integration of different 3IR technologies like mechanical robots, web connectivity and so on into one smart production system.

While the evidence on the employment impact of 4IR technologies in LICs remains inconclusive, it is unlikely that sustainable and inclusive economic transformation can occur without manufacturing in most settings. Most existing contributions focus primarily on HICs, leaving largely unexplored the question of how automation will reshape the economic-transformation and job-creation prospects of LMICs. In the early stages of successful economic-transformation processes, manufacturing has historically absorbed mostly low-skilled, low-wage labour carrying out repetitive tasks. The manufacturing-led development path is widely recognised as necessary for sustainable growth and economic transformation. Bypassing it directly to a service economy may not lead to productive and sustainable growth. For instance, CDC (2020) provides a literature review on the manufacturing-led path and highlights that those countries that have bypassed manufacturing to services now realise the importance of a local manufacturing ecosystem and capabilities for technological upgrading, human-capital accumulation, productivity growth and job creation.

**Impact on Skill Intensity**

While the net effect on job quantity is ambiguous, it is clear that 4IR-technology adoption profoundly changes the skill composition of manufacturing labour, gradually reducing the prevalence of low-skill repetitive human tasks and increasing the demand for higher-skilled labour. Most empirical studies find that the use of automation and industrial robots largely has a negative employment impact on less skilled workers, with a decreasing share of routine and manual task-intensive jobs in HICs and an increase in skill requirements of workers (De Vries et al, 2020; Bartel et al, 2007); Michaels et al, 2014); Graetz and Michaels, 2018). AI-enabled automation technologies specifically are expected to displace low-skilled workers but also create more jobs in the interaction between humans and machines, which would be more skill-intensive (WEF, 2018).

04

# Sector Case Studies

## Focus Countries: South Africa, Ghana and Kenya

**South Africa** is the third biggest economy on the continent after Nigeria and Egypt and has the most advanced manufacturing base in Africa with roughly $49 billion in annual output, including in the automotive, agro-processing, textiles and apparel, and mining-equipment industries. South Africa's well-established automotive industry alone consistently accounts for over $10 billion in annual exports. In 2019, the industrial sector (which covers construction and mining as well as manufacturing) accounted for 22 per cent of total employment and 12 per cent of South Africa's gross domestic product (GDP). The government is proactive in promoting industrial development, for example through the National Industrial Policy Framework (2007) and several industrial policy action plans focusing on specific sectors. The most comprehensive of these sector-development plans is the South African Automotive Masterplan, which aims to increase local content in the automotive sector from 40 per cent (2020) to 60 per cent. In T&A, a total of 4.8 billion rand ($360 million) has been disbursed to more than 500 companies along the value chain, and total assets in the sector have increased to 7.2 billion rand ($540 million) (Smith, 2017; Parschau and Hauge, 2020). Existing 4IR-related government initiatives include the Centre for the Fourth Industrial Revolution South Africa – a multi-stakeholder hub that influences regulatory policy on technologies such as IoT, AI and blockchain – as well as the National and Future Digital Skills Strategy of South Africa.

**Kenya** is the seventh-largest economy in Africa and the largest in East Africa in terms of both total output and GDP per capita. While Kenya's manufacturing sector represents only 7 per cent of GDP, and industrial (including construction and mining) jobs account for just 6 per cent of total employment, it is by far the largest industrial base in East Africa in absolute terms, with about $8 billion in total annual output. Kenya's mature F&B sector consistently accounted for around $2.5 billion in annual exports over the past 5 years, while the T&A and automotive industries are more nascent. Manufacturing is also recognised as a major future growth driver and has been a policy focus both under the previous administration (as part of President Kenyatta's Big Four Agenda) and under President Ruto's new administration beginning in 2022. Kenya is a continental frontrunner in technology adoption and leads East Africa in terms of broadband connectivity, ICT infrastructure, mobile money and mobile-banking services, among others. The ICT sector accounts for 8 per cent of GDP and IT-enabled services are recognised as a major driver of job growth. The government continues to prioritise the ICT sector, for example through an allocation of $210 million in 2021/2022 toward the ICT sector, the ambitious Digital Literacy Programme, a digital economy blueprint adopted in 2019, and the development of Konza City – the country's first smart city.

**Ghana** is the tenth-largest economy in Africa. Manufacturing represents about 10 per cent of total GDP. At 21 per cent, Ghana has the highest share of industrial employment in West Africa. The country's manufacturing sector is led by agro-processing, T&A and pharmaceuticals. A nascent automotive sector has recently emerged, with initial investments in assembly plants by global industry leaders. Industrialisation is a top policy priority, led by the Ten Point Industrial Transformation Agenda. Recent policy efforts at fostering a technology-intensive industrial ecosystem include the National Science, Technology, and Innovation Policy (2017-2020). Ghana is a regional leader in ICT, with one of the highest mobile-network penetrations (GSMA, 2020) and a relatively mature digital entrepreneurial ecosystem. The eTransform Ghana project aims to reduce the connectivity gaps in the country (World Bank, 2020).

## Case Study: The Automotive Industry

### SECTOR OVERVIEW

The automotive industry has always been an influential industrial sector in which large economies of scale and scope favour continuous technological and organisational innovation. The sector has helped pioneer technological innovations such as industrial robots, complex machine tools for metal pressing and painting, and software to manage long-distance production networks, among others. In terms of organisational innovations, the industry was at the forefront of the emergence of Taylorism, Fordism and lean production.

Automobile production has played a central role in the industrialisation strategies of many countries. The multiplier effect on employment is significant – about four indirect jobs are created for every direct job in the automobile industry – and significant linkages created with other sectors such as the machine-tool industry, electronics and plastics, resulting in upgrading the overall productive structure. This is observed across a broad spectrum of countries' development experiences, such as early industrialisers like Germany and the United States and late industrialisers like South Korea, Brazil, Mexico and South Africa.

The industry and its value chain were profoundly reshaped by fragmentation of production and the evolution of Fordism, which started to move lower value-adding parts of the value chain (for example, assembly) to countries with lower labour costs. The automotive GVC is characterised by a small set of big multinational assembly plants also called original equipment manufacturers (OEMs). These firms have high market power and their choices affect the characteristics of the automotive industry, its geographical distribution and the adoption of new technologies along the value chain.

In 2015, the ten biggest OEMs represented 75 per cent of total global output in the sector (International Organisation of Motor Vehicle Manufacturers, 2015). The value chain also includes an increasingly powerful small group of so-called Tier 1 suppliers of parts and components – which have consolidated and are becoming geographically and relationally closer to the assembly plants (Wong, 2017) – and a larger number of Tier 2 and Tier 3 suppliers which are more dispersed despite being increasingly controlled by assembly plants (Anzolin et al, 2020). The world's leading automotive companies focus on the design and engineering stages of the value chain, which account for a large share of total value addition (Anzolin et al, 2020).

The automotive sector in Africa is growing fast. South Africa is a historically strong player on the continent. Over the past two decades, Morocco has emerged as a new competitive hub selling mainly to European markets and achieving similar automotive export volumes to South Africa with significant local content through a strong network of component manufacturers.

Kenya, Nigeria and – most recently – Ghana are new actors in the sector, with relatively small plants that so far mainly focus on the assembly of imported kits with minimal local content (Black et al, 2017).

South Africa's automotive industry represents 6.8 per cent of the country's GDP, 29.9 per cent of its manufacturing output, and 14.3 per cent of its exports (2020 data from the Department of Trade, Industry and Competition) and employs between 110,000 and 120,000 people. South Africa produces about 0.68 per cent of the global market, with 631,983 motor vehicles manufactured in 2019, ranking 22nd globally. A total of 60 per cent of automotive production is exported, mainly to Europe and the US (Automotive Export Manual, 2019). South Africa has seven final-assembly plants: BMW, Ford, Isuzu, Daimler, Nissan, Toyota and VW; these are foreign-owned and have strong ties with their headquarters in Europe, the US or Japan. In addition, there are about 200 Tier 1 suppliers (75 per cent are foreign-owned) and around 80 Tier 2 suppliers (mostly South African-owned) in the industry. Suppliers in South Africa produce a wide range of components, from metal and plastic parts, automotive trim, tyres and wiring harnesses to catalytic converters. However, the production shares of key parts such as exhaust systems, safety systems and powertrains are declining or very limited. The automotive industry has been struggling to develop a local value chain, and most of the value-added still lies within assembly plants, 97 per cent of which are foreign-owned.

Kenya's automotive industry is characterised by FBU (fully built units)[6] and CKD (completely knocked down)[7] production, including both vehicle production and assembly. There are five final-assembly plants: Isuzu East Africa, Associated Vehicle Assemblers (AVA), Kenya Vehicle Manufacturers (KVM), Transafrica Motors and Mobius Motors (which assembles cars designed in-house). AVA and KVM undertake assembly work on behalf of various brands such as Toyota, Volkswagen, Ford and others (FES, 2020; KAM, 2020). These manufacturers have a combined capacity of 46,760 units, yet they have not produced more than 9,000 units per year – running at just 20 per cent of their installed capacity as of 2019 (KAM, 2020). In addition, Kenya has 13 bus-body plants that supply the domestic and East African markets, with an installed capacity of 36,000 bus bodies per year, and four trailer assemblers with a capacity of 4,400 per year (KAM, 2020).

KAM (2020) also lists 27 approved plants assembling motorcycles for global brands like Honda, TVS, Boxer and others. Finally, there are about 25 component suppliers manufacturing a range of low- to medium-value parts such as seats, batteries, cables and others (KAM, 2020).

Ghana's automotive sector is nascent, with VW, Sinotruk, Nissan and Toyota all setting up new assembly plants since 2020, and more global industry leaders considering investment in the country. These plants currently assemble vehicles from semi-knocked-down kits (SKD).

## TECHNOLOGY-ADOPTION TRENDS

### Global Trends

Automation technologies in the automotive sector are not a recent phenomenon; they have been evolving for several decades. The automotive industry is the second most robotised industrial sector after electronics, accounting for about 28 per cent of the total stock of installed industrial robots worldwide in 2019. The sector's high level of automation is mainly linked to compliance with international standards, which require absolute precision and stability throughout the production process (Krzywdzinski, 2017; Sjoestedt, 1987). Technologies are highly task- and process-specific and Figure 6 presents a typology of the main technologies adopted at each stage of the automotive value chain.

The level of automation varies across different stages of automotive manufacturing. For example, stamping, welding and painting have been highly mechanised and automated since the 1970s. In contrast, previous attempts to automate final assembly – the segment where most of total employment in factories lies – did not work because manual workers are more flexible and efficient in dealing with the complex processes involved in final assembly. When confronted with frequent downturns of machines and the lack of flexibility that automation implies, many firms decided to decrease automation at this stage of production (Jürgens & Krzywdzinski, 2016; Pardi, 2019).

FIGURE 6

## Technology adoption along the automotive value chain

| VALUE-CHAIN STAGE | RESEARCH & PRODUCT DEVELOPMENT | COMPONENT MANUFACTURING | ASSEMBLY & SUB-ASSEMBLY | DISTRIBUTION & SALES |
|---|---|---|---|---|
| KEY ACTORS | OEMs | Tier 1, 2, 3 suppliers | OEMs & suppliers | OEMs & distributors |
| ACTIVITIES | Prototyping<br>Product-design system<br>Product & process engineering<br>Process development & scale-up | Engine bodies<br>Brake systems<br>Electrical components<br>Press die<br>Welding jigs / fixtures<br>Batteries | Press shop<br>Body shop<br>Paint shop<br>Assembly | Customisation<br>Direct sales<br>Local distribution<br>Transport & logistics |
| TECHNOLOGIES | CAD<br>CAM<br>3D printing for rapid prototyping<br>Virtual development system | Industrial robots (metal casting, laser cutting, handling)<br>ERP / MES / PLC<br>Connectivity (RFID sensors / QR codes / M2M)<br>Internet of Things | | |

Source: Anzolin, 2021.

Several types of software technology are already common in the sector. These include enterprise resource planning (ERP) systems, manufacturing enterprise systems (MES), programmable logic controllers (PLC) and various kinds of supply-chain management systems. Such technologies were responsible for profound changes, starting in the 1990s, in product development, planning, production control and quality, among many others (Krzywdzinski, 2021). Hardware technologies in the sector include industrial robots, 3D printing, sensors and actuators, cobots and exoskeletons, the latter used mainly in the final assembly stage.

The high degree of interconnectedness of these technologies makes their integration into the production process complex and often not economically viable. As a result, recent studies are calling into question the likelihood of rapid 4IR-technology adoption in the coming years in the automotive industry, especially in mass vehicle production (Paus, 2018; Pardi, 2019). However, niche luxury-car manufacturers, such as Lamborghini, already demonstrate widespread adoption of IoT, cobots and big-data analytics, with computerised workstations in all segments of the firm, from engineering departments to assembly lines (Cirillo, Rinaldini, Staccioli, & Virgillito, 2021).

### Trends in the Study Countries

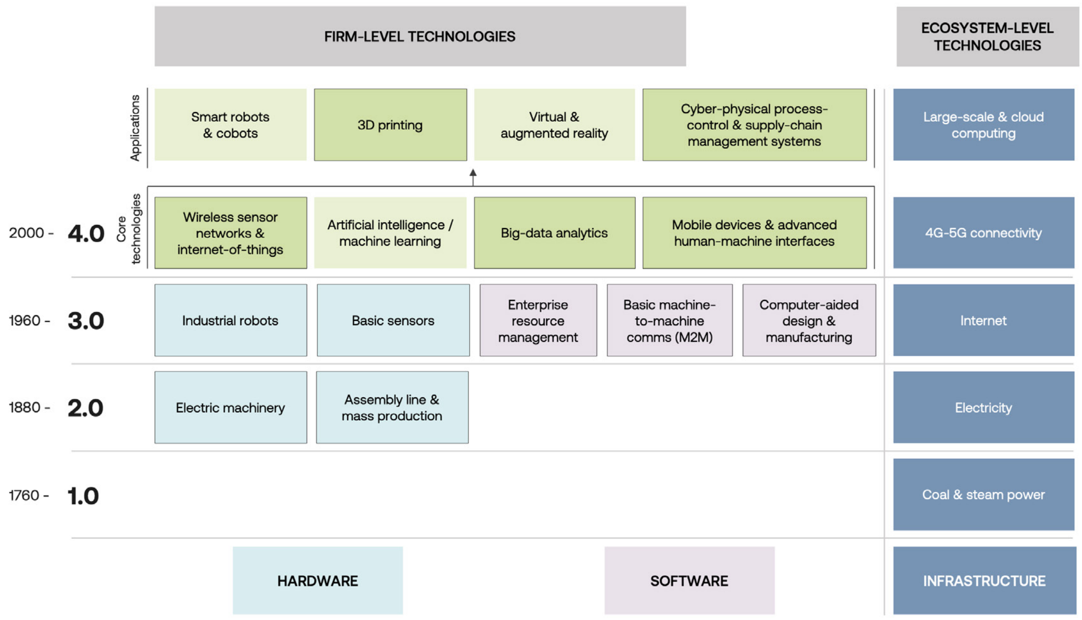
As illustrated by Figure 7, automotive-sector firms in Kenya and South Africa are sitting in the 3IR with a growing trend towards the 4IR. With product cycles that change between every seven and nine years, new technologies tend to come in at the beginning of these cycles. Interviews revealed a high degree of heterogeneity across value-chain segments.

Assembly plants are more technologically advanced; they are highly dependent on technology-related decisions taken at their global headquarters and are generally highly automated compared with other sectors. Assembly plants in Kenya are somewhat less automated than those in South Africa, which have a long tradition of production and value-chain organisation as well as significantly higher volumes, and therefore operate with the most advanced level of technology.

The press shop is characterised by machine tools that press metal sheets. Robotisation and automation have been increasing, especially with the use of picking and placing robots. The body shop is highly automated in South Africa and Kenya. Different types of welding robots are deployed and there is an increasing use of closed cells that perform multiple tasks without the need for human intervention. One Kenyan assembly plant introduced sensors at the body-shop level to monitor the production process and improve efficiency. The paint shop is highly automated in both countries. An assembler in Kenya indicated that this was the first shop floor to be fully automated in their plant.

FIGURE 7

# Technology adoption in automotive industries in South Africa and Kenya




Note: Coloured boxes with boundaries represent technologies that are adopted by several firms in the sector in our study countries. Light coloured with no boundaries means adopted at the global tech forefront of the sector but not in our study countries. Grey means not yet adopted worldwide in the sector.

Source: Authors

Operations within the final assembly stage are highly automated with widespread use of industrial robots in South Africa, and slightly less so in Kenya. Our interviews also revealed how IoT technologies are starting to take off, for example for machine-maintenance planning. One company has adopted a camera inspection system that verifies that the correct parts have been assembled and automatically halts the process if something does not look right. A similar system records the accuracy of the tightening of bolt nuts, feeding this information directly into the company's global data-management system and signalling a red flag if performance is below target.

The bulk of component manufacturers' technologies in South Africa and Kenya currently sits within the 3IR layer. There is widespread – though heterogeneous – adoption of industrial robots, basic automation and increased use of ERP systems and supply-chain management software, and little evidence of 4IR technologies. The first forays into the 4IR are being made in battery production. One Kenyan firm that manufactures batteries for various sectors including the automotive industry has gone through a process of rapid automation over the past two to three years, becoming one of the most automation-based firms in Africa, with the use of robotics, IoT, big-data analytics, sensors and machine-to-machine communication.

Suppliers in both South Africa and Kenya mentioned that the adoption of new technologies is strongly related to the raw material being processed. For example, metal-component suppliers tend to be strong adopters of new technologies. These are also firms with strong retrofitting capabilities where automation is likely to happen in-house, buying the hardware and (sometimes) software needed and integrating it within the firm. In contrast, for example, foam and headrest-component manufactures are characterised by smaller production volumes and high variety, both obstacles for technology adoption and the efficient use of it.

Aside from some specific technologies, the general expected future trend is one of rather slow 4IR-technology upgrading. Some specific technologies are expected to play a bigger role in the sector in the coming years. One battery manufacturer mentioned the potential of AI and VR to speed up pre-production analysis. Assembly plants could also benefit significantly from AI simulations, for instance to help choose from different potential materials. Some interviews revealed that assembly plants are near the beginning of a product cycle, which are typically between seven and nine years in the sector, and therefore do not expect rapid 4IR-technology adoption. This is especially true at the supplier level, where investment capacity is narrower than assembly plants. These plants are constrained by the business case and by HQ-level decisions – yet they have a greater decisional space to operate in.

### FACTORS AFFECTING TECHNOLOGY ADOPTION

Technology adoption in the automotive sector is mainly driven by considerations around the return on investment and expected production-efficiency outcomes. Interviewees reported that, while 4IR technologies have great potential, their adoption at the shop-floor level is constrained by technological feasibility and business viability. In line with the existing empirical literature at the firm level, we find that volume, quality standardisation and new materials stand out as the key drivers of automation-technology adoption.

FIGURE 8

## Principal factors affecting technology adoption in the automotive industry

| ECOSYSTEM FACTORS | FIRM-LEVEL FACTORS |
|---|---|
| Availability of technologies | Scale/volume |
| Relative costs of labour v robots | Industrial & technological capabilities |
| Skills | Flexibility & proximity to demand |
| Infrastructure | Operational & resource efficiency |
| Access to finance | Quality & standardisation |
| Tech-related services | Ergonomics & safety |
| Incentives & regulation | |

Source: Authors

## ECOSYSTEM FACTORS

### Availability of Technologies

The fact that almost all 4IR technologies need to be imported is another key factor that often leads to long delays for firms between the identification of a new technology and full integration into their production processes.

### Skills

The adoption of new technologies requires global support and specific skills, generally not available in the local market. One assembly plant mentioned that IoT innovations are partially helping with this issue since advanced and real-time communication tools allow problems to be fixed remotely. These findings further corroborate the evidence in the literature: introducing new technologies is not only a matter of cost but also of integrating them into pre-existing production systems.

### Access to Finance

Firms indicated that, given the large upfront cost of some 4IR technologies and the importance of a strong business case for technology adoption, access to credit is a major constraint. This is especially true for component suppliers that cannot rely on global HQs for internal financing.

### Technology-Related Services

A significant bottleneck is the cost, time and difficulty of setting up, integrating and implementing the newest automation technologies. Component suppliers in South Africa and Kenya reported that when they purchase a machine, it may take up to one year to start using it due to training and other integration-related issues.

## FIRM-LEVEL FACTORS

### Scale/Volume

Volume creates the business case for investment in automation technologies while increasing productivity and efficiency. Conversely, the main bottleneck for technology adoption is low expected return on investment, i.e., the lack of a business case, especially due to insufficient economies of scale that prevent the adoption of new technologies. This confirms that the automotive sector is still scale-intensive: it requires high production volumes to improve productivity and efficiency. While assembly plants have more substantial financial capabilities and are ultimately constrained by their internal (or HQ-level) dynamics, for component manufacturers the most critical driver is the demand volumes coming from assembly plants, which ultimately determine whether the economies of scale necessary for effective technology adoption can be achieved. Component manufacturers reported that when they are forced to adopt new technologies that the customer requests, they are almost always unable to use the technology's full capacity. A lack of volume therefore translates into low productivity. Most of the interviewed component suppliers emphasised that their 4IR-technology adoption is fully driven by assembly plants and would not have happened otherwise due to high costs. Automotive firms in South Africa and Kenya expect volume to remain the most crucial element for future technology adoption. Volume ultimately depends either on export growth or on growth in local and regional demand. While growth driven by domestic and regional demand carries lower risks, it is not likely to lead to the kind of transformative sector growth that breaking into global export markets would – at least in the short to medium term.

**Industrial and Technological Capabilities**

New materials that require adopting more sophisticated technologies (for example, lighter materials that trigger the adoption of laser-welding industrial robots). Within this driver, we also include commodity-specific adoption of technologies.

**Operational and Resource Efficiency**

Reducing scrap rates and achieving higher process reliability was a motivation for technology adoption among most firms interviewed.

**Quality and Standardisation**

The necessity for higher quality (i.e., process stability) to comply with industry standards and consistently carry out tasks that require high precision and consistency.

## IMPACT ON PRODUCTION

All automotive firms interviewed in the three study countries reported that adopting new automation and digital technologies improved resource efficiency and productivity. There is wide agreement that technologies improved product quality and – in most cases – process quality, leading to lower scrap rates and higher process reliability. However, there was no clear consensus on the impact of 4IR technologies on the flexibility of production processes. Interviewed automotive assemblers did not mention flexibility as a driver of technology adoption; in fact, they tend to avoid using potentially versatile machinery such as robots for different tasks because this raises the chances of maintenance issues and requires complex software reprogramming. However, when considering a longer time horizon, firms mentioned that production flexibility could play an important role in the more distant future.

## IMPACT ON LABOUR AND SKILLS

### Global Trends

Studies on European automotive sectors (e.g., Dauth, Findeisen, Südekum, & Woessner, 2017; Jürgens et al, 1993; Krzywdzinski, 2017, 2020) have found little evidence of labour displacement but rather of changes in the composition of employment and in working conditions. They generally find a decrease in blue-collar workers accompanied by a rapid increase in engineers, technicians and data scientists, with no net job losses (Krzywdzinski, 2021). Similarly, Drahokoupil (2020) finds no evidence of significant job cuts but does find initial indications of workers being reassigned to new tasks requiring new skills. A more pessimistic analysis on South Africa finds that the high level of internal redeployment (as opposed to layoffs) observed when automation technologies were adopted in stamping, welding and painting is less likely to happen in final assembly automation (Chigbu & Nekhwevha, 2020).

Technology adoption in the auto sector is shifting firms' skills requirements (Jürgens, Malsch, & Dohse, 1993; Lüthje & Tian, 2015). In the automotive sector, this shift has generally been away from medium-skilled jobs and towards more low-skilled as well as high-skilled ones. A higher presence of low-skill workers is part of the slow process of automation-technologies adoption. For example, if a welding station is substituted with a robotic cell, in most places the process will be automated but there will still be a need for a low-skill worker to feed the cell, whereas previously this worker would have carried out medium-skill welding activities. This is expected to be a temporary phase as in the future even the machine will be fed automatically. Finally, in the auto industry, the introduction of new technologies is not only a matter of cost consideration but a complex decision in which employee representatives and collective bargaining have often played an important role (Jürgens et al, 1993).

More nuanced – and often ambiguous – findings on the effect of automation on working conditions include that robot-exposed workers have a higher probability of job security at their original workplace but may end up performing different tasks (Dauth et al, 2017), that some new technologies result in more impersonal rules and constraints (Moro, Rinaldini, Staccioli, & Virgillito, 2019), more intense working rhythms (Gaddi, 2020; Virgillito & Moro, 2021),[8] and increases (Carbonell, 2020) or decreases in the discretionary power of workers (Cirillo et al, 2021).

### Trends in the Focus Countries

In line with the evidence from Europe, the general trend suggests that technology adoption in Africa's automotive sectors is having a labour-complementing rather than a labour-replacing effect. In South Africa, and to some degree in Kenya, labour replacement is a sensitive topic in the context of severe job shortages. As a result, the creation of new jobs is a key rationale behind any government support to manufacturing firms and in many cases crucial to a firm's licence to operate. Firms reported that when they adopt new labour-displacing technologies, they seek to redeploy workers to other parts of the production process whenever possible. For example, one assembly firm mentioned that when a new technology led to direct job losses, they employed more people in the health-and-safety protection areas, as well as in lean production, with a positive net effect on the number of jobs. This reinforces the role of production volumes as a driver of technology adoption: automotive firms in South Africa and Kenya tend to adopt new technologies when volumes increase, and technology adoption and employment creation can go hand in hand.

Technology adoption in the automotive sector is leading to a general shift towards higher-skill jobs with firms reporting gaps in practical skills. Both assemblers and component manufacturers reported skills gaps in PLC programming, machine maintenance, and reading and understanding data. Assembly plants report a lack of skills in mechatronics, while component suppliers mentioned that tool makers, automation engineers and press engineers have become hard to find. Due to highly specific firm-level requirements, workers are often trained and retrained in-house by companies, as is common in the automotive sector worldwide. However, synergies between firms and training institutions are growing: Kenyan firms mentioned particularly positive feedback from technical and vocational education and training (TVET) institutions, through which graduates can obtain initial experience with technologies such as 3D printing and CAD.

Hiring in the sector tends to be local in both South Africa and Kenya. In South Africa, where the national unemployment rate is above 30 per cent, firms' hiring choices are restricted by legal quotas on foreign workers and a requirement for the employer to demonstrate that the skills sought from any foreign employees are not present within the domestic labour force. Although new hiring is mostly domestic, assembly plants rely significantly on headquarters to bring in experts for periods of a few months or even years in some cases. Firms also report that retraining is more difficult with older workers because most of them have not received training in a long time and because they lack basic digital literacy.

As automotive firms see the adoption of new technologies going hand in hand with an increase in volumes, labour is expected to increase as output increases. Moreover, firms in both countries reported that the servicification of manufacturing will be an important trend in the future for two reasons. On the one hand, firms require specific capabilities to set up, integrate and adapt complex new technologies. This applies to both 3IR and 4IR technologies that combine software and hardware elements and generate large amounts of data. Software generation and integration have already opened an important new market space to system-integrator firms. On the other hand, servicification is also related to opportunities in post-production. One assembly plant sees a growing trend towards post-sale services enabled by data generated throughout the car's life. Sensors, data analytics and predictive maintenance are critical to anticipate issues for cars on the road – new software programmes, skills and market opportunities are expected to emerge from this.

## Jendamark: Creating Value Between Manufacturing and Services

Jendamark is a South African company launched in the early 1990s to build small robotic cells and production lines mainly in the auto sector, for instance for the manufacture of power trains, electric vehicles, batteries, engines and catalytic converters. The firm has around 200 employees. It recently started designing and integrating software and is increasingly moving into the digital space. Jendamark exports 95 per cent of its products and services, mainly to the US and EU, and is well established in its sector. The company is equipped with a precision-tool room and a general machining shop and is planning to open a new fabrication facility.

Jendamark's core business cuts across conceptualisation, design, manufacturing and providing solutions to problems. The firm provides tailor-made hardware and software that enable fully functioning robotic cells. The company works extensively with 4IR technologies such as cobots, AI, virtual reality, big-data analytics and 5G. A growing part of the business is the set-up and integration of highly customised production lines able to produce products for different segments of the auto industry.

Jendamark is both a machine-tool company, a system integrator and a software-development company; its success lies in a deep consolidated set of production capabilities around the machine-tool industry and a continuous ambition to find solutions to industry problems.

According to our interviewee, automation has been the main trend in manufacturing especially in the EU and US, a process triggered by the cost of labour in those areas and by other specificities such as high volumes. Moreover, he mentioned that digitalisation would help to democratise manufacturing because it has the potential to change the relevance of volume on manufacturing production, which is a big constraint in countries like South Africa, and instead to focus on the flexibility of the production processes.

Jendamark is the only interviewed company that sees small production volumes not primarily as a constraint but rather as an opportunity to leverage technological sophistication for production versatility and customisation at small scales.

## Case Study: The Food and Beverage Industry

### SECTOR OVERVIEW

The F&B manufacturing industry is a critical sector for countries at varying income levels (ILO, 2022; Caldwell, 2013). It consists of numerous and diverse product categories such as dairy products, vegetable fats and oils, fresh and processed meats, confectionary, milled grains, soft drinks and water, and alcoholic beverages, to name a few. As a result, a key characteristic of the sector is that its products are highly variable in size, shape and strength. However, four generic value-chain stages apply to almost all F&B manufacturing: raw-material handling, processing, packaging and distribution (see Figure 9).

The F&B sector (along with tobacco) represents about 38 per cent of manufacturing value added in Kenya, 35 per cent in Ghana and 22 per cent in South Africa (UNIDO, 2022) and is highly heterogeneous in the three focus countries. South Africa is a major producer and exporter of finished processed F&B products. In 2018 the sector employed about 450,000 people with an annual output of $143 billion. There are over 1,800 food-production companies but 80 per cent of the industry's production revenue comes from the top ten companies. The largest subsectors include meat, fish, fruits, dairy, grain milling and beverages.

Ghana's food-processing industry represents more than half the country's manufacturing value added. The sector is dominated by SMEs – 85 per cent are micro-enterprises, 7 per cent are very small firms, 5 per cent are small firms, and 3 per cent are medium sized (Affulf-Koomson et al 2014). Advanced, export-oriented food processing is done mainly by medium-sized state-owned firms such as Fan Milk and multinationals such as Nestlé. Kenya's total F&B exports reached $2.8 billion in 2021. The most technologically advanced F&B plants in Kenya tend to be in the beverages subsector. Kenya consistently exports around $50 – 70 million per year in fruit juices, beer, spirits and mineral water as well as serving a relatively large and growing domestic market. The leading firms include breweries that are part of global groups such as East African Breweries Limited (owned by Diageo); medium-sized Kenyan-owned or joint-owned beverage companies such as BidCoro (Kenyan-Danish joint venture), Del Monte and Kevian; diversified Kenyan F&B groups such as BidCo Africa (a diversified group); and bottlers for global soft-drink brands such as Coca Cola, among others.

## TECHNOLOGY-ADOPTION TRENDS

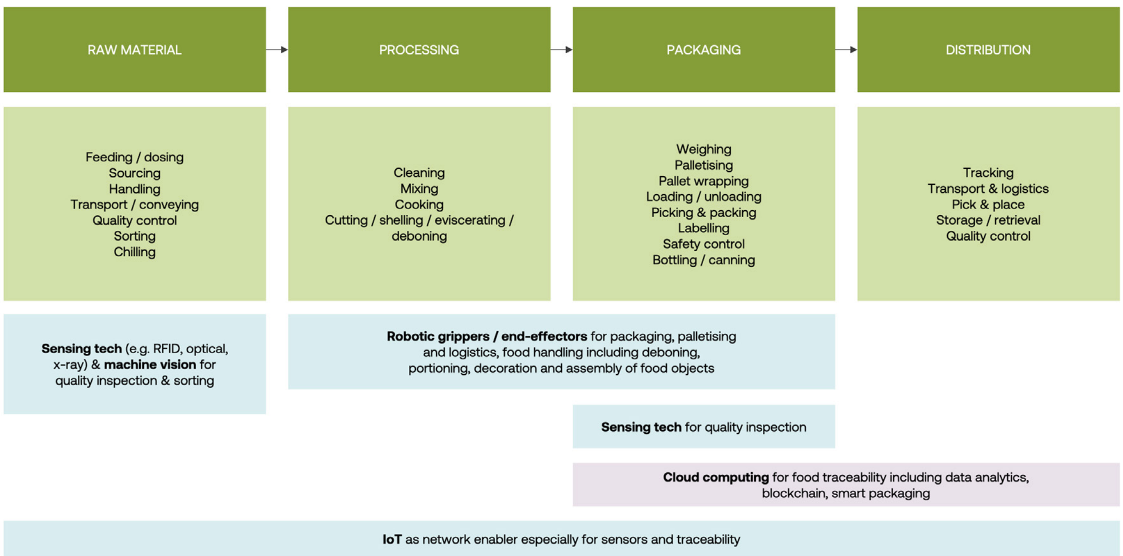
### Global Trends

The degree of 4IR-technology adoption in the F&B sector varies widely by firm size, stage of the production process and subsector.

In general, the F&B sector is not a global frontrunner in terms of robotisation: of the 384,000 industrial robots installed in 2020, only 3 per cent (12,000) were in the F&B sector (IFR, 2021). However, advances in technology, market forces, and legislative and demographic forces are beginning to transform the sector's technology-adoption trends (Caldwell, 2013; KPMG, 2014) and investment in robotics and automation is predicted to accelerate (Bostan, 2021). In smaller firms around the world, F&B production is still labour intensive. In contrast, in the most advanced F&B plants globally, 3IR and 4IR technology has already enabled the creation of a digital, end-to-end "closed-loop production mechanism" that allows for high-precision production planning and continuous process optimisation (Siemens, 2022). Among the industry's technology pioneers, the use of automation and robotics is well established in end-of-line tasks, including packaging and palletising, but more limited in the primary packaging and assembly of food, where the bulk of the sector's manual labour is concentrated (Moreno-Massey et al, 2010; BEIS, 2021).

FIGURE 9

# Technology adoption along F&B value chains




Source: Authors

The following major advanced technologies are starting to be applied in various parts of the F&B industry globally.

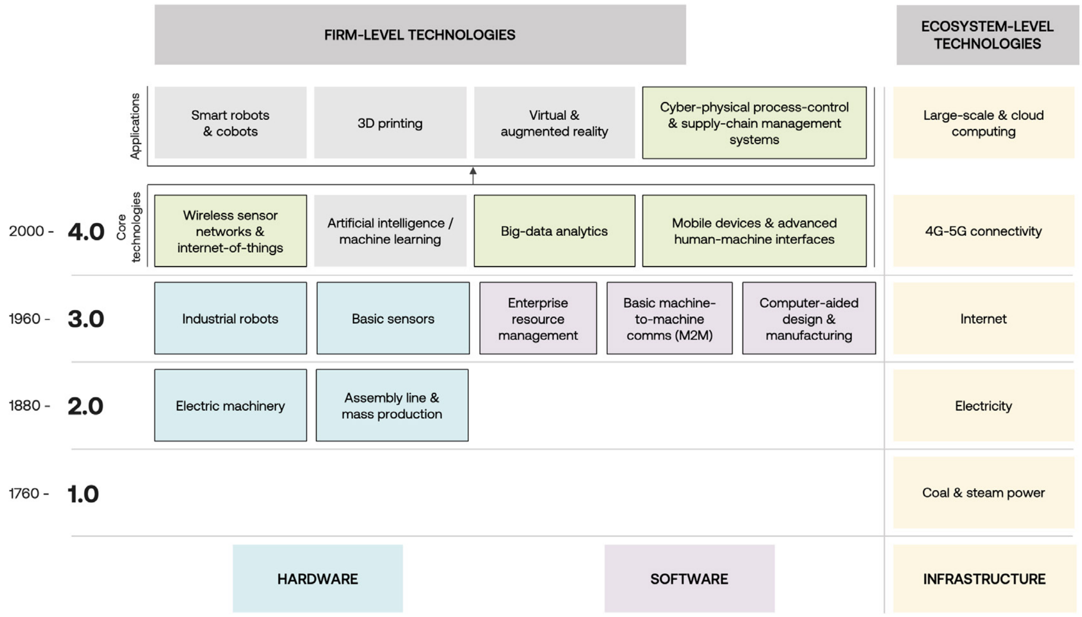
**Sensors and machine vision for automated food-process control:** X-ray and RFID technologies are used for automatic inspections for hygiene, safety and reliability. Smart packing sensors are used to detect temperature and other conditions of food products. Optical sensors and online spectroscopy can enable fast, accurate, non-destructive and automated food-quality monitoring, inspecting food colour, texture, flavour, shape, nutritional value, composition and safety. Wireless sensor networks generate and process data using a centralised system. Food-recognition and machine-vision technology can be used to inspect raw-food material and maintain control of quality. 2D image-processing methods can be used if food products or materials are separately located on a flat surface. 3D imaging technology can be used in other cases.

**Robotics:** Gripper technology and robotic end-effectors are used for packaging, palletising, and logistics, handling of food including deboning, portioning, decoration and assembly of food products such as sandwiches, pizza, and so on. Food products vary greatly in terms of physical properties like shape and weight. As a result, robotic end-effectors or grippers must be tailored to the unique target product, meet hygiene requirements and accommodate the physical variations between food products (Caldwell, 2013).

**Food traceability and IoT:** Intelligent packaging technologies use a range of sensors to monitor the condition of a food item once it is in its final packaging. Wireless sensor networks are increasingly used in the F&B industry using RFID tags and readers attached to products to provide supply-chain traceability information. This information is then analysed using cloud computing, big-data analysis tools and, at times, blockchain technology. IoT systems are also used to manage and analyse data generated by motion, temperature and other sensors to monitor the quality, consistency, and movement of ingredients and final products.

FIGURE 10

# Technology adoption in F&B industries in Ghana, Kenya and South Africa




Note: Coloured boxes with boundaries represent technologies that are adopted by several firms in the sector in our study countries. Light coloured with no boundaries means adopted at the global tech forefront of the sector but not in our study countries. Grey means not yet adopted worldwide in the sector.

Source: Authors

### Trends in the Study Countries

Firm interviews revealed that the most advanced F&B firms in Ghana and Kenya run their operations with highly automated and digitalised production processes. For example, one beverage company reported the use of a single automated line for the cleaning, filling and sealing of bottles. Several plants have production lines that generate digitally accessible real-time data that are processed and analysed to correct for errors, report failures, increase efficiency, and which reduce losses along a chain. Multiple production lines also had cleaning-in-place systems to clean and purify production equipment requiring stricter sanitary standards, especially in the production of carbonated beverages, dairy and juice. The interviewed companies also reported extensive use of sensors to measure and regulate the flow, temperature and pressure of liquids.

In addition, industrial robots, especially robotic arms, are used in the packaging stage, including to wrap boxes and place them on pallets.

These palletisers are fully automated and digitalised using QR codes that store information on the specific location of the packaged box. Machine-to-machine communication is in place, reducing the need for human intervention, except in a few cases where high-skilled engineers are needed to address a malfunction that the machine is unable to fix automatically. Some firms use IoT technology allowing the machine manufacturer to connect with the machine directly and solve the issue remotely in a short period of time.

These end-to-end digitalised production systems are also making use of computer-aided recipe generation that meets international and internal standards. CAD software systems are giving the plant management full control to adjust the recipe and meet high quality standards. The management is also able to initiate, pause and terminate a production line, either partially or fully using a human-interface system as part of the CAD software. Finally, all companies reported the use of cloud-based enterprise resource-planning software to manage all activities from sales and accounting to human resources and inventory.

Companies reported that despite already high automation levels, there will be further scope in the coming years to adopt leaner production methods and to operate technologies that improve runtime, increase productivity and reduce error margins. Some F&B manufacturers are exploring the introduction of virtual/augmented reality software and devices for remote troubleshooting in the coming years, supplemented by high-speed cameras and drones to visually access normally inaccessible parts of a machine. In terms of automating tasks that continue to be semi-automated or manual, companies have indicated their interest in purchasing automatic wrapping and packaging machines, automatic palletisers, and automatic testing equipment to ensure that strict sanitary and quality standards are met.

### FACTORS AFFECTING TECHNOLOGY ADOPTION

The most important driver of the timing, pace and level of technology adoption by F&B firms in Kenya and Ghana is the nature of ownership of the establishment – whether it is a subsidiary of an international organisation with the headquarters located elsewhere, partly owned by a multinational company or an indigenous firm. For instance, with HQs located in Europe or the Americas, upgrading requests and decisions for local plants in Africa were made at a senior executive level in the HQ. Although influenced by local conditions in the plant country, global HQs made key decisions related to the timeline and level of technology upgrading, changes in product standards or recipes, and the choice of machinery supplier. In most cases, new equipment has been tested in other company locations before being approved for the African plant.

FIGURE 11

## Principal factors affecting technology adoption in the F&B industry

| ECOSYSTEM FACTORS | FIRM-LEVEL FACTORS |
|---|---|
| Availability of technologies | Scale/volume |
| Relative costs of labour vs robots | Industrial & technological capabilities |
| Skills | Flexibility & proximity to demand |
| Infrastructure | Operational & resource efficiency |
| Access to finance | Quality & standardisation |
| Tech-related services | Ergonomics & safety |
| Incentives & regulations | |

Source: Authors

## ECOSYSTEM FACTORS

### Relative Cost of Labour Versus Robots

A range of machinery that automates tasks in the F&B industries is available at prices lower than prevailing labour costs for the equivalent human workers needed for those tasks. This a key driver of the significant adoption of automated lines or single machines as discussed above. However, locally owned F&B firms in Kenya and Ghana cited the high cost of advanced machinery as the most important constraint on technology adoption. This is exacerbated by reportedly high import tariffs on machinery in both countries, an issue firms cannot get around as the technologies in question are not being manufactured in Kenya or Ghana.

### Skills

In all interviewed F&B firms, recent technology purchases were followed by visits from specialised personnel from the technology manufacturer to train current employees. At the same time, companies hired new high-skilled employees to meet these new skills requirements. According to F&B firms, this high-skilled labour is scarce in both Kenya and Ghana due to a mismatch between education curricula and industry needs, presenting a severe bottleneck to technology adoption. About half the interviewed firms reported having to hire foreigners to fill more senior technical and management positions.

### Infrastructure

A minor but widespread barrier to automation reported by companies is the high cost of electricity, especially in Kenya. Advanced equipment is more energy intensive than manual labour, and at times proved to be a vital issue for the continuation of operations.

### Access to Finance

Locally owned F&B firms cited access to capital to finance large upfront investments in new technology as the most important bottleneck to technology adoption. This is, however, not a substantial bottleneck for large corporations and their subsidiaries operating in the two countries as investment typically follows an HQ-level decision to upgrade technology across its plants. Because HQs provide the necessary financing for technology acquisition, subsidiaries in Ghana and Kenya do not need to access finance from local banks at high costs like their indigenous counterparts.

## FIRM-LEVEL FACTORS

### Operational and Resource Efficiency

The adoption of technology is driven mainly by the incentive of saving time on tasks and increasing employee efficiency and productivity. Companies also cited the need to remain relevant, attract new clients and stay at par with their direct competition in the market as drivers of technology adoption. For instance, one beverage firm with operations in Kenya mentioned that severe competition faced in the local market for carbonated beverages motivated the purchase of new machinery for that production line.

### Quality and Standardisation

In many cases, new automation machinery is employed to standardise product quality, meet sanitary requirements and establish quality controls based on industry guidelines. Some subsidiaries of multinational companies used automation technologies to achieve standardisation of recipes and processes across various plants. The decision to introduce new technologies to achieve standardisation was mostly driven by HQ-level requirements to achieve consistency in output and monitor its quality. These decisions come in the form of standard operating procedures and guidelines that are issued on a regular basis by the parent company to all its subsidiaries, including those located in Kenya and Ghana.

### Ergonomics and Safety

The decision to introduce new machinery was also influenced by the need to improve employees' working conditions and introduce smarter rather than harder working patterns.

## IMPACT ON PRODUCTION

All seven companies interviewed in Ghana and Kenya reported that the adoption of new automation and digital technologies in the last five years had led to improvements in total output, labour productivity, quality, speed and resource efficiency. They all highlighted how machine upgrading led to a rise in output with fewer employees but in the same operation time, a rise in production capacity, as well as better quality control and ease in monitoring. For example, some plants reported that the move from manual or semi-automated to fully automated lines allowed continuous production for 24 hours a day, with pauses needed only for cleaning. One manufacturer reported lower consumption of electricity and water due to increased production efficiency and shorter processing times to meet daily output targets.

### IMPACT ON LABOUR AND SKILLS

Some job losses occurred at both the low-skill and medium-skill level due to new technology adoption. Two companies reported laying off a marginal percentage of manual workers when their tasks were automated. The Coca-Cola bottling plant in Nairobi, which has 1,500 employees, runs several semi-automated production lines as well as one fully automated line. The fully automated line produces 16,000 bottles per hour and requires five workers while the semi-automated lines produce 22,000 per hour with 20 workers. At the medium-skill level, when one beverage manufacturer introduced upgraded machinery that requires little human intervention, the plant went from four factory-floor managers overseeing one production line each to just one manager overseeing all four production lines.

However, most F&B companies in Kenya and Ghana reported that the size of their workforce remained unchanged after the adoption of automated technology. This can be attributed to two reasons. First, although some manual processes were automated, displacing manual labourers, those labourers were usually reabsorbed by either being retrained as machine operators or redeployed to other manual tasks. Second, companies reported that some manual jobs that involved packaging of products and loading of boxes on trucks were not automated as they did not pass the cost-benefit analysis. Companies also cited a social responsibility towards the country they were operating in to meet their minimum local employment requirements to continue operations.

Those interviewed underlined that the adoption of new technology has increased the requirement for advanced technical skills to operate automated machinery, carry out routine maintenance activity and solve unforeseen issues. For instance, a Ghanaian manufacturer noticed a considerable skill gap in its employees to operate new machinery. As a result, it needed to hire new experts, but this was restricted by a small budget. Instead, it requested skilled personnel from the machine manufacturer to visit its plant to train the employees. Another firm, a subsidiary of a large multinational corporation, reported similar training activities to improve the skill level of its workforce. It had laid out extensive internal development plans for upskilling its staff, in addition to providing scholarships to learn new skills. While this translated to an added cost and time spent on technology adoption, it also led to an overall increase in efficiency. Companies also reported an overall shift towards hiring operators with at least an engineering diploma and mid-level managers with at least an engineering degree in the operations department. Nevertheless, these positions were mainly filled by locals in both Kenya and Ghana.

Companies expressed concern about re-absorbing the displaced manual labour over a prolonged period, observing that, on balance, the employee base is likely to shrink in the future due to the job-substitution effect. While several F&B firms interviewed expect further automation to lead to some level of labour displacement, they are ready to invest in in-house reskilling activities as well as rigorous training to prepare new hires to keep up with the pace of technological development. The additional training will add to operating costs, but the benefit in terms of increased productivity, efficiency and output will counterbalance this rise. One interviewee commented that "with technological change, more low-skilled jobs will be replaced. The only option is to train our employees in-house".

# Case Study: The Textile and Apparel Industry

This section presents findings from the global literature as well as nine interviews conducted with T&A manufacturers in Ghana, Kenya and South Africa. Firms were chosen according to their level of adoption of technology and automation techniques. Therefore, a rich mix of medium-sized and large companies were interviewed to understand the uptake of technology across various levels of sophistication, level of export activity and size of the company. For instance, this included large exporters such as DTRT Dignity in Ghana and United Aryan EPZ in Kenya; Sixteen47 and Omega Apparels, both of which are medium-sized firms supplying only to the local market; textile mills Thika Cloth Mills and Gelvenor Africa; clothing retailer Woolworths, and outdoor-clothing brand and manufacturer, K-Way.

## SECTOR OVERVIEW

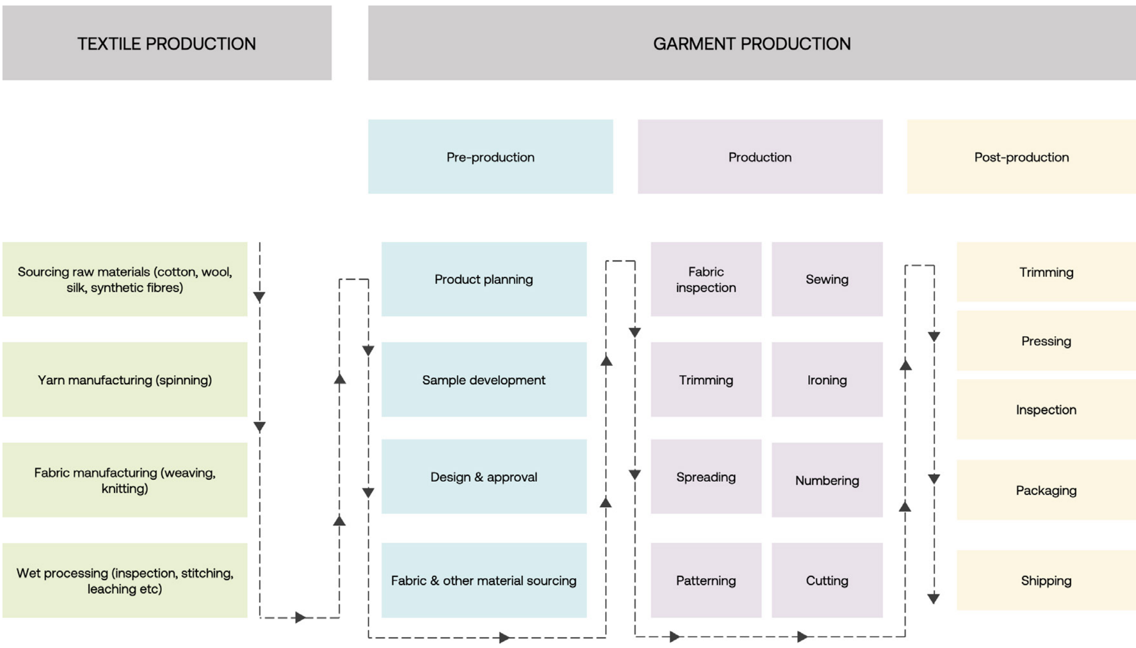
The T&A industry is one of the oldest and largest labour-intensive manufacturing industries. The sector historically played an instrumental role in the early stages of the industrialisation of most of today's advanced economies (Bárcia de Mattos et al, 2022; Kim et al, 2006). In 2019, more than 91 million workers across the globe were employed in the T&A sector, with 55 per cent being women (in garment production, it is estimated that women account for over 50 per cent of employees) (ILO, 2020).

High labour-intensity has meant that the cost of labour has historically impacted the geography of production, especially in the apparel segment, shifting from Europe to countries such as China, Bangladesh, Vietnam, Sri Lanka and more recently African countries like Ethiopia (Gereffi and Memedovic, 2003). However, the future of production in the T&A sector depends not only on labour costs but also on several other factors such as new technologies, labour availability, skills, cost and reliability of energy, cost of capital, infrastructure, logistics, trade policies and the broader institutional setting in which production takes place (Bárcia de Mattos et al, 2022).

Figure 12 details the main steps of the T&A value chain. The first activity in textile manufacturing is sourcing raw materials – these can be natural, such as cotton, silk and wool, or synthetic, such as polyester, rayon or nylon. The next step is processing raw materials into yarn through spinning, followed by the conversion of yarns into fabrics. The final stage in textile production is wet processing which involves fabric inspection, stitching, scouring, bleaching, dyeing, printing and finishing. The main garment production process can be divided into three major steps (Nayak and Padhye, 2018). First, the pre-production process includes product planning, sample development, designing, approvals, fabric sourcing and production scheduling. Second is the production process which includes fabric spreading, cutting, bundling and sewing. Finally, post-production processes involve thread trimming, pressing, inspection, folding, packaging and shipment.

FIGURE 12

## Textile and apparel manufacturing value supply chain




Source: Authors

Textile production is significantly more capital intensive than garment manufacturing and has recently experienced accelerated automation while garment production remains labour intensive. Labour-intensity in textiles, and particularly in spinning, has rapidly decreased over the past decades. A production level in spinning that required 200 to 300 operators 20 years ago requires only 50 operators today. The most recent innovation in textiles is the digital printing of fabrics and this innovation is expected to significantly grow in the coming years, as digitally printed fabrics can generate a raft of products with reduced delivery times and resource consumption, particularly water.

The application of automation and robotics is expected to gradually increase even in garment production, potentially transforming the sector into high-tech production (Nayak & Padhye, 2018). Some degree of automation can be applied in fabric inspection, spreading, cutting, sewing and material handling. However, core garment-production activities such as sewing have proved to be very difficult to automate due to the high dexterity and motor-skill versatility they require (Bárcia de Mattos et al, 2021). The technologies needed to automate these tasks are not expected to become available and cost-competitive with human labour in the next one or two decades (Bárcia de Mattos et al, 2021). In addition, both textile and garment producers run on tight margins and will therefore be highly sensitive to the cost-competitiveness of automation technologies and rather conservative about further automation as long as relatively cheap labour is accessible (Bárcia de Mattos et al, 2020a; Bárcia de Mattos et al, 2020b).

South Africa's modern T&A industry can be traced to the post-Second-World-War era (Chitonge, 2021). South Africa followed an import-substitution strategy until 1989, and then gradually liberalised the sector between 1994 to 2005, which increased imports substantially (Vlok, 2006), putting intense pressure on domestic firms. Employment in T&A dropped by approximately 62 per cent between 1995 and 2019. During the same period, several South African T&A producers moved operations to Eswatini and Lesotho in search of more competitive wages and other business conditions. Currently, the sector contributes about 2.5 per cent of South Africa's total manufacturing output and 2 per cent of its exports, and has approximately 4,500 tax-paying manufacturers, dominated mainly by small enterprises. The sector is considered critical for national development and the government has invested considerably in it in the past decade, leading to a gradual transformation from labour-intensive production processes to more automation in order to achieve greater international competitiveness (Parschau and Hauge, 2020).

In Kenya, the T&A sector is a priority sector targeted for its job creation and export-growth potential under Kenya's Vision 2030 and the previous regime's Big Four Agenda, with the new administration expected to continue promoting the sector. The sector accounts for 6 per cent of the overall manufacturing sector, contributes 0.6 per cent to Kenya's GDP and 7 per cent of Kenya's total exports. There are around 52 textile mills and thousands of large, medium and small companies in the apparel sector. In 2019, Kenya's total import of T&A was worth $293 million while its export value was $160 million. Kenya is the fifth-largest global importer of second-hand clothing, supplying local consumers with cheap clothing and representing significant competition to local firms. Kenya produces and exports garments in all major textile and apparel categories but its greatest T&A exports by volume are in men's and women's trousers. Because apparel production is mainly focused on the cut, make and trim model, Kenya is heavily dependent on imported fabrics, primarily from China, India, Pakistan and Vietnam. Kenya's apparel sector is dominated by export-oriented firms with high levels of worker productivity and higher wages than regional neighbours such as Ethiopia (though still lower than a number of Asian countries).

Ghana's T&A industry is beginning to experience a resurgence. In the 1970s, Ghana's T&A industry accounted for 27 per cent of manufacturing employment but, due to trade liberalisation, a lack of firm competitiveness and foreign-exchange shortages the sector all but collapsed in the 1980s and 1990s (Sutton and Kpentey, 2012). As a result, most companies did not survive beyond the 2000s. Today, the Association of Ghanaian Apparel Manufacturers has 45 members, mostly small scale, locally owned and largely focused on the domestic market, having been generally unsuccessful so far in exporting, even with support from donor-funded programmes. The first large FDI in the sector occurred in 2015 through joint ventures between two existing local factories and foreign firms with expertise in the sector.

Currently, Ghana is West Africa's main exporter of clothing to the US and the top global importer of second-hand clothing. According to foreign investors, Ghana is an attractive location for apparel export production compared to Asian countries given its proximity to Europe and the US as well as its African Growth and Opportunity Act (AGOA) trade preferences. Investment, output and exports in the sector are expected to grow further in the coming years. By the late 2010s, the T&A sector had become a focus area for the government of Ghana once again, with an aim to revive an old textile mill, attract foreign T&A investors and support local apparel firms.

## TECHNOLOGY-ADOPTION TRENDS

### Global Trends

Globally, there have been numerous recent technological advances in the T&A sector in both software and hardware.

In terms of software, recent years have seen accelerated adoption of solutions for CAD including 3D design, computer-aided manufacturing (CAM), ERP, statistical process control, production planning and inventory management (Nayak and Padhye, 2018). The application of these tools cuts across designing, patternmaking, digitising, grading, spreading, planning and inventory management, and automated body scanning. Furthermore, there are advances in knitting technology, such as computer-controlled or 3D knitting. These technologies have helped decrease product-development time and increase efficiency, allowing trial and error before initiating cutting operations on the fabric (Hoque et al, 2021; Zhang et al, 2016).

On the hardware side, three main types of automation machinery are being adopted (Nayak and Padhye, 2018). First, there are some attempts to begin automating sewing, the most labour-intensive part of apparel production. For example, the company SoftWear Automation is currently at the forefront of innovations in fully automated sewing and many others are making investments. Second, inspection is beginning to be automated. Fabric inspection is usually carried out manually, but studies show that an inspection expert cannot usually detect more than 60 per cent of the typical defects on a piece of fabric wider than two metres (Goyal, 2018). The use of RFID tags enables an error-free system of inspection and tracing of parts and products throughout the value chain – from suppliers to manufacturing, distributors and retailers (Tajima, 2013) – with minimal human intervention and increased efficiency and accuracy (Azevedo and Carvalho, 2012). Third, unlike sewing, fabric cutting is already one of the most automated parts of the garment production process (Textile and Made Jahrbuch, 2011). Various semi-automatic cutting technologies are now available, such as straight-knife cutting, band-knife cutting machines and computer-controlled automatic cutting machines. Estimates around the future adoption of fully automated sewing processes vary widely, with expert opinion divided on whether this will be achieved in the US within a decade and when increased automation will lead to nearshoring of T&A production (Altenburg et al, 2020; Andersson et al, 2018).

### Trends in the Focus Countries

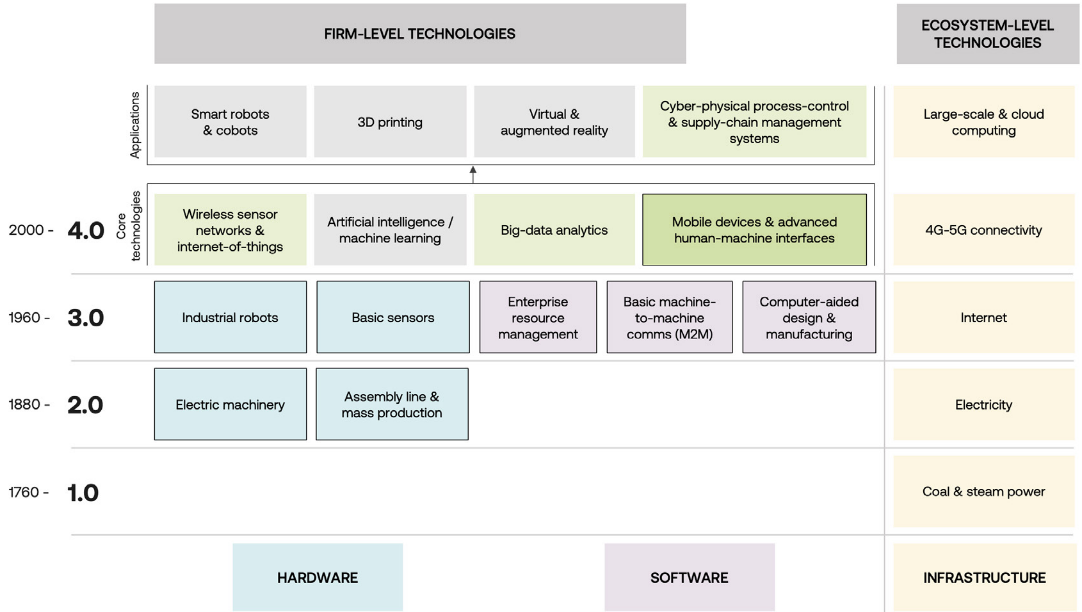
Our findings from T&A firm interviews in South Africa, Ghana and Kenya indicate that the industry currently mostly lies between the 2IR and 3IR in terms of technology adoption, with few examples of 4IR-technology adoption.

Firms in Kenya and South Africa and a company in Ghana reported a general increase in basic automation, including adoption of ERP (both at the supply chain and factory level). For example, an export-oriented Kenyan manufacturer started using the World Fashion Exchange (WFX) since 2011, an ERP highly customised to the needs of the T&A industry.

A couple of South African and Kenyan manufacturers and retailers reported the use of CAD through 3D for prototypes and product design as well digital printing, which led to time and resource savings. Firms in the three countries reported the adoption of new technologies such as automatic fabric-spreading machines, digital sewing machines, CAM, or automated laser-cutting and pattern-making machines. The adoption of these technologies is uneven across firms. Digital sewing machines help perform a wide range of stitches and intricate patterns such as embroidery but are still not labour replacing. In Kenya, an export-oriented manufacturer recently started making patterns in jeans using digitally controlled lasers, which increases the precision and efficiency of this step in the production chain and helped the company to connect with premium brands. In South Africa, apparel firms reported a general increase in machine-to-machine communications through ethernet connections.

FIGURE 13

# Technology-adoption trends in the T&A industry in South Africa, Kenya and Ghana




Note: Coloured boxes with boundaries represent technologies that are adopted by several firms in the sector in our study countries. Light coloured with no boundaries means adopted at the global tech forefront of the sector but not in our study countries. Grey means not yet adopted worldwide in the sector.

Source: Authors

At the retailer level, there has been an increase in data-analytics tools for interpreting big data, mainly to understand consumer behaviour and the speed at which consumers' preferences change. Interviewed firms indicated that, despite a move towards more automation, the garment segment will remain relatively labour intensive for the foreseeable future due to the difficulty of automating sewing.

## FACTORS AFFECTING TECHNOLOGY ADOPTION

### ECOSYSTEM FACTORS

**Relative Costs of Labour Versus Robots**

As most T&A firms run on low margins – especially compared with the other two sectors analysed in this report – the importance of having a valid business case is essential for the adoption of new automation technologies. Currently, the cost of labour in the focus countries remains lower than the cost of technology and robots, particularly in the garment segment, which therefore delays the adoption of automation technologies.

FIGURE 14

# Principal factors affecting technology adoption in the T&A industry

| ECOSYSTEM FACTORS | FIRM-LEVEL FACTORS |
|---|---|
| Availability of technologies | Scale/volume |
| Relative costs of labour vs robots | Industrial & technological capabilities |
| Skills | Flexibility & proximity to demand |
| Infrastructure | Operational & resource efficiency |
| Access to finance | Quality & standardisation |
| Tech-related services | Ergonomics & safety |
| Incentives & regulations | |

Source: Authors

### Skills and Technology-Related Services

Firms indicated that technical support and skills for more advanced technologies are critical constraints for technology adoption. This confirms that although there is an initial cost to purchase new technologies, other costs can be even more challenging, such as the need for maintenance services and the extra training required for the workforce.

### Infrastructure

Suppliers reported that energy remains a structural issue in all three countries. Both reliability and cost of energy hinder firms' growth and their capacity to invest in energy-intensive technologies.

### Incentives and Regulations

Firms reported the lack of government support for growing export opportunities and limiting competition from imported fabrics – particularly from China – as one of the bottlenecks for increasing their competitiveness, scale and, therefore, capacity to invest in 4IR technologies.

## FIRM-LEVEL FACTORS

### Scale/Volume

Production volume is one of the drivers of investment in new equipment: the increase in demand from customers requiring more units acts as a push mechanism to increase productivity, and this is often undertaken through the adoption of more advanced technologies. Interviewed firms reported the lack of volume and scale as one of the critical bottlenecks to technology adoption: "Volume is where the money sits", according to one interviewee.

### Proximity to Demand and Flexibility

Since the industry moves at a fast pace, flexibility and versatility are also important drivers for technology adoption, especially at the retailer level. Firms in South Africa reported how global trends such as value-chain disruptions and fragmented production are increasingly challenged, and there is an intention to move towards automation and nearshoring.

### Operational and Resource Efficiency

Reduction of waste, scraps and increase in resource efficiency and consistency of the tasks involved in the production process are critical drivers of technology adoption. Automation technologies help perform repetitive tasks with absolute precision, reducing scrap rates. In addition, the necessity to decrease energy consumption, improve resource efficiency (mostly for water and energy) and align with best environmental practices is becoming a central concern in the industry.

**Quality and Standardisation**

In Kenya and Ghana, firms mentioned that the necessity to standardise output and provide a good quality product for existing and new clients plays a crucial role.

## IMPACT ON PRODUCTION

Most interviewed firms reported a noticeable increase in efficiency and productivity as a result of new technology adoption. For instance, one medium-sized garment firm reported an increase in output by 50 per cent after the introduction of digital sewing machines and automated cutting and laying machines. As a result, the same task of laying and cutting that previously required seven workers is now performed by only three. Another firm, a textile mill, reported that the introduction of automated spinning machines translated into higher output, with only 10 per cent of the labour previously required for the task. The same mill also highlighted a three-fold increase in capacity of their unit and a 12.5 per cent rise in total output in response to the new automated machines. Additionally, a small-scale garment manufacturer reported doubling its product efficiency as a result of new technologies being adopted.

Some companies also reported an increase in resource efficiency, notably through a reduction in energy and raw-material consumption due to automation and advanced technology adoption. Garment factories reported lower usage of fabrics, and overall reduced wastage of fabric due to automated cutting machines that were more efficient and eliminated human error. A garment factory reported a reduction in fabric usage by 5 per cent since the introduction of new technology. A textile mill noted that the cost of energy decreased by 40 per cent since the introduction of automated machinery. Centrally, an important outcome of automation has also been the reduction in waste generation and better processing of waste disposal across manufacturing firms. For example, a large manufacturer reported using water-recycling plants in line with their environmental targets. Moreover, retailers are increasingly focusing on recycling used clothes to reduce wastage and lower their carbon footprint.

Finally, several firms in Kenya and Ghana also reported that the introduction of automation technologies improved their image with regard to international clients. Seen as an investment in the future of the firm, automation technologies helped position firms as capable of handling more sophisticated and larger orders. The same firms also reported client perception as a key driver for the adoption of automation.

## Sixteen47

Sixteen47 Ghana Limited is a fully Ghanaian owned apparel designer and manufacturer established 20 years ago. It specialises in the production and distribution of uniforms for schools, Ghana's military, the forestry department, sanitation agencies, chefs and others. The company has introduced several new technologies in the last few years, including:

- **digital sewing machines** that collected data on the quantity of pieces sewn over time and generate real-time data on labour productivity.
- **CAD software** that reduced the number of employees needed for patternmaking from three to one.
- an **automatic spreading machine** that replaced six workers with one operator.

During the past year, the company increased its total capacity from 720 to 2,000 units per day while achieving efficiency gains, especially through the introduction of digital sewing machines. With the introduction of this new semi-automated technology and increases in productivity, it aims to achieve 3,500 units per day. To meet this requirement, the management expects to hire more workers, with 70 per cent of these being women from low-income households and with low skill levels.

Therefore, thanks to technology-enabled firm growth, the net effect on employment within the firm is expected to be positive, even as some tasks are automated and workers need to be retrained. Workforce training and reskilling has been supported by a range of actors. For example, International Trade Centre (ITC) provided the company with export support, training in logistics management and ISO accreditation, and marketing tools. The company has also benefited from technical training workshops run by Ghana's two major foreign investors in T&A – Ethical Apparels and DTRT Dignity – on the use of new automated machinery and software.

The firm's next objective is to become a large exporter under the AGOA export scheme through new investment and technology upgrading. They hope to purchase automated laser-cutting machines, automated fabric-spreading machines, an ERP system, and an auto-placket machine. However, the company suffers from a tight budget constraint owing to its commitment to remain wholly Ghanaian owned.

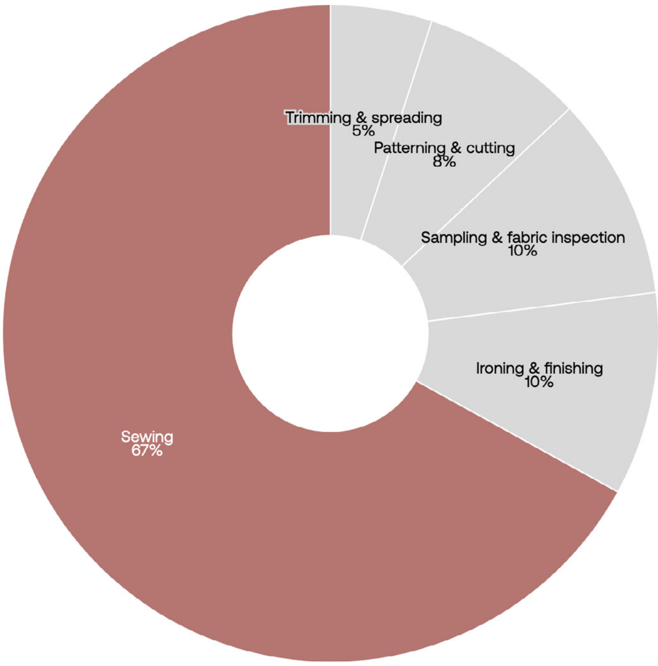
## IMPACT ON LABOUR AND SKILLS

### Global Trends

The literature studying the impact of robots and automation on employment in the global T&A sector is inconclusive. Some studies conclude that there will be a negative impact (Acemoglu and Restrepo, 2020; Acemoglu, Lelarge, and Restrepo, 2020; Borjas and Freeman, 2019), others a positive one, while a number of studies indicate that the impact would be insignificant (Dauth et al, 2021; Graetz and Michaels, 2018; Hirvonen et al, 2022; Adachi et al, 2022; Dekle, 2020). While automation displaces some workers, it also increases firms' productivity and profitability, enabling those firms to expand and create new jobs, potentially with higher skills intensity. As a result, the net impact of automation and robots on employment in the sector, like any other sector, depends on the balance of displacement and reinstatement effects.

FIGURE 15

# Distribution of labour in apparel manufacturing




Source: ILO, 2017

Figure 15 shows the distribution of labour in apparel manufacturing. It demonstrates that sewing is the most labour-intensive part of the apparel production process. Therefore, the automation of sewing would have the greatest impact on employment.

While some studies project that a large proportion of T&A jobs is at risk of automation, most recent studies estimate a negligible or limited impact on T&A employment through automation in the near future. Vashist and Rani (2020) predict a limited impact of automation on employment in India because of the economic feasibility of adopting robots and the fact that only a few garment-production processes are expected to be automated.

They also find a significant shift in labour demand towards highly skilled managers and professionals at the expense of craftspeople like tailors and cutters. Based on 26 interviews with firm managers, Parschau and Hauge (2020) found that adopting automation technologies in the South African apparel sector has a negligible impact on unemployment while in some cases, the increase in productivity due to automation technologies is predicted to increase employment. In one Vietnamese firm, Viet Thang Company, workers were made redundant through the adoption of an automatic grinding machine run by software, but those employees were transferred to another production section as the company expanded its production volumes (Lan, 2020). In Bárcia de Mattos et al's (2021) study, key personnel at leading apparel brands said that they did not expect automation technologies in the apparel sector to lead to significant losses in employment or reshoring in the near future and suggested that a more likely outcome is the greater use of semi-automation.

### Trends in the Focus Countries

The impact of automation technology on labour across textiles and garment factories varies, but the general trend is one of reduced overall labour intensity after the introduction of automation technology, with the exception of sewing. According to T&A firms in South Africa, Kenya and Ghana, the introduction of new automation machinery has replaced some manual labour in various tasks but not in sewing. For example, one towel manufacturer in South Africa introduced machinery to automate fabric cutting and the attachment of labels and belt loops to towels. Before automation, 25 workers produced 100 face towels per hour; after automation, just two workers were needed to produce 1,500 face towels per hour. However, companies that adopted new automation technologies were determined to keep employees and stated that most displaced workers were redeployed to other tasks and departments.

Companies unanimously agreed that automation will lead to growth. As a result, they expect the labour-displacing impact of automation to be mitigated by an expansion of production accompanied by greater demand for labour. In addition, sewing and possibly some other tasks are likely to remain manual or at least only semi-automated for the foreseeable future as that is the most efficient production method.

The demand for medium- and high-level skills increased in T&A companies across the three countries. However, most companies were able to meet this skills requirement through internal training activities carried out by in-house senior engineers and training personnel from the equipment providers. Interestingly, it did not add much to the overall cost to the firm. To support the increased demand for higher skill levels, some large, export-oriented companies also launched mid-level management-training programmes focusing on operations across departments. In the future, most firms expect to hire younger employees with medium-level skills and at least a diploma (or its national equivalent) to ensure they are capable of operating sophisticated machinery and associated hardware.

## United Aryan EPZ Ltd

United Aryan EPZ Ltd is a Nairobi-based garment manufacturer with special-economic-zone status that employs over 10,000 local workers.

The firm has taken a proactive approach to adopting new technologies across all levels of the business, investing over $400,000 in laser technologies, digital cutters and industrial washers to replace manual washing, dyeing and embellishment. These investments have enabled the factory to work with premium international brands such as H&M and Levi's who require such technologies not only for quality standards but to ensure producers can keep pace with fast-fashion requirements. The adoption of this new technology has also facilitated greater efficiency for the firm by reducing fabric waste by 30 per cent, combining multiple workstreams and enabling greater output.

Despite these initiatives, United Aryan EPZ has faced significant bottlenecks to technology adoption. High electricity tariffs and import duties on machinery weaken the business case for technology upgrading. Furthermore, interruptions and fluctuations in power supply threaten to damage expensive machinery.

Finally, a lack of local expertise to maintain new technologies means that the company must depend on support from the machine manufacturers for diagnosis and repair which is costly and can cause delays.

United Aryan EPZ has ambitions to become Africa's first farm-to-fashion company, with the ability to grow cotton, produce textiles, and design, manufacture and market clothing. To this end, the company is in the process of creating an e-commerce store complete with a specialised e-wallet. It is also considering investing in VR factory tools to allow prospective partners to tour the factory and perform quality-assurance measures remotely and virtually.

## Summary of Findings for the Three Sectors

### TECHNOLOGY ADOPTION

The most advanced firms in South Africa, Kenya and Ghana are relatively close to the global frontier in the adoption of 3IR manufacturing technologies, ranging from basic robots and other automation machinery to ethernet-enabled machine-to-machine communications, basic sensors and digital production-management software. Many technologies in this category have been adopted in the past five years. Overall, there is an advanced adoption of 3IR technologies for large firms, however, with a large variation across sectors. In T&A, industrial robots are used in the textiles segment but rarely in the apparel sector. For instance, tasks such as cotton spinning, weaving, printing and fabric cutting have been widely automated using specialised machinery. In F&B, some tasks are still more labour intensive in the study countries than at the global technology frontier – for example pallet wrapping, packaging and loading. These are tasks that advanced F&B firms in the study countries are looking to automate in the coming years.

The most advanced firms in all three sectors are also beginning to make significant inroads into the 4IR. In terms of automation and 4IR technologies' adoption, the automotive and F&B industries are ahead of the T&A sector, in line with global trends. Firms in these two sectors have installed wireless sensor networks for quality standardisation and product-safety control, and are using IoT systems to analyse large amounts of data and collaborate with HQs and machine manufacturers on maintenance and process optimisation. This is not happening at a significant scale in the T&A sector yet (here, the African firms are somewhat behind the global frontier, where garment manufacturers are increasingly using these technologies throughout the supply chain). 3D printing is starting to be used by some accessories manufacturers for prototyping but are not yet used in garment production.

In the foreseeable future, the interviewed firms expect incremental 4IR-technology adoption instead of a sudden disruptive change. In the automotive and F&B sectors, virtual/augmented reality is a key next frontier that is expected to enable, among other things, better remote troubleshooting by machine manufacturers and maintenance engineers. Apart from this, firms are looking to gradually automate additional tasks using 3IR technologies while also incrementally building out the digital layer through sensors, data analytics and cloud computing. In T&A, sewing is predicted to remain labour-intensive, and at most only semi-automated, for the foreseeable future, and firms are continuing to invest in highly manual sewing lines, while gradually automating other tasks such as fabric laying and cutting.

## FACTORS AFFECTING TECHNOLOGY ADOPTION

The drivers of technology adoption are diverse and varied: while volume and scale are a common driver in the three industries, a variety of other drivers were highlighted as important for technology adoption. In the automotive industry, the key drivers are volume, quality standardisation and new materials. In T&A it is cost, volume, quality, efficiency, flexibility and proximity to demand. In F&B the key drivers are cost, efficiency and worker safety. Firms that are subsidiaries or suppliers of multinationals in the automotive and T&A sectors confirmed that the decisions taken at the global headquarters have the biggest impact on technology adoption at the local level. This can take the form of the introduction of new product standards and quality requirements, product specifications such as new materials or production volumes that can dictate, force, enable or preclude the adoption of new technologies at the plant level.

Key constraints also vary somewhat across the three sectors. The availability of skills – for instance in mechatronics, programming and engineering, as well as soft skills – is a common constraint that cuts across all three sectors and countries studied. This is related to the availability of services, such as system integration, maintenance and training, which was cited as a key constraint by several automotive and F&B firms. Access to finance was cited as a bottleneck to technology adoption by locally owned firms in the automotive and F&B sectors, but not by subsidiaries of foreign companies and to a lesser extent in the T&A sector. In the auto sector, volume is the key constraint: the latest technologies in this sector require very large production scales to be viable and profitable investments, and these volumes are not attainable for many auto assemblers or component manufacturers across the continent. Where global HQs dictate the adoption of such technologies, this often leads to productivity-sapping underutilisation due to insufficient or volatile production volumes. Finally, T&A and F&B firms explained that the adoption of automation and digital technologies is hampered by unreliable or expensive electricity and internet connectivity in all three countries, but this was not a binding constraint in the auto sector.

## IMPACT OF TECHNOLOGY ADOPTION ON PRODUCTION, EMPLOYMENT AND SKILLS

The impact of new technologies on production is consistent across the three sectors: greater productivity, production capacity (in terms of output volumes and speed) and resource efficiency, with reduced input wastage. In addition, several T&A firms reported that adopting the latest technologies improved their image in respect of potential global clients and investors and this was a key motivation for adoption. In terms of the impact of technology on production flexibility, the evidence remains ambiguous: while T&A firms mentioned it as an important driver of technology adoption, auto manufacturers and their suppliers mainly experienced a negative effect due to rigid automation technologies and underutilisation due to insufficient volumes.

The adoption of new technologies is not leading to a net reduction in jobs among interviewed firms, but rather to a shift towards higher-skill tasks. In addition, the firms adopting new technologies are often already growing or grow because of technology adoption: this leads to the creation of new jobs within the firm at different skill levels, and workers displaced by automation technologies are, in most cases, retrained and/or redeployed into new tasks, complemented by new hiring. In this way, firm growth across the studied sectors is likely to mitigate the labour-displacing effect of new technologies. In addition, firms in the F&B and automotive sectors noted that the focus on retaining and retraining staff even when new technologies are adopted is significantly driven by the fact that these firms' (formal or informal) licence to operate in their host countries is linked to job creation. Others mentioned a "social responsibility" to create and retain jobs. However, while this is the aggregate picture, it should be noted that some technology-induced job losses are reported in the T&A and F&B sectors as firms adopt new automation technologies. It should also be noted that these job losses are generally occurring due to the adoption of 3IR technologies. 4IR technologies, in contrast, often create new higher-skill jobs needed to install, maintain and manage new advanced hardware and software as well as analyse the data it generates. These trends are expected to continue.

Large, leading firms across the sectors and countries studied unanimously reported an ongoing shift away from low-skill tasks and towards a greater need for employees with mid-level and advanced skills due to new technologies being adopted. As a result, manufacturers are experiencing a shortage of locally available skills in areas such as production-management software programming, machine maintenance and data analysis, as well as a lack of basic digital literacy for the operation of digital machinery (though digital literacy was notably not cited as an issue in Kenya). Going forward, advanced manufacturing firms in the auto, F&B and T&A sectors are likely to hire younger workers (who can more easily be trained in digital technologies), machine operators with a basic engineering diploma as a minimum requirement, and mid-level managers and technical specialists with more advanced skills in engineering and the other aforementioned areas.

Finally, the servicification of manufacturing is beginning to emerge in Kenya and South Africa at a small scale but appears almost non-existent in Ghana. There is significant job-creation and value-addition potential in manufacturing-related services in the three countries studied, including for export. This is particularly the case in Kenya and South Africa, where several locally owned "system-integrator" firms have emerged to support manufacturers in the installation and integration of 4IR technologies, the collection and processing of data from new devices, and in some cases even the development of proprietary software and hardware technologies. These services are both enablers of technology adoption and job creators in their own right. However, they require the existence of a robust manufacturing base that has the foundational productive capabilities required to adopt 4IR technologies.

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# Policy Recommendations

For most government leaders in Africa, job creation and economic transformation are two top policy priorities. The 4IR will increasingly force African policymakers to rethink their countries' economic development pathways. In particular, there is a growing anxiety that manufacturing can no longer be the main engine for job creation and economic growth in LICs as it was historically in virtually all of today's advanced economies. This section presents five key policy recommendations based on the study's findings:

- Pursue the window of opportunity to develop labour-intensive manufacturing sectors through smart industrial policies.
- Build a strong industrial base that is ready for 4IR-technology adoption.
- Support and encourage African manufacturing sectors to gradually upgrade into 4IR technologies.
- Foster the new skills needed in 4IR manufacturing.
- Manage the transition of labour into 4IR jobs and tasks.

## Pursue the Window of Opportunity to Develop Labour-Intensive Manufacturing Sectors Through Smart Industrial Policies

Many manufacturing activities – such as textile and soft-drink manufacturing – already require firms to employ highly automated techniques to be globally competitive. However, in a number of other subsectors, the comparative advantage of large-scale manual labour will remain relevant for some time, such as in the sewing of garments, the final assembly of cars and certain smaller-scale food-processing activities. A window of opportunity therefore exists to drive labour-intensive manufacturing growth through industrial policies that prioritise these subsectors.

While core activities in these subsectors are expected to remain labour-intensive for the foreseeable future, it is likely that even they will eventually become increasingly automated in the long term. For example, significant research and innovation are taking place to attempt full automation in garment manufacturing, including sewing.

While the technologies enabling this shift will likely remain more expensive than low-skill labour in many countries, industries will need to adapt as wages rise and technologies become cheaper. The inflection points at which automation technologies become more competitive than manual labour will occur at different times in different subsectors. As these inflection points approach, governments should support labour-intensive manufacturing sectors to shift into more automated processes (through technology adoption by existing firms as well as the entry of new, technology-intensive firms) while lowering the social cost of this transition for displaced workers. How governments can do this is discussed below.

## Build a Strong Industrial Base That Is Ready for 4IR-Technology Adoption

In the 4IR era, manufacturing will continue to be a core driver of economic transformation and a requirement for building a competitive and resilient economy. But 4IR technologies and capabilities build on 3IR technologies and capabilities: an economy cannot jump into the 4IR without a strong base of industrial capabilities. These include investment, technological and production capabilities, which emerge via “learning by doing” when firms engage in industrial activities in a supportive and competitive environment. This also applies to 4IR services sectors, which cannot emerge without a technology-intensive manufacturing sector to serve. Adopting the newest and most advanced industrial technologies will require existing manufacturing processes and capabilities in manufacturing industries.

Governments should adopt smart industrial policies to foster the development of competitive industries using the most appropriate technologies before moving into the most advanced emerging technologies.

Policies can foster the growth of competitive industrial capabilities through the entry, emergence and growth of manufacturing firms that become increasingly competitive through learning by doing.

Industrial policies should focus on fixing market failures, providing the public goods necessary for market development, and actively attracting investment to spur the growth of industrial ecosystems. Industrial policies should focus on attracting FDIs to these sectors while strengthening the business environment and its enablers (for example, finance, infrastructure, labour and energy). Therefore, policymakers should work on building domestic linkages with local firms and manufacturers to ensure that local firms are prepared to engage in GVCs and have an opportunity to acquire technological and knowledge capabilities.

Smart industrial policies require a careful prioritisation of high-growth sectors. The selection of sectors is important for at least three reasons. First, LMICs generally have very limited fiscal resources, due to the small size and low productivity of the formal economy; second, there is generally limited management and technical capacity within governments during the early stages of economic development; and third, efficiency gains can be attained by focusing on high-potential sectors and activities in which countries have a clear chance at developing a competitive advantage. Governments can make use of a range of methodologies for identifying economic sectors that present the largest opportunities as well as demonstrating a reasonable feasibility of developing competitive advantage in a given country. It should be noted that industrial policy is an active policy choice that involves taking risks but with high payoffs in terms of new industrial capabilities and job creation, among others.

## Support and Encourage African Manufacturing Sectors to Gradually Upgrade Into 4IR Technologies

Building or maintaining a globally competitive economy will increasingly require embracing 4IR technologies. In some sectors – such as large-scale beverage production – the use of advanced technologies is already widespread. In others, 4IR technologies are gradually being adopted and

leading to productivity and efficiency gains. African manufacturing sectors will need to embrace 4IR technologies to keep up.

Not embracing automation and 4IR technologies more broadly is likely to lead to the unintended consequence of lagging competitiveness: industrial sectors and firms risk falling behind and losing their ability to compete internationally. So, while not embracing automation may work temporarily for firms serving domestic markets, it is likely to lead to job losses and missed job-creation opportunities in export-oriented manufacturing in the medium to long term.

In most manufacturing subsectors, firms must embrace and effectively apply frontier technologies to some extent in order to become or remain globally competitive. The most advanced African manufacturing firms are growing and becoming more competitive thanks partly to the integration of productivity-enhancing technologies. Similarly, in subsectors that are still labour intensive, such as garments, in the medium- to long-term future automation technologies should be expected to gradually become competitive with manual labour.

As mentioned above, the new 4IR manufacturing-related service sectors that are expected to be major job creators in the future will not develop in the absence of a strong technology-intensive manufacturing sector. Therefore, slowing down technology adoption in manufacturing would also jeopardise African countries' chances to become competitive in these new service sectors and would represent an opportunity lost in terms of job creation and economic transformation.

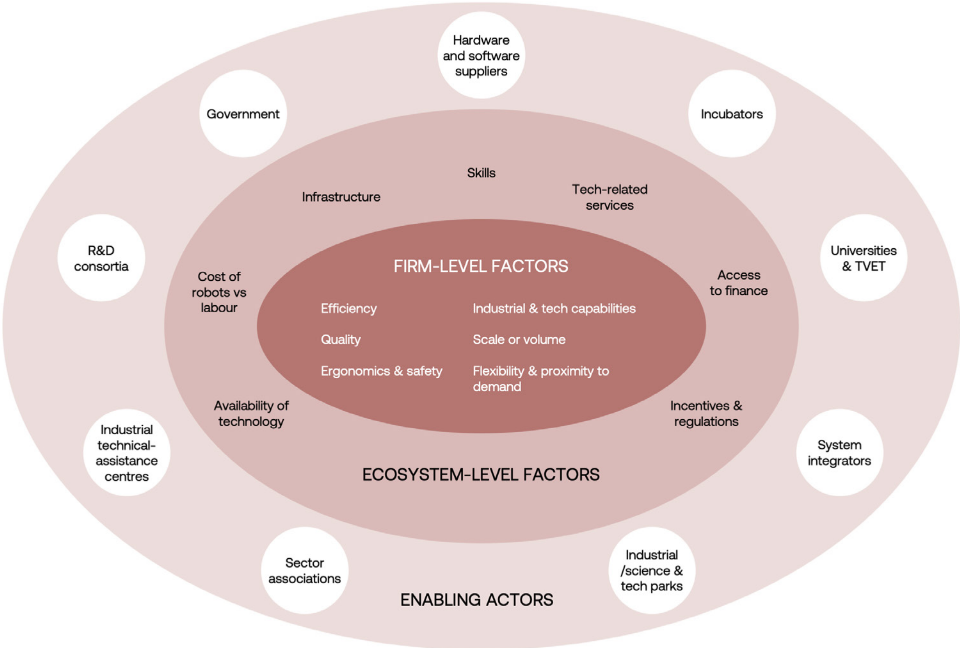
Policy has a central role to play in building an ecosystem that fosters the adoption, absorption, adaptation and innovation of 4IR technologies in manufacturing. African manufacturing sectors will need to continue approaching the global technology frontier to further enhance their scale and international competitiveness, therefore creating more job opportunities. There is an urgency to this need: without active policies to foster technological catch-up, the productivity and competitiveness divide between manufacturers in Africa and those at the global frontier is likely to continue growing and, in the 4IR, this divergence may accelerate. African governments should therefore foster technology adoption and technological learning through smart industrial policies that help lift the binding constraints to technology adoption.

Smart industrial policies should also target technology-related services that are expected to drive job-creation opportunities in the future. Technology-related services are both an enabler of 4IR-technology adoption in manufacturing and a tradable, job-creating sector in their own right. They include system integration, software engineering, data analytics, spare-parts supply, and machine repair and maintenance. For example, South Africa targets knowledge-intensive manufacturing-related services, including robotics, 3D printing and IoT technology.

Technology adoption is influenced by the industrial ecosystem, which consists of several enabling actors and functions. Enabling actors include government, industrial-development centres, industrial parks, sector associations, universities and others. Enabling functions include regulations, incentives, infrastructure, skills and so on and can apply at the firm level or ecosystem level. Below, we discuss the policy tools for enabling functions that governments can implement to foster technology adoption within their ecosystems.

FIGURE 16

# The industrial ecosystem supporting technology adoption




Note: Policies addressing ecosystem-level factors often need to be tailored to firm- or sector-specific needs, for example in skills development, where technology-related skills requirements are likely to vary across firms and sectors.

Source: Authors

## FIRM-LEVEL FACTORS AND POLICY LEVERS

### Achieving Economies of Scale

The most fundamental driver of production scale is general industrial competitiveness: when domestic firms can compete with international firms to produce goods for local, regional and global markets, they attain the scale that makes advanced technology adoption viable.[9] Specific industrial policies can spur higher volumes. These include:

- **Free-trade agreements.** Trade agreements such as the African Continental Free Trade Area (AfCFTA) as well as regional (for example, the East African Common Market Protocol), bilateral and multilateral agreements such as AGOA can provide access to larger markets, which in turn provides an opportunity for firms to build competitive industrial capabilities and achieve economies of scale – two key enablers of technological upgrading.

- **Competitiveness-improvement programmes.** Taking advantage of large export markets requires achieving international competitiveness. Active public programmes can provide technical support to industrial firms on the improvement of management and production skills and processes to achieve greater competitiveness. For example, the US's Manufacturing Extension Programme runs a countrywide network of industry experts that work side-by-side with SME manufacturers to reduce costs, improve efficiencies, upgrade employee skills, innovate new products and identify new markets in order to improve competitiveness. In a more targeted example, the Kenyan government works with the Kenya Association of Manufacturers to provide subsidised energy audits that help industrial firms identify how they can increase their energy efficiency while reducing operating costs. This sometimes directly leads to the adoption of 4IR cyber-physical production-control systems aimed at energy-use optimisation.

- **Direct incentives to encourage economies of scale.** In South Africa, for example, the automotive industry policy encourages "one model per factory", whereby each car-assembly plant specialises in a single car model instead of producing a wide range of models.

- **Local content requirements and higher tariffs on carefully selected imports.** Import protection can support local capabilities development in specific circumstances when they are time bound and where domestic producers have a reasonable chance at developing competitive capabilities. In other cases, they often fail and come at a high social and economic cost. In Kenya, some firms reported achieving new levels of production volume thanks to new local-content requirements that spurred greater demand for local production. Firms in Ghana asked for increased import duties on used cars, used clothing and fabrics.

- **Ensuring the rule of law and good governance.** In some cases, the greatest impediment to firms scaling up is a fear of predatory behaviour by the state: some larger firms in Ghana mentioned a fear to expand because “the government will come knocking”.

### Generating Demand for Technology-Related Services

This can be achieved through a voucher-based subsidy system for certified locally provided services. Qualifying manufacturing firms would be given vouchers with a certain monetary value that they can use to purchase 4IR-related services, such as system integration, installation, data analysis, training or maintenance services, from certified local service providers. Certifying local providers ensures quality and can be linked to training for those providers, for example, in partnership with a multinational corporation (MNC) that provides technology such as Schneider Electric – which can use their technology assets and know-how to help upskill local service providers who later become their partners.

### R&D Grants and Tax Incentives

R&D grants and tax incentives have been widely used as a tool to incentivise investment in innovation and access to technology. R&D tax incentives are an indirect mechanism of supporting firms to carry out R&D by effectively lowering its cost to firms (Koehler et al, 2012). Grants (or contracts) are a more direct means through which government can induce R&D in the private sector (Koehler et al, 2012). Tax incentives for R&D can take different forms, including a tax credit allowing firms to directly deduct a specific share of their R&D from corporate tax bills, or a patent box, which grants a lower corporate tax rate on profits generated from patents. Tax incentives can also help firms import new 4IR technologies by reducing import tariffs on certain categories of hardware and software technologies. Automotive firms in Ghana, for instance, asked for reduced import duties on imported machinery.

**Building Firm Awareness and Capabilities**

4IR-technology adoption "requires concentrated efforts to raise firms' awareness on the potential use and benefits of these technologies together with the facilitation of funding for their adoption" (UNIDO, 2020). Policy tools aimed at fostering awareness of new technologies and industrial/technological capabilities at the firm level include:

- **Trade shows, technology fairs and international platforms to create awareness about the latest tech available for the industry.** These platforms allow firms to increase their awareness and understanding of the latest technological progress and innovation.

- Expand the scope and number of **research institutions working on 4IR technologies** to provide the local know-how needed for the absorption and adaptation of 4IR technologies (UNIDO, 2020).

- **Public-private R&D consortia** leading large projects that are difficult for the private sector to finance by itself. These consortia can help pool knowledge from private firms, universities and public R&D agencies. They can also act as a monitor and interpreter of global cutting-edge R&D activities and help local manufacturers adopt and absorb new technologies. For example, Make in India public R&D centres showcase practical applications of 4IR technologies to raise awareness and build capacity among local manufacturers, with each regional centre focusing on technologies relevant to local manufacturing specialisations and firm competences. In Malaysia, the Malaysia Automotive, Robotics and IoT Institute is an agency under the Ministry of International Trade and Industry with strong ties with the private sector. The agency serves as the focal point, coordination centre and think-tank for the nation's automotive industry and functions to enhance technology, human capital, supply chain, market outreach and aftersales capabilities of all automotive stakeholders and ecosystems. In Vietnam, public and private actors are collaborating to grasp the latest technological advancements in manufacturing and develop interventions and programmes to improve the technological competitiveness of industrial firms in the country (UNIDO, 2020).

- **Private-private technology partnerships and dissemination.** Dissemination of technology awareness and capabilities often occurs through large technology leaders sharing know-how with smaller firms. These lead firms can be hardware- or software-technology providers or leading technology adopters. Policy can encourage these kinds of business-to-business linkages by collaborating with technology lead firms to finance technology transfer, support and mentoring to smaller firms.

## ECOSYSTEM-LEVEL FACTORS AND POLICY LEVERS

### Technology R&D and Incubation

Several policy tools can be implemented to improve the availability of technology, notably investment in R&D in universities and the establishment of technology transfer intermediaries such as technology-transfer offices (TTO) in universities. TTOs are responsible for matching the supply and demand for technology and innovation. For instance, in Germany, the Patent and Valorisation Agency, Mecklenburg-Vorpommern AG is responsible for the screening, patenting and commercialisation of research results stemming from the regional universities and research institutes in one of Germany's federal regions. The agency assists researchers with the commercialisation of their research, including on 4IR technology applications. Another example is Uruguay's Centre for Industrial Automation and Mechatronics (CAIME), a collaboration with UNIDO and the German industrial control and automation company Festo. CAIME is a public institution that provides technical training in 4IR technologies and encourages Uruguayan manufacturers to adopt smart factory processes (UNIDO, 2020). Another policy tool is the establishment of industrial R&D institutes to incubate tech-oriented firms in manufacturing and tech-related services. Incubation for startups can include a range of support mechanisms such as office space with free internet and electricity, mentoring, legal support for startups, seed grants or concessional investment, technical advisory, commercialisation of public R&D (for example, a prototype software tool developed in a public R&D institute), commercialisation of a 4IR technical advisory service out of a public R&D institute (for example, Cambridge Institute for Manufacturing).

### Public Procurement to Create Demand for Innovation and Technology-Intensive Activities

Public-procurement interventions can stimulate markets for innovation and technology by using the purchasing power that the government has, and by using innovation to devise cost-effective solutions for the delivery of essential public services. Governments can also support in the developing of standards and regulations that could foster innovation and technology adoption. For instance, procurement for innovation is an element of the European Commission's Action Plan to raise R&D expenditure to 3 per cent of GDP in EU member states.

### Infrastructure

- **High-speed internet access** is vital to digitalise manufacturing. However, in most of Africa, internet access is more expensive than in many places. Policy can step in by making the internet more affordable, for instance through subsidised rates in priority locations (such as industrial or technology parks) and through incentives to network providers to expand access to rural areas. Firms in Kenya asked for stronger digital infrastructure.

- **Reliable and affordable electricity** is a basic necessity for any technology adoption in manufacturing. Cash-strapped governments are usually unable to provide competitively priced, reliable electricity countrywide in the short term, but industrial parks or science-and-technology parks aimed at technology-intensive manufacturing can be prioritised because of the positive spillovers these firms would create for the rest of the economy. South African interviewee firms asked for energy subsidies and stabilised electricity (the latter also in Kenya).

- **Data centres** can be described as the new industrial parks for the 4IR technologies. Data are globally recognised as being the new oil or gold and many 4IR technologies are built around data collection and analysis to improve current production systems. Data centres become, therefore, a foundational infrastructure for 4IR, and policymakers in LMICs need to invest in building them and ensuring that companies have access to their services.

- **Infrastructure and machinery sharing** is an important strategy that can help improve firms' access to affordable 4IR-enabling infrastructure. One way this can be achieved is through industrial or science-and technology-parks or zones where manufacturing firms (and potentially their service providers) cluster together. Infrastructure sharing can achieve cost savings by allowing companies to share the costs of infrastructure such as telecom networks and data centres, efficiency gains by ensuring that infrastructure, such as a data centre, is used at capacity by multiple firms rather than being underutilised by one firm, and improved access to infrastructure by small or remote firms by making it more feasible to extend a network to serve a group of companies as opposed to just one.

- **Industrial and technology parks** with facilities where firms can share use of or co-own expensive machinery (for example, embroidery machines in T&A to make samples for clients).

**Data-Localisation Requirements**

Data-localisation laws require certain data to be stored or processed within a specific country or geographic location. These laws are typically implemented for reasons of national security, data privacy and/or infant-industry protection. They essentially force or incentivise manufacturing firms to buy data-storage and processing services from local firms rather than foreign ones. This can support the development of technology-related services that supply tech-intensive manufacturing firms. For example, Indonesia's Minister of Communication and Information Technology issued a regulation requiring companies to store and process certain categories of data within the country, including data generated by 4IR technologies, unless certain conditions are met. It is important to note that data-localisation requirements can impose a significant cost on businesses as they require the development of local infrastructure and skills that may be more cheaply available abroad. As such, data localisation-requirements should be carefully considered given the capacity of local firms to deliver data-storage and processing services and, in most cases, accompanied by public support on training and infrastructure, especially data centres.

**Access to Finance**
In many countries, national development banks or sovereign-wealth funds provide:

- **Concessional finance** (for example, seed venture capital, blended finance, low-interest loans or loans with reduced collateral requirements, or concessional lines of credit to commercial banks). For example, South Africa's Industrial Policy Action Plan 2017/18–2019/20 proposes a Sovereign Innovation Fund to provide funding certainty for high-technology projects, particularly in smart manufacturing-related areas, with seed investment of about $111 million pledged for the 2019/2020 fiscal year and aimed at the adoption of locally developed technologies (UNIDO, 2020).

- **Loan guarantees** to priority sectors, including for the acquisition of new capital goods such as 4IR technologies.

## Foster the New Skills Needed in 4IR Manufacturing

4IR technologies are not primarily about replacing human labour with machine work; rather, they are about adding a digital layer to existing manufacturing technologies to enable increased production efficiency, scale, quality, versatility and so on. The evidence shows that, while automation in manufacturing does create some job displacement in specific activities, the net effect on employment remains negligible or even positive. This is due to some technologies being labour-complementing and the ability of firms to reskill and redeploy displaced workers as the company grows, thanks to technology-enabled upgrades in productivity, quality and scale. Governments and public authorities can play an important role in supporting firms in this process.

However, technology adoption is fundamentally changing the skills profile of manufacturing labour in Africa and globally. Increasingly automated production lines require fewer manual workers and more engineering and IT graduates. The successful adoption and use of 4IR technologies requires machine operators, managers, analysts, engineers and service providers with analytical skills; specific technology-related skills including STEM and ICT-related skills; and soft skills (UNIDO, 2020). Factories are also hiring more young people familiar with digital technology.

The servicification of manufacturing is beginning to emerge at a small scale, especially in Kenya and South Africa, where locally owned system integrators have emerged to support manufacturers in 4IR technology installation and integration, data collection and processing, and proprietary software- and hardware-technology development. This means that some jobs are leaving the factory and moving into outsourced service firms.

Governments should foster the development of 4IR skills in close collaboration with manufacturers and technology leaders. Policymakers must therefore invest in workforce skills development in order to build 4IR-ready talent. Policy interventions to address the 4IR skills gap might include:

- **Revising the broad education curriculum to strengthen general STEM and ICT learning**, with courses on data analysis, robotics, etc., as well as a stronger focus on practical skills versus purely theoretical training, with involvement from the private sector through talks, industrial visits, curriculum co-design and so on.

- **Fostering soft-skills learning at all levels of education.** Soft skills or cognitive skills are expected to gain momentum and importance. Because tasks that rely heavily on complex soft skills are unlikely to be automated, the demand and premium for these skills is likely to grow. The quality and composition of human capital in African countries will play a significant role in the adjustment of their economies to the future of work and to the technological revolution.

- **Public or public-private TVET and university courses.** This can include sector-specific training centres. These sometimes work best with the involvement of MNCs that bring international exposure and experience with 4IR technologies and skills. The need for sector-specific skills is best addressed through close collaboration between government and industry.

- **Incentivised apprenticeship and on-the-job training programmes.** For example, the Kenya Association of Manufacturers is working with Japan International Cooperation Agency (JICA) to improve access to technical jobs and economic opportunities for young people in Kenya. It entails working with industries, TVET institutions, government agencies in charge of TVET and other implementing partners to place graduates in industry apprenticeships and subsequently jobs. In another example, many US states run a workforce-training fund that provides financial assistance to manufacturers to offset the cost of on-the-job training and apprenticeships aimed at upgrading their employees' skills, including in the use of new technologies.

- The absence of locally available trainers in the use of 4IR technology is a market failure that can be addressed through **targeted, time-bound training subsidies** (e.g., a voucher system for firms) and/or a **public R&D/ technology institute** that provides subsidised or at-cost training services to companies.

- **Incentives or requirements for technology and skills transfer** from MNCs to local firms and employees, which could include MNCs providing technology-training to local suppliers, service providers and their own local employees. Requirements for training or technology transfer can be included as a condition for a multinational firm's investment licence in a country. Incentives can take the form of tax benefits such as a payroll tax deduction for local employee-training expenditure or a direct government subsidy to cover part of the training cost.

## Manage the Transition of Labour Into 4IR Jobs and Tasks

The above mentioned shifts in the skills profile of manufacturing as well as in the organisation of production will continue to create a need for new skills while also causing labour-market disruption and adjustment costs, including the displacement of low-skilled workers. Policies are also needed to manage these labour-market shifts.

**Active labour-market policies** are policies and programmes adopted to improve the functioning of the labour market and its outcomes. In the context of the 4IR, policymakers should focus on the re-skilling and upskilling of displaced workers, as well as on improving the job-search process.

- **Job-search assistance.** These services help individuals find new jobs that match their skills and qualifications, especially after they have been displaced by technological changes. They may also provide assistance with writing CVs and interview skills, as well as offering counselling and coaching on job-search strategies and career development, and other job-search-related activities.

- **Subsidised employment programmes.** These programmes aim to reduce the cost of recruiting workers, in order to increase their access to job opportunities. These programmes exist both in the private and public sectors and often target workers with no prior experience or workers in long-term unemployment.

- **Skills support for impacted workers.** These programmes can be designed and delivered with firms and can support workers whose jobs are at risk of being automated either by reskilling and retaining those workers within their current firm or reskilling in order to find new work outside the current company. The first approach is sometimes referred to as "retrain and retain", which encourages companies to invest in the training and development of their current employees instead of laying them off or replacing them with new hires. One example of a successful government-funded "retrain-and-retain" scheme is the US Trade Adjustment Assistance (TAA) programme. The programme provides assistance to workers who have lost their jobs or had their hours reduced as a result of increased imports or offshoring of production. The TAA programme provides a variety of benefits including training and re-employment services, unemployment benefits and tax credits to employers. According to the US Department of Labour, the programme helped more than 2 million workers return to employment between 1974 and 2014 (Department of Labour, 2014). Policies can also shift the responsibility of technology-related training directly on to employers, for example by requiring firms to notify employees and unions about the adoption of new technologies and provide assistance to employees to reduce their risk of unemployment. The second approach refers to public reskilling support for workers who have been laid off or are expecting to be laid off due to automation to ease their search for new employment.

**Social-protection measures** typically provide a source of income for workers who have lost their jobs as a result of technological changes. They can also provide a cushion for workers as they transition to new employment opportunities. Policy tools include the establishment of unemployment insurance or social safety nets. In many African countries, these policies are still not operational and the 4IR and its adjustment costs will increase the need for such social measures.

## Delivery Mechanisms for Industrial Policy in the 4IR

Industrial policies in the 4IR era need to focus on fostering technologies, learning and adaptability. Their success, like traditional industrial policies, will depend on the existence of strong political support and coordinated government action. Tech-oriented industrial policies will also require a certain level of tech-embeddedness, which calls for the existence of specific delivery structures, particularly:

- **Implementation of effective delivery mechanisms.** For industrial policies focused on technology adoption, there is a need for strong market surveillance and monitoring to identify new frontier technologies and pathways to their adoption in the ecosystem. This requires strong technical expertise with the right delivery structures that will enable leadership to monitor progress closely, while communicating effectively with all the implementing agencies.

- **Establishment of a Chief Scientist's Office.** This office can play the role of "technology monitor" with the objective of identifying frontier technologies and their application in industrial activities. This office needs to be equipped with the right skillsets and processes. For instance, the governments of Israel and Singapore have established a Chief Scientist (CS) whose role is to promote and support scientific research and innovation, particularly in areas of strategic importance to the country's economic development. In Singapore, the CS sits within the Ministry of Trade and Industry and oversees the National Research Foundation, which is the main government agency responsible for funding and coordinating research and innovation across the country. The CS also serves as a liaison between government and academia. In Israel, the CS sits in the Ministry of Economy and Industry and is responsible for promoting and supporting R&D with a focus on high-tech and innovative industries. The CS also works to foster R&D collaboration between academia, industry and government and coordinates the Israel Innovation Authority. Both CSs play a pivotal role in developing and implementing policies and programmes aimed at driving global competitiveness and innovation in the countries' most high-tech industries. They also work to attract investment in R&D and promote collaboration between researchers, industry and government.

- **New forms of public policy and public–private partnerships** with coordinated support from different government agencies. Implementing the policy measures discussed in this paper requires effective cross-government coordination. It also often entails bilateral or trilateral partnerships across government, knowledge-generating institutions such as universities or R&D centres, and the private sector.

- **International partnerships.** A series of 4IR technology-adoption case studies carried out by UNIDO (2020) concluded that companies tend to access new 4IR technologies through an external partner such as a university, foreign investor or global technology leader. This typically occurs through a cooperation agreement and is often supported by government. International collaborations can accelerate learning curves for domestic firms adopting 4IR technologies. Partnerships can also be leveraged to carry out studies on the latest smart-manufacturing technologies. For example, a partnership between Microsoft and Fundación Chile supported a study on the state of cloud computing in the country. The study assessed the level of cloud-computing adoption and identified the chief barriers to adoption. 4IR partnerships between middle-income country firms and German stakeholders have been particularly common. These often involve both countries' chambers of commerce, specialised research institutes, large multinational leaders in 4IR technologies, the Fraunhofer Institute and Acatech (the German Academy of Science and Engineering). These partnerships have mapped 4IR adoption in local industries, identified high-potential sectors for technology adoption and established technology-transfer schemes. (Santiago, 2018; UNIDO, 2020).

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# Endnotes

1 Mechatronics, also called mechatronic engineering, is an interdisciplinary branch of engineering that focuses on the integration of mechanical, electrical and electronic engineering systems, and also includes a combination of robotics, electronics, computer science, telecommunications, systems control and product engineering.

2 The exception is the final stage of car assembly, which is still relatively labour-intensive in the African plants we visited compared to the global technology frontier (however, at this stage, there has in fact been some reverse automation globally due to challenges, e.g., with reduced production flexibility).

3 In addition to these technologies, biotechnological advances like molecular nanotechnology / gene editing / biomaterials are often mentioned in discussions of the 4IR, which is sometimes defined as the merging/blurring of the digital, physical and biological worlds. An examination of biotechnologies and their impact on manufacturing in Africa was beyond the scope of this study.

4 AI and machine learning are closely related, but they are not the same thing. AI refers to the overall field of creating intelligent machines, while machine learning is a specific method for achieving AI. There are many other approaches to achieving AI besides machine learning, such as rule-based systems and evolutionary computation.

5 Although this assertion was challenged by several scholars in the 1980s and 90s (Zammuto & O'Connor, 1992; Suarez et al, 1996; Jaikumar, 1986).

6 FBU (fully built units) refers to a motor vehicle being exported as a complete car fully assembled, i.e., not requiring any further assembly before being sold to the final customer.

7 CKD (completely knocked down) refers to a motor vehicle being delivered in parts and assembled afterwards.

8 http://gerpisa.org/node/6415

9 This is, to some extent, a chicken-and-egg problem, but 4IR-technology adoption is not the only – and often not the most important – driver of competitiveness (think tax incentives, raw-material costs, transport costs, utility costs, skilled managers and workers, efficient production processes, etc.).

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