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New Technology, Entrepreneurship and the Revival of Manufacturing in Africa: Opportunities for Youth and Women?

by Wim Naudé
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New Technology, Entrepreneurship and the Revival of Manufacturing in Africa: Opportunities for Youth and Women?

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Abstract. The digitization of the economy and advances in smart materials are transforming the nature of manufacturing. This is often described as features of the "Fourth Industrial Revolution" or Industry 4.0. For African economies, not yet having industrialized, this is of great importance, especially given the challenge of youth job creation and the need for gender equality. A combination of Industry 4.0 technologies and a resurgence in tech-entrepreneurship will have four broad impacts on manufacturing in Africa (i) the sector will continue to grow significantly in terms of value added; (ii) net job creation will be positive; (iii) it will stimulate technological and complex skills development, as well as (iv) investment in supportive infrastructure. The opportunities that these impacts will have for youth and women are outlined in the following report. Youth and women stand to benefit because of the ability of manufacturing to provide quality, high-productivity jobs in urban areas, to stimulate the development of human capital, including gender equality, and to provide, through new technologies that "democratizes" production for small businesses, new opportunities for both male and female entrepreneurs. The author also identifies policy support measures, to help realize these outcomes.

Key words: Technology, Industrialization, Sub-Saharan Africa, Innovation, Development, Labour Markets

JEL Classification Codes: O14, O25, O33, O38, O55, J24

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1. Introduction

Industrialization, and in particular the development of the manufacturing sector, remains a high priority for African countries. One of the main reasons for this is the need for sustainable creation of quality jobs for a growing labor force – population growth in Africa has been amongst the fastest in the world. Between 2010 and 2020 an estimated additional 170 million labourers will enter Africa's labor force (Fox et al., 2013). More of these will search for jobs in cities, as rural-urban migration continues unabated. The number of people in cities in Africa is expected to triple by 2050 (Freire et al., 2014). Of these, a substantial share will be young people: already in 2017 approximately 43% of the continent's population was younger than 15 years of age, making it the world's youngest continent.

When countries in Europe, North America and East Asia (most recently China) experienced similar demographic pressures in the past, the growth and development of their industrial sectors[1], specifically manufacturing, enabled them to create jobs and welfare at the same time. It allowed the structural transformation of their economies from agriculturally-dominated, rural-based economies to modern industrial economies.

Until the present, most African countries have however not yet industrialized. Even where some limited industrialization has occurred, it has recently been concluded that (premature) de-industrialization has set in (Rodrik, 2015; Timmer et al. 2014). Some have even questioned whether Africa can ever industrialize (Page, 2012). Others have concluded that manufacturing is not as important anymore and that developing countries (such as those in Africa) should not even try to industrialize, but be content to by-pass the typical patterns of structural adjustment by rather focusing on services (IMF, 2018). For instance Newfarmer et al. (2018) argue that African economies should promote not manufacturing per se, but rather activities that have the "characteristics of manufacturing". Hallward-Driemeier and Nayyar (2018) conclude that, in general for developing countries, manufacturing will be less important in the future and also more difficult or complex to steer through government policies. There is thus a prominent narrative that Africa should pursue "structural adjustment without industrialization" (Gollin, 2018).

This paper advances an alternative narrative, one that is more optimistic about the prospects for manufacturing in Africa. Moreover, it is argued in this paper that the revitalization of manufacturing in Africa is already underway, facilitated by new technologies (due to digitization

[1] As per the ILO definition, industrial sectors consist of manufacturing, construction, mining and quarrying and electricity, gas and water supply.

and smart materials) and a more vibrant entrepreneurship scene. Africa's growing middle class is providing a supportive base for the continent's first generation of indigenous tech-entrepreneurs.

For youth[2] and for women, often marginalized groups, the new pathways of industrialization opened up by new technology and more vibrant entrepreneurship offer promising opportunities. This is because of the ability of manufacturing to provide quality, high-productivity jobs in urban areas, to stimulate the development of human capital, including gender equality, and to provide, through new technologies that "democratizes" production for small businesses, new opportunities for both male and female entrepreneurs.

The current generation of African youth may be especially ready to take up this challenge, as they form a central portion of what has been called the world's "digital natives" who have, compared to the older generation, been more exposed to modern digital technology (Moran, 2016). As Azoulay et al. (2018:2) put it: "among the advantages of youth in technology and innovation, young people are sometimes argued to be cognitively sharper, less distracted by family or other responsibilities, and more capable of transformative ideas". In this perspective, Africa's large youth population is one of its major assets, and its hope for the future.

The rest of this report is structured as follows. Section 2 motivates the need for industrialization, given the demographic and development challenges that African countries face, and the implications of these challenges for labor markets. Section 3[3] describes the new technologies that are driving what has been called the new industrial revolution, or "fourth industrial revolution". Then, in section 4, the relevance of these technologies for African development are pointed out. Section 5 describes the resurgence in tech-entrepreneurship in Africa. Section 6, the core of the report, brings together new technologies and vibrant entrepreneurship, and identifies the likely impact that these will have on the future of industrialization in Africa, and how it may allow Africa to face its development challenges; in particular to provide jobs to youths and to promote gender equality. Section 7 concludes.

[2] In this paper "Youth" is defined, following the International Labour Organization (ILO) and UNESCO, as persons between the ages of 15 and 24 years.
[3] Sections 3 to 5 of this paper rely on Naudé (2017) and Naudé (2019).

2. Demographics and Development: The Challenge

2.1 Demographic distinctions: fast, young, and rural

There are four aspects of the demographics of African countries that are distinct, compared to the rest of the world.

The first is that population growth in Africa has been amongst the highest in the world over the past half a century. The African population has tripled in size since 1960. This means that Africa is, with just more than 1 billion people, the region with the second largest population after the East Asia and Pacific region.

Second, Africa has a greater proportion of young people in its population than any other region in the world. In 2017, around 43% of its population were younger than 15 years of age. This means that the population will continue to grow into the near future, and that the numbers of new job seekers will increase: an additional 170 million workers will enter Africa's labor markets between 2010 and 2020 (Fox at al., 2013).

Third, the majority of Africans are still living in rural areas (62%) – a significantly greater share than in any other region of the world (for instance it is only 42% in East Asia and 20% in Latin America). Moreover, the rural population in Africa is continuing to expand by an average of almost 2% per year, while in most other regions of the world the share of the rural population is either contracting or stable. Thus, the absolute size of Africa's rural population is set to increase, at least until 2030.

Fourth, Africa's population is largely employed in the agricultural sector. In 2017 agriculture provided 57% of all jobs in SSA – a share much greater than in any of the world's other regions and much higher that the world average of 26%.

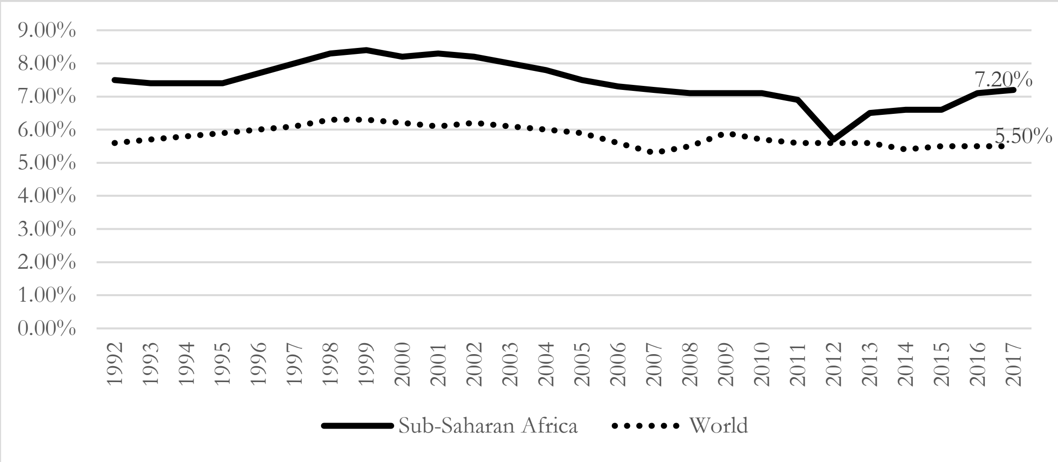
These demographic distinctions have implications for labor markets – a topic that will be explored in the next sub-section.

2.2 Implications for labor markets: (youth) jobs, gender, cities

Having the world's second largest population, the world's fastest growing population, its youngest population, and its most rural population, has three important implications for its labor markets.

First, there is the job creation challenge. More jobs – quality, stable jobs – are needed, as is suggested not only by the large number of new labor market entrants, but called for by the fact that the average unemployment rate in Africa is already higher than the global average, as *Fig.1* shows.

Figure 1: Unemployment rates in Sub-Saharan Africa and the World, 1992-2017



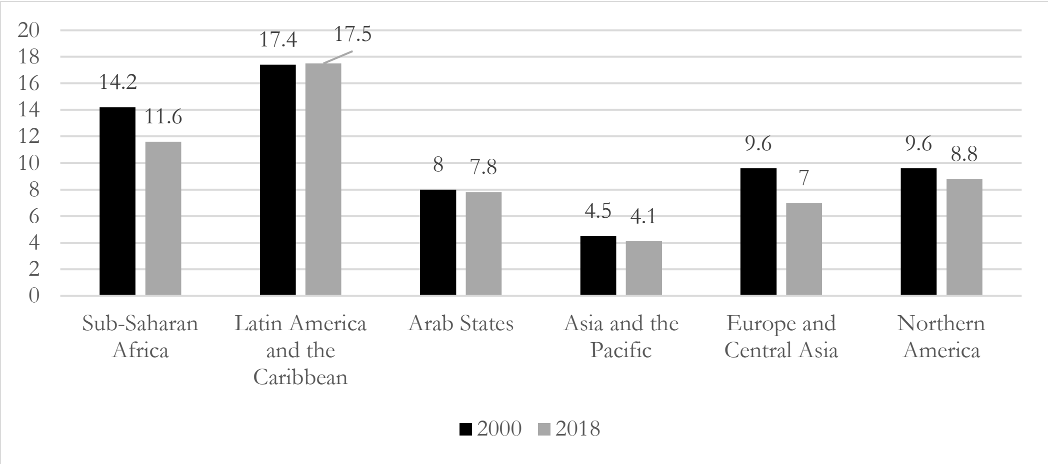
(Source: author's compilation based on data from International Labour Office, Trends Econometric Models (ilo.org/wesodata)

Moreover, more proportionate jobs are needed for youths. This is a particular challenge, given the fact that youth unemployment rates worldwide are (at a world average of 12%) around 3 times higher than adult employment rates. *Fig. 2* shows that Sub-Saharan Africa has the second highest youth unemployment rates in the world, after Latin America and the Caribbean region (LAC). Often, youth are not in employment because they are in education. A more serious cause for concern then are the numbers of youth that are not in either employment or education. This is referred to as the NEET rate – the rate of youth not in education, employment or training. In many African countries this rate is amongst the highest in the world, for instance in Zimbabwe the NEET rate is the highest at 48,5%, followed by Mauritania (39,5%), Senegal (36,2%), Côte D'Ivoire (36%) and Botswana (35,5%).

The imperative to address youth unemployment is not only to tackle poverty, but also to reduce the potential for social and political instability. It is in particular unemployed young men that pose a risk in this regard. The UNDP (2017:26) notes with respect to young men in Africa, that in "reality there are significantly more male than female members of violent extremist groups" and that the great majority of these men were younger than 30 years of age. In the UNDP (2017) Africa sample, 81% of all members of violent extremist groups were male and 53% were recruited between age 17 and 26. In 2015, the "global economic costs of violent extremism totaled approximately USD 89.6 billion" (UNDP, 2017:13). The cost of the unemployed youth is clearly significant.

A positive implication from *Fig. 2* is that the youth unemployment rate in Africa has declined from 14,2% in 2000 to 11,6 % in 2018, despite high population growth. This is partly due, as will be shown below, to the revitalization of many African economies in recent years, partly due to higher growth (up to 4% on average) in manufacturing and a more vibrant entrepreneurship scene.

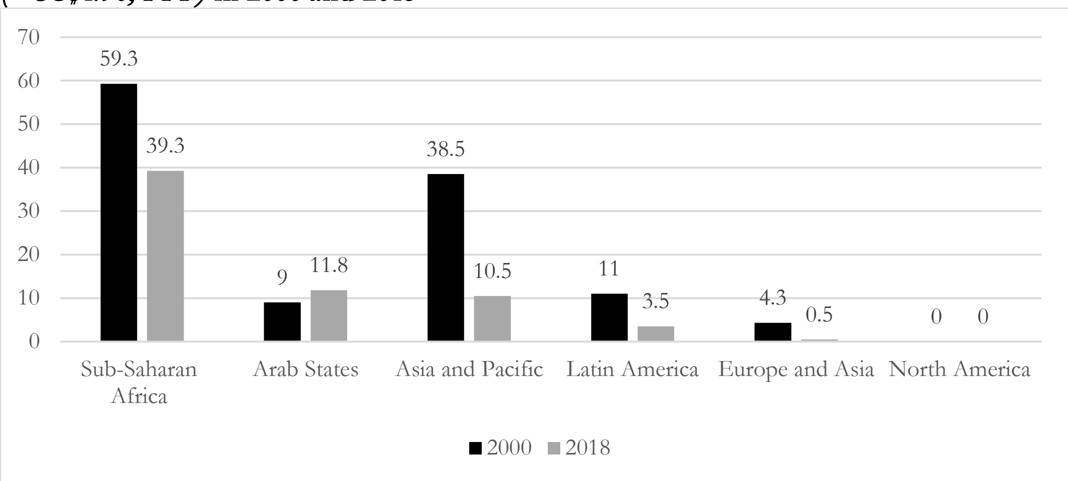
Figure 2: Regional differences in youth (aged 15-24) unemployment rates, 2000 and 2018



(Source: author's calculations based on ILO labour database)

The challenge however, is not only providing jobs to the youth, but also to provide better quality jobs – including jobs that allow workers to increase their productivity and wages. The need for this is reflected in the fact that the youth in employment in Africa tend to earn not enough – almost 40% of working youth in 2018 were in extreme poverty, the highest of any region in the world (*Fig. 3*).

Figure 3: Regional differences in working youth (ages 15-24) that are in extreme poverty (<US$1.90, PPP) in 2000 and 2018



(Source: author's calculations based on ILO labour database)

In this report it will be argued that the manufacturing sector offers potential better working conditions and quality jobs, so that development of this sector would be a potentially important way of creating opportunities for the working youth to escape from extreme poverty.

Second, there is the gender equality challenge. The current structure of most African economies, being dependent on smallholder agriculture, requires special consideration of the role of women. For a start, as *Fig. 4* shows, women are more likely than men to be unemployed.

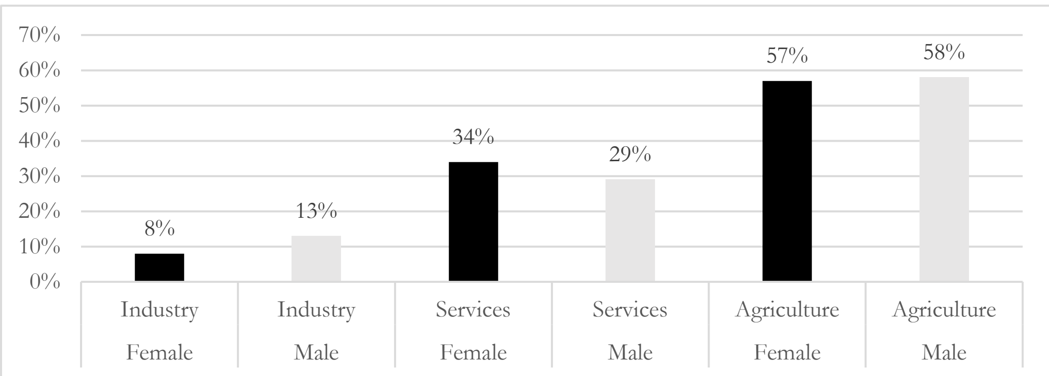
Figure 4: Unemployment by sex in Sub-Saharan Africa, 1992-2017

(Source: author's compilation based on data from International Labour Office, Trends Econometric Models (ilo.org/wesodata)

Not only are women currently more likely to be unemployed, they are also more likely to be in vulnerable employment than men. For instance, the ILO estimates that in 2017 around 78% of women were in vulnerable employment in Sub-Saharan Africa, compared to 67% of men. The world average is respectively 43 and 42%.

The possible reasons for this are the nature of rural and farming labor markets, and because women in Africa tend to be more dependent on services for a job than men – they are less represented, so far, in industry, where the quality of jobs tend to be better. As *Fig. 5* shows, in 2017 only 8% of the African female labor force was employed in industry, with most women working in agriculture (57%) and services (34%).

Figure 5: Labor force participation per broad sector and by sex in SSA, 2017



(Source: author's compilation based on data from International Labour Office, Trends Econometric Models (ilo.org/wesodata)

The imperative is not just to create more jobs outside of agriculture, but also to ensure that women are empowered to have a fair share of these jobs. As will be argued in this report, the technologies that are driving smart manufacturing may facilitate the entry of women into the manufacturing sector, and create better conditions for the social mobility of women than prevailed in older models of low-cost labor driven manufacturing – where often the hours of work, demands on physical strength, and work-household role conflicts hindered the entry of women. The greater ease and flexibility of manufacturing business models relying on Industry 4.0 technologies, as will be explained in greater depth in the next section, allows women to overcome these barriers.

The third implication of Africa's demographic distinctions is for city labor markets, and more generally the process and success of urbanization. This is because well-functioning city labor markets are essential. Farming, based in rural areas, cannot provide enough jobs for the growing population. In fact, the requirement that African becomes much more productive in order to feed the population, will require more mechanization and a decline in labor inputs. The experience of all other regions that have developed has certainly shown that gains in agricultural productivity will be accompanied by reduced employment growth. Therefore, developing cities, including secondary cities and towns in Africa, is a priority. In this context, manufacturing is a sector that can benefit from the localization and urbanization externalities in cities, and moreover can contribute to provide jobs to rural-urban migrants.

In conclusion, this section has shown that the demographics of Africa are such that there are implications for labor markets in terms of youth jobs, gender equality, and urban development. It has been indicated that manufacturing is a sector that can potentially make a useful contribution in this regard. Historically though, Africa has not yet been able to significantly industrialize, and there have even been claims that the continent has been prematurely de-industrializing (e.g. Rodrik, 2015; Timmer et al. 2014). Some have even questioned whether Africa can ever industrialize (Page, 2012) ot that such developing countries should not even try to industrialize, but rather focus on services and by-pass the typical patterns of structural adjustment (IMF, 2018). Others argue that African economies should promote activities that have the "characteristics of manufacturing" (Newfarmer et al. 2018) or pursue "structural adjustment without industrialization" (Gollin, 2018).

In this report a different view is taken, because of two game-changing developments: one is due to new technologies associated with the "fourth industrial revolution" (Industry 4.0), as well as a resurgence in the tech-entrepreneurship scene in Africa. It is argued that the combination of high-tech and entrepreneurship also offers new opportunities for Africa's youth and women to enter into manufacturing. To motivate this argument, the following sections will respectively deal in greater detail with the nature of the new technologies of Industry 4.0 and the surge in African tech-entrepreneurship.

3. The New Technologies that are Transforming the Nature of Manufacturing

The world is in what has been described as a "second machine age" (Brynjolfsson and McAfee, 2016), or a "New Industrial Revolution" (Marsh, 2012) or even a "Fourth Industrial Revolution"

(Schwab, 2016), sometimes refered to as "Industry 4.0". The term is perhaps not as important as what it signifies: transformative change to the way goods are being manufactured and consumed, with significant implications for human society, including a new window of opportunity for African economies to industrialize.

Industry 4.0 is driven by a convergence of advances in the Internet of Things (IoT), advanced materials, digital platforms, robotics, artificial intelligence, the Interface of Things and big data analytics, and is giving rise to mass customisation through 3D-printing (additive manufacturing), production-as-a-service through digitisation, and new business models such as the sharing and on-demand economies. Cost reductions in computing power, data storage and bandwith are facilitating this convergence (Deloitte, 2018). Often these advances proceed exponentially, meaning they are "characterized by continuous improvement in price and/or performance per unit of price over time" (Combes et al., 2017:5). The disruption that these technologies cause is not due to the individual technologies, but to their convergence, which accelerated especially after 2007 (Friedman, 2016).

Table 1 lists and explains the most important of the new technologies that are changing the nature of manufacturing. Typical of the impact of the technologies in Table 1 is to make things better, cheaper and more accessible (Friedman, 2016). An example familiar to most people on the planet in the year 2019, is all the virtually free functions on most smartphones: GPS, videoconferencing, processing power, video player, video camera, and more. It has been estimated that to have owned all of this technology in 1985, would have cost at least US$ 32 million[4].

In the case of manufacturing, these technologies make manufacturing easier, and more accessible, especially for small enterprises and artisans in Africa. This is because it reduces the need to obtain scale in production, it allows rapid and easy prototyping; and it reduces the need for and cost of making hard moulds for manufacturing of machine parts.

They key aspect to this simplification of manufacturing is that integration with software systems makes 'complexity invisible'. This is aptly described by Friedman (2016:65) quoting former Microfost researcher Craig Mundie:

> 'Software is this magical thing that takes each emerging form of complexity and abstracts it away. That creates the new baseline that the person looking to solve the next problem just starts with, avoiding the need to master the underlying complexity themselves'.

[4] See: https://www.webpagefx.com/data/how-much-did-the-stuff-on-your-smartphone-cost-30-years-ago/

Deloitte (2018) ascribes the simplification of manufacturing as due to the greater use of plug-and-play components for collaborative robots. These enable end users to build their own robots.

A technology such as 3D-printing simplifies manufacturing due to a number of advantages, such as that 3D-printers are much more mobile than much other manufacturing machinery; the price of 3D-printers is less than many traditional machines – and declining; the energy requirements of 3D-printers are less than that of traditional machinery; and, by printing spare parts and components using open source software the dependence of manufacturing on traditional transport and logistics are reduced (Juma, 2015). Moreover, 3D-printing facilitates agile manufacturing since it can "reduce the lead time from conception to the production stage by 70% or more" (Frost and Sullivan, 2016).

In addition to making manufacturing easier, the technologies described in Table 1 also allow firms to tailor-make and customize their production according to the wishes of their consumers. This customization of products to the consumer need gives an advantage to firms in serving their local market, and as such it is facilitating the rise of what is descrbied as Localized-Additive-Manufacturing-on-Demand (LAMD) (Graham, 2018) .

Finally, smart manufacturing is not only making manufacturing easier and more customer-oriented, but it is also environmentally more sustainable: less stock needs to be kept, and products use fewer physical inputs, last longer and allow shared use.

Table 1: Most important new technologies, their applications and impact

Technology	**Description and role in manufacturing**	**(Potential) global market value**
(Industrial) Internet of Things	The Internet of Things refers to a system of devices, networks, software platforms and applications that makes possible for "sensors on physical objects to gather and shares information on the objects and their environment" (ECLAC, 2018:25). Applications are in optimization of production, predictive maintenance, the servicification of manufacturing, tracking products, automated flows, customized production. Around 8,4 billion objects were connected to the IoT by 2017 (ECLAC, 2018).	US$ 4 trillion (2025) US$ 15 trillion (2030) (Accenture, 2015)
Digital platforms	A digital platform is "a technology-enabled business model that creates value by facilitating exchange between two or more independent groups…built on a shared and interoperable infrastructure, fuelled by data and characterized by multistakeholder interactions" (ECLAC, 2018: 61). Applications are in online and digital trade, software-as-services, infrastructure-as-services, the on-demand economy, collaborative manufacturing and manufacturing design, customization, recruitment, and financing (ECLAC, 2018).	176 platform firms were valued at US$ 4,3 trillion by 2016.
Biomanufacturing	"The use of biotechnology to use biological systems to produce commercially important biomaterials and biomolecules for use in medicines, food and beverages and industrial applications" (Deloitte, 2018,p. 38). Applications are in pharmaceuticals, renewable oils, clothing and textiles, food and beverage synthetic flavourings, green bioplastics, and cellular agriculture.	US $ 584 billion (2021)
Advanced materials	"Chemicals and materials like lightweight, high-strength metals and high performance alloys, advanced ceramics and composites, critical materials, bio-based polymers, and nanomaterials" (Deloitte, 2018, p. 32). Applications are in automotive and aviation manufacturing, sporting goods, wind turbine generators and batteries, building materials (e.g. coatings) and displays.	US$ 283 billion (2021)
Robotics	"Machines or systems capable of accepting high-level mission-oriented commands and performing complex tasks in a semi-structured environment with minimal human intervention" (Deloitte, 2018, p.34). Applications are in assembly and packaging of products, including welding, painting,and loading; and in manufacturing of drones.	US $ 225 billion (2021)
Artificial intelligence	"The theory and development of computer systems able to perform tasks that normally require human intelligence" (Deloitte, 2018, p. 36). Applications are in predictive maintenance, computer vision (for e.g. quality assurance of production), automated driving, and personalizing consumption.	US$ 72 billion (2021)
3D-printing	"An additive process of building objects, layer upon layer, from 3D model data" (Deloitte, 2018, p. 28). Applications are in automotive and aviation design, dental printing and medical implants. By 2014 already more than 11% of US manufacturers had "switched to volume production of 3-D printed parts" (Tuuli and Batten, 2015:3).	US$ 3,6 billion (2021)
Blockchain	A digital technology that allows data to be structured and distributed "without the need for a centralizing authority" and that is "immutable, safe, secure and tamper-proof" (Deloitte, 2018, p. 40). Applications are in tracking and verifying of products, performance reviews of suppliers, and reduction of fraud.	US $ 2,3 billion (2021)
Interface of Things	The Interface of Things includes "virtual reality (VR) which creates a fully immersable digital environment that replaces the user's real-world environment; augmented reality (AR) which overlays digitally-created content into the user's real-world environment; mixed reality (MR) which seamlessly blends the user's real-world environment and digitally created context; wearables and gesture reognition technology that enables humans to communicate and interact with a machine" (Deloitte, 2018, p. 50). Applications are in virtual assembly manuals for factories, virtually designing factories and products, quality checks, instruction and training for manufacturing, and remote assistance.	US $ 1,5 billion (2021)

(Source: author's compilation based on Deloitte (2018) and ECLAC (2018))

The technologies in Table 1 are therefore making manufacturing an attractive option for Africa, offering new business models on which to base industrialization. In the next section the relevance if this for Africa is stressed.

4. Relevance for Africa

4.1 Relevance for Manufacturing in General

The technologies listed in Table 1 offer many potential opportunities for revitalizing Africa's manufacturing sector[5]. Examples of these in the context of Africa are provided in the paragraphs below.

One of the largest manufacturing sub-sectors in Africa is food and beverages. Companies in this sector include giants such as *SABMiller*, *Tiger Brands*, *East African Breweries* and *Nestle Nigeria*. Trends such as population growth, urbanisation, the rise of the middle class and rising food prices are increasing the demand for more and better quality, as well as for more diversified, food products. It is a huge opportunity for agro-processing manufacturing (and for other sectors related to the processing, and transport and storage of food). Emerging technologies in AI, 3D-printing, renewable energy (green industrialization) and the Industrial Internet of Things (IoT) in particular, can play a catalyzing role.

In the expansion of food processing manufacturing in Africa, many downstream and upstream opportunities will be created for the manufacturing of machinery used in processing, including electrical and electronic equipment, and also transportation and storage equipment, including *drone*s[6]. These are also the sectors where most of Africa's imports are concentrated, implying that there is a ready domestic market[7]. The *Internet of Things* (IoT) could play a catalysing role in helping to make domestic African manufacturers more efficient and more competitive.

The data generated by the IoT are already allowing AI applications to contribute elsewhere in the world to improve food production from the "farm to the fork" by, for instance, helping farmers to monitor growing conditions and timeously identify crop diseases; by tracking products along the entire supply chain (see *Box 1*); by improving food sorting and equipment cleaning; by

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[5] These paragraphs draw on the author's earlier contribution to the World Trade Organization's World Trade Report 2018 on digital technologies and world trade, see p. 46 of https://www.wto.org/english/res_e/publications_e/world_trade_report18_e.pdf

[6] Drones increasing being used in Africa, for instance in farming, surveillance, construction site monitoring, wildlife protection, and in deliveries, see Naudé (2017).

[7] According to UNECA (2015) Africa's top imports in 2013 included US$ 69.3 billion of machinery, US$ 48.8 billion in vehicles and transport equipment, and US$ 47.7 billion in electrical and electronic equipment: a huge market then for local producers of these goods.

monitoring hygiene in factories; and by helping entrepreneurs develop new products. AI – and specifically machine learning – is already being used to map and predict poverty and crop success in Africa[8].

Box 1: Using the IoT to Manage the Supply Chain of Coffee in Africa

Ethiopia's ECX e-Trade platform, established in 2015, is a joint initiative of the Ethiopian Commodity Exchange and IBM, and uses mobile and IoT technology to keep track of coffee production and sales throughout the entire supply chain. This now enables Ethiopia to ensure full traceability of coffee, which "*helps firms in the coffee business obtain organic certification for their products*".

See : http://www.geeskaafrika.com/10240/ethiopia-will-the-new-e-trade-platform-be-effective-in-ethiopia/

Blockchain, a digital technology (a distributed ledger technology) that improves trust between parties and reduces the need for intermediaries, is already widely used to underpin trade and for use in cryptocurrencies in Africa – for instance in sending and receiveing remittances. It is moreover also being used to improving the functioning of financial and land markets (see *Box 2*), with a number of advantages for the food processing sector, such as that quality and reliability of inputs are improved, and entrepreneurs can get better access to loans (Stanford, 2018). The *African Women in Blockchain Initiative*[9] works to promote women's access to, and participation in, this technology.

Box 2: Blockchain for Managing Land Rights in Africa

An example of the use of blockchain for improving rights over land in Africa is a pilot project of the *Bitland* organization in Kumasi, Ghana. Bitland's technology enables land to be surveyed and land titles to be recorded via a mobile device. As Bitland states on its website: "*By attaching a land title to the blockchain, it creates a time-stamped, immutable, transparent ledger of who owns land. This will be much more resistant to corruption and fraudulent transactions than the current system in place... [and] it will make the process of mortgage lending much more efficient and resistant to fraud*".

See : http://landing.bitland.world

[8] See the work being done at the Sustainability and Artificial Intelligence Lab at Stanford University: http://sustain.stanford.edu/predicting-poverty
[9] See https://afriblockchain.org/africa-women-in-blockchain/

3D-printing is taking off in Africa, and indeed in many respects the continent is at the forefront of the technology (see *Box 3*). It is contributing not only to the 'mass customization' of new food products in Africa, for example in the 3D-printing of food items (e.g. confectionary) but also to reduce food waste. For example, *Studio H*[10] uses one of South Africa's first food 3D-printers to improve the appearances of fruit and vegatables – therefore encouringing less wastage. 3D-printing is also being used upstream in farming. An example is the *3D4AgDev* project that uses 3D-printing to provide African women smallholder farmers the technology to 'design and develop their own labor-saving agricultural tools' whereby '…*local tool manufacturers (artisans, blacksmiths) can copy plastic prototypes and develop their own modifications*' (Naudé, 2017).

Box 3: The World's Largest 3D Printer is in Africa

Africa is already home to many leading applications in 3D printing. One of these is the 3D printer that has been built by South Africa's Centre for Scientific and Industrial Research (CSIR) and the Aerosud Innovation Centre in Pretoria. This printer, said to be the world's largest, uses titanium powder to print aircraft parts.

See https://www.businessinsider.co.za/south-africas-largest-3d-printer-is-so-big-that-it-takes-up-to-r75-million-in-titanium-powder-to-fill-it-2018-7

In conclusion, the technologies that are changing the nature of manufacturing in the new industrial revolution have particular relevance for Africa, in that the areas where may of the most salient businesses opportunities are, and where it also will grow, namely: the market for food and food processing. These markets are very local, increasing due to the growing middle class and mounting urbanization, and getting more sophisticated. Moreover, upstream there are the linkages to farming, which means that as farming will become more productive, the positive spillover effects will benefit production downstream.

4.2 Relevance for Youth and Women

A special focus of this report is on the role of youth and women in Africa during the 4th Industrial Revolution. The technologies associated with this "revolution", as set out in section 3, were shown in section 4.1 above to be highly relevant for manufacturing in Africa in general. Key technologies such as digitization (IoT, blockchain) and 3D-printing are already being applied in innovative ways.

[10] See https://www.studio-h.co.za

This sub-section will show that these technologies, and their positive impact on manufacturing in general, also augers well for youth and women.

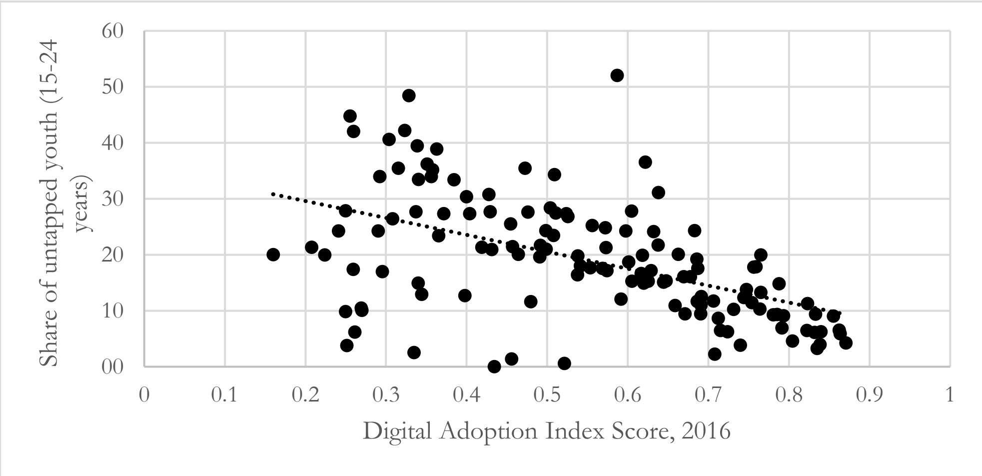
4.2.1 Youth

As far as the youth is concerned, the current generation of African youth may be especially ready to benefit from the technologies of Industry 4.0, as they form a central portion of what has been called the world's "digital natives" who have, compared to the older generation, been more exposed to modern digital technology (Moran, 2016). They have also been in the vanguard of the Fintech revolution in which Africa has played a major role. By 2023, it is estimated that more than 1 billion Africans will have a mobile phone. Thus, the youth can be seen as a natural demographic for applying the new technologies. As Azoulay et al (2018:2) put it "among the advantages of youth in technology and innovation, young people are sometimes argued to be cognitively sharper, less distracted by family or other responsibilities, and more capable of transformative ideas". In this perspective, Africa's large youth population is one of its major assets, and its hope for the future. It is therefore vital that the youth's talents and potential be harnessed, and utilizing their match and proclivity for technology to empower them.

The tentative evidence indeed seems to suggest that utilizing new technologies associated with Industry 4.0 can improve labor market outcomes for the youth. For instance, countries worldwide that have adopted digital technologies have fewer youths that are not in employment or education (i.e. a lower NEET rate). They thus utilize the potential of their youth much better, as *Fig. 6* shows using the *World Bank's Digital Adoption Index*[11]. The direction of causality is likely to be bi-directional: better adoption of digital technologies is likely to engage the youth in either learning, education or employment, and better engagement of the youth is likely to lead to faster adoption of digital technologies. Thus, investing in youth education in STEM areas, and specifically in ICT fields, and supporting the diffusion of digital technologies in Africa, should clearly be priorities.

[11] The *Digital Adoption Index* (DAI) provides a relative measure of how countries are adopting digital technologies across the domains of business, governments and households. It uses data reflecting on the use of inter alia the following digital technologies: ***business websites, secure servers, download speeds, 3G coverage, mobile-cellular access at home, internet access at home, cost of internet access, e-customs, e-procurement, digital signatures***, and *e-filing* for taxes. See http://www.worldbank.org/en/publication/wdr2016/Digital-Adoption-Index.

Figure 6: Digital Technology Adoption and Utilization of Youth Potential



(Source: author's compilation based on data from the ILO and the World Bank's Digital Adoption Index)

4.2.3 Women

As discussed in section 2, not only are women currently more likely to be unemployed in Sub-Saharan Africa, they are also more likely to be in vulnerable employment than men (in 2017 approx. 78% of women were in vulnerable employment, compared to 67% of men) (ILO, 2017).

Possible reasons include the structure and practices of rural and farming labor markets (most women work in agriculture: 57% of the African female labor force in 2017), and that women in Africa are relatively more dependent on services for a job (34%), and find fewer job opportunities in industry (only 8%, where the job quality tends to be better), than men.

The 4th industrial revolution may change this. While more research is needed to make better predications as to the impact of the fourth industrial revolution on gender equality in developing countries, many existing studies focusing on advanced economies are guardedly optimistic (OECD, 2018). For instance Sorgner et al. (2017:7) conclude that 'new digital technologies will likely replace women's jobs to a lesser extent than men's jobs. This is primarily because many jobs typically held by low-skilled women, like those in health care or household services, are less easily automatized than jobs typically held by low-skilled men, like machine operators or assembly-line workers'. Thus women in Sub-Saharan Africa may be less threatened by the technologies of the fourth industrial revolution.

Moreover, it is predicted that the 4th industrial revolution will increase the demand for the occupations in which women tend to be predominantly found, and wherein social and emotional skills are at a premium (ODI, 2017; Bughin et al., 2018). These include occupations such as teachers, lecturers, and mentors, for which the demand in Sub-Saharan Africa is high and rising due to the large and growing young population.

New technology can also improve the quality of employment for women by providing flexibility, and household labor and time-saving technology. There may also be benefits from the new technology in terms of broadening women's access to the labor market – and to manufacturing jobs specifically. Examples include the digitization of financial services (fintech) that are improving women's access to finance, resulting in more opportunities for women in entrepreneurship (Sorgner et al., 2017). Digital platforms allow for easier entry of women entrepreneurs into the economy, including into manufacturing: for instance, by using platforms to connect to both customers and production technology (such as 3D printers) at the same time and with smaller start-up costs (World Bank, 2018a).

Thus, the 4th industrial revolution will bring more opportunities for women and can further gender equality in Sub-Saharan Africa. An important condition for this however is that both education and labor market policies should actively support women in terms of access to jobs, and access to the education and skills they need, in order to benefit from the 4th industrial revolution. However, regulatory support may be needed to avoid women and men becoming locked into low-wage and exploitative working conditions in the largely unregulated online 'gig' economy (Galpera et al., 2018; OECD, 2018). As Howcroft et al. (2018:68) correctly point out '…the issue is not with the technology, but the policies'.

Promotion of gender equality remains therefore, paramount. In this respect Sub-Saharan Africa (and the world for that matter) still faces important gender gaps. The gender gap in higher education enrollment and employment in high-tech areas, including science and engineering fields, is a well-known cause for concern. For instance in the EU, women's share of jobs in the high-tech manufacturing industry are around 32%. In the USA, women earn around 23% of all degrees in science and engineering annually[12]. Globally, 72% of the world's researchers in 2013 were men (UNESCO, 2015).

To illustrate and underscore the importance of gender equality, consider the following. Growth in employment in manufacturing in recent times in Sub-Saharan Africa has been fastest in countries where there are more legal restrictions on women in the labor market.

[12] See: https://www.catalyst.org/knowledge/women-science-technology-engineering-and-mathematics-stem

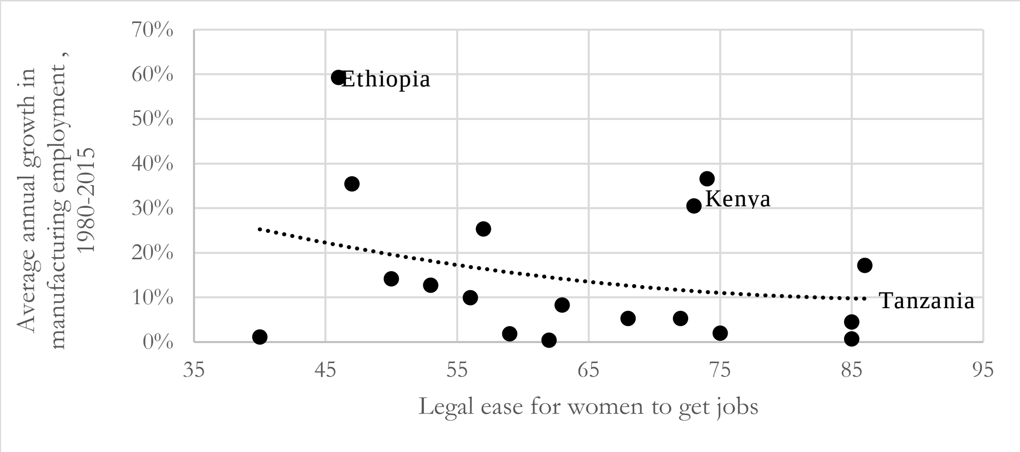
In this regard, *Fig.7* plots the relationship between the World Bank's 'Getting a Job' measure and the employment growth in manufacturing in African countries for which data is available. The *Getting a Job* measure 'assesses restrictions on women's ability to work, such as prohibitions on working at night or working in certain industries" (World Bank, 2018b: 25). It ranges from 0 to 100, and the higher the score the easier women legally have access to jobs, i.e the fewer restrictions they face. There are still many countries in the world where women are restricted legally from working in the manufacturing sector. According to the World Bank (2018b), the majority of Sub-Saharan African countries still have at least one legal restriction on women working in industry, for example against night time work. In fact in only 14 out of 47 Sub-Saharan African countries for which the World Bank reports data, are there no legal restrictions singling out women's work[13].

What *Fig.7* also shows is that there is a (weak) negative relationship between the legal ease of getting a job (or lack of restrictions) and employment growth in manufacturing. A possible interpretation of this relationship is that in countries where manufacturing employment growth is high, women face more restrictions, hence they cannot benefit from the developments in this sector.

If the 4th industrial revolution is set to stimulate growth in African manufacturing in the future, it means that women may miss out if manufacturing grows rapidly in countries where women face legal restrictions. The recommendation, if this is the case, would be that countries prioritise the removal of legal restrictions that discriminates against women and their opportunities of benefiting from future growth in manufacturing.

[13] The only Sub-Saharan African countries which by 2018 had no legal restrictions specifically on women to work in the labor market, where Botswana, Eritrea, Kenya, Malawi, Liberia, the Gambia, South Africa, Namibia, Uganda, Rwanda, Tanzania, Togo, Zambia and Zimbabwe (World Bank, 2018b).

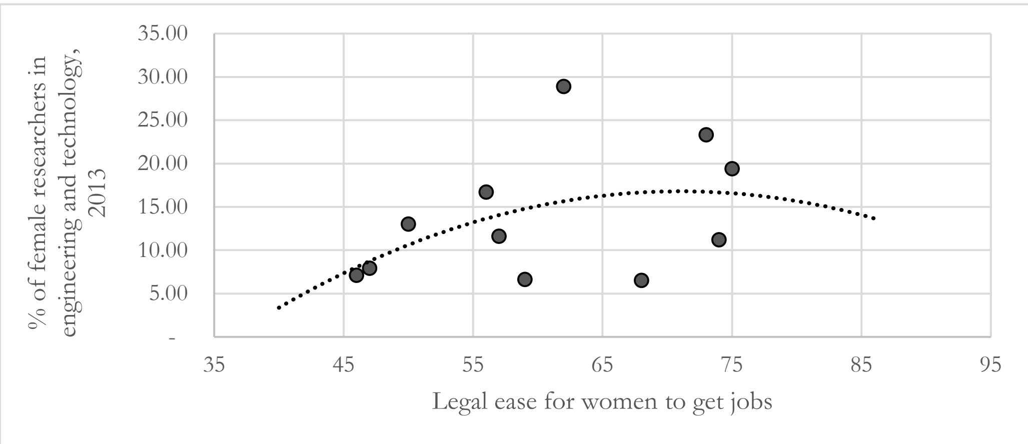
Figure 7: The relationship between legal ease of labor market participation for women and the average annual growth in manufacturing in Sub-Saharan African countries, 1980-2015



(Source: Author's compilation based on data from the World Bank's Women, Business and the Law Report (World Bank 2018b) and from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Improving the legal ease for women to get jobs will create an incentive for women to pursue careers in science, technology and engineering and to qualify themselves further in this field. *Fig. 8* shows for instance that there is a strong positive correlation between the legal ease for women in sub-Saharan Africa to get a job, and the share of women who work as researchers in engineering and technology.

Figure 8: Relationship between legal ease of labor market participation for women and the share of women in researchers in engineering and technology in Sub-Saharan African countries, 2013.



(Source: Author's compilation based on data from UNESCO, 2015 and from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Indeed, more and more women in sub-Saharan Africa are qualifying themselves in science, technology and engineering fields. According to Hayer, (2015: 97) "Much of sub-Saharan Africa is seeing solid gains in the share of women among tertiary graduates in scientific fields…Female representation in engineering is fairly high in sub-Saharan Africa in comparison to other regions".

For instance in South Africa, women made up 49,1% of all tertiary graduates in science in 2013, thus achieving gender parity.

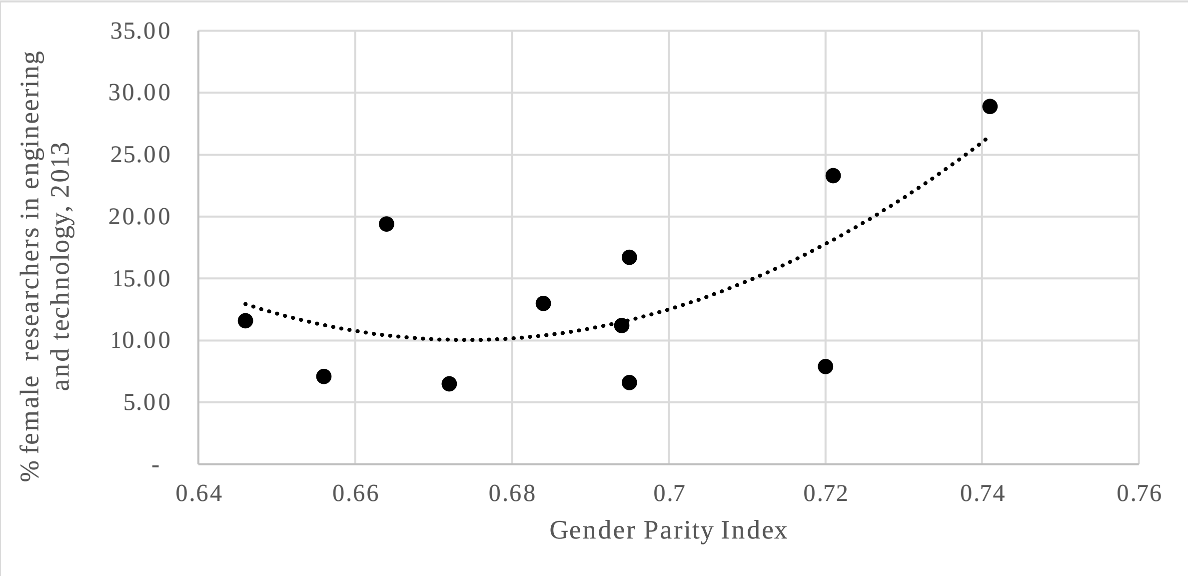
Whether many of the women qualifying themselves or pursuing careers as researchers in engineering and technology will have access to, or will want to, work in manufacturing however, is an important question. It may have to be the case that countries should do more than only remove legal restrictions on women in the labor market. They may need to actively encourage the recruitment of women into science, technology and engineering fields. The reason is that it has been seen in other contexts that where women are empowered, they tend to choose *not* to enter into engineering and science fields[14], the fields often most required for manufacturing – especially advanced manufacturing associated with the 4th industrial revolution (see Stoet and Geary, 2018).

In studies women have been found to tend to leave careers in science and engineering more often and earlier than men – for instance, surveys in the USA have found that around 30% of women working in STEM jobs indicated that they plan to leave for a job in another sector within a year[15], more than twice the rate for men.

Research is needed to establish whether this also holds true in Africa. Tentative evidence would suggest that it perhaps does not: that just as there is a positive relationship between fewer legal restrictions on women's work and women entering science and engineering professions (*Fig.8),* so there is also evidence, shown in *Fig.9*, that in Sub-Saharan Africa, improvement in gender parity is correlated with more female participation in science and engineering. This tentative picture is a cause for hope for those concerned whether the digital divide between men and women, and between Sub-Saharan Africa and the rest of the world, can be overcome.

[14] In countries where there is more gender equality, there are proportionately fewer women in science fields, than in countries with more gender inequality. Khazan (2018), referring to the findings of Stoet and Geary (2018), interprets this as women in more unequal countries being more restricted in their choices.
[15] See : https://www.catalyst.org/knowledge/women-science-technology-engineering-and-mathematics-stem

Figure 9: Relationship between the Gender Parity Index and the share of female researchers in engineering and technology in sub-Saharan African countries, 2013



(Source: Author's compilation based on data from UNESCO, 2015 and from World Economic Forum's Global Gender Parity Index, 2018).

Such hope is further boosted by the continued progress in Africa in terms of women empowerment and striving to achieve gender parity. As previously mentioned, in South Africa, women make up half of all tertiary graduates in science. Another achievement to metion in this regard, is that in 2017, the gender gap in terms of labor force participation in Africa was the lowest of all regions in the world, at 11,7%. This is much smaller than the labor force patrticipation gender gap on a worldwide level (26,7 %), and comparable to that of North America (12%). Also, in terms of internet penetration rates per gender, the 'digital gender gap' in Africa at 6,3% was less than that in Europe (6,6%) in 2017 (Badran, 2018).

In conclusion, this section has shown that the technologies of Industry 4.0 are highly relevant for Africa – not only for manufacturing development in general, but also for empowering the youth and women.

Finally the technologies will, through further creative and competitive use by new start-up entrepreneurs, also help to develop capacity in African manufacturing, and also help in non-traditional manaufacturing areas, such as for instance medical equipment, aircraft components, automotive components, and the like. Here, the resurgence in African entrepreneurship, and the development of its entrepreneurial ecosystems, offers promise. This is described in more detail in the following section.

5. The Resurgence of Tech-Entrepreneurship in Africa

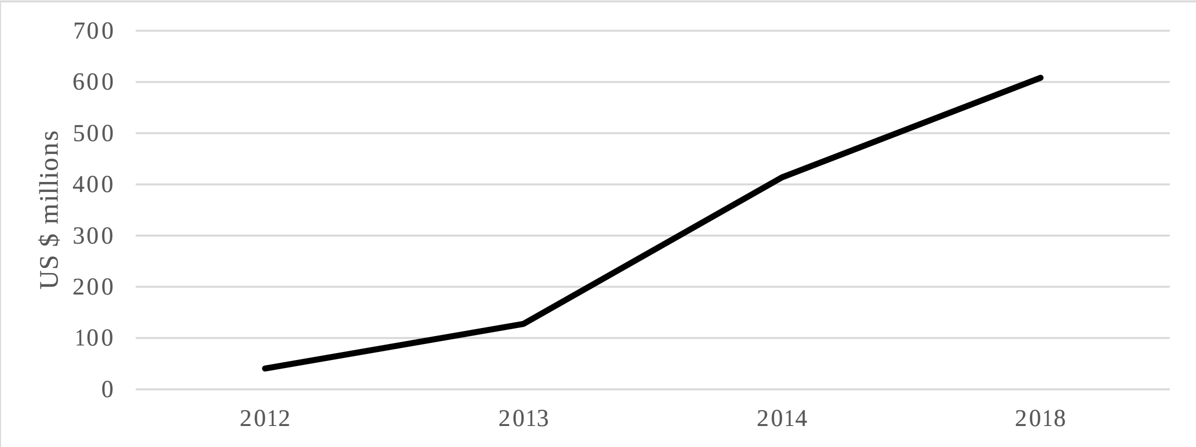
Start-up and innovation ecosystems are needed for Africa's industrialization to adapt and commercialize the new technologies described in Table 1, for local conditions, and to promote the adoption and deployment of these new technologies by local firms. New entrepreneurial start-ups are generally how most commercialisation of high-tech, especially for unproved and unknown technologies, where risk and uncertain are high, takes place.

In Africa, the entrepreneurial ecosystems that are needed for such agile manufacturing are at present, developing rapidly (Lalunde, 2017). Entrepreneurial ecosystems are "sets of actors, institutions, social networks, and cultural values that produce and sustain entrepreneurial activity" (Roundy et al., 2018:1). They provide the business networks, mentoring and entrepreneurial finance, and the skills, knowledge, and R&D support for the successful start-up and growth of new businesses.

The rise in entrepreneurship and entrepreneurial ecosystems benefits greatly from a rising middle class (Bhorat et al., 2017), who are demanding more and more consumer goods. Estimates are that the consumer retail market in Africa will exceed US$ 2,5 trillion by 2025.

Indicators of a developing entrepreneurial ecosystem include both Venture Capital (VC), and the number of start-up accelerators and incubators that are spreading across the continent. As *Fig. 10* shows, in VC there was a ten-fold increase in funding flowing into African tech start-ups between 2012 and 2018.

Figure 10: Money going to where the opportunities are: Venture capital funding to African tech startups, US$ millions



(Source: Based on data from Jake Bright)

As far as the number of start-up incubators and accelerators are concerned, these have been spreading since 2007, when M-Pesa was launched in Kenya (Bright, 2016). Today there more than 314 "tech hubs", and at least 60 specialized start-up tech accelerators on the continent.[16] Examples of the latter include *iHub* in Kenya, *blueMoon* in Ethiopa, *BongoHive* in Zambia and *Startpreneurs* in Nigeria. The latter is an accelerator focusing on artificial intelligence, machine learning, virtual reality, blockchain, and data science. The *GrowthAfrica* accelerator that is active in Kenya, Uganda and Ethiopia, reported assisting 289 new entrepreneurs and creating 25,000 jobs since 2002.[17]

Moreover, more and more global tech giants are joining this local resurgence of entrepreneurship by investing in Africa's tech entrepreneurs and tech talent: in July 2018, *Google* announced that it planned to establish an Artificial Intelligence Lab in Ghana[18], and in August 2018, it was announced that *Google* and *Facebook* would be funding a new Masters program in Machine Intelligence with Rwanda's African Institute for Mathematical Sciences (AIMS).[19] Since 2015, Silicon Valley's Y-Combinator start-up acceleration program, probably the most famous in the world, has started to invite African entrepreneurs, and since then at least 19 African high-tech start-ups graduated from its program and obtained venture capital seed funding[20].

A number of encouraging complementary trends, such as rapidly rising investment in ICT in Africa, bodes well for entrepreneurial ecosystems: Ericsson predicts that by 2022 around 80% of mobile phone subscriptions in Africa will be WCDMA/HSPA, LTE and 5G; and moreover that

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[16] See: https://www.gsma.com/mobilefordevelopment/programme/ecosystem-accelerator/things-learned-tech-hubs-africa-asia/ and https://www.galidata.org
[17] See: https://growthafrica.com/about/entrepreneurial_impact/
[18] See: https://edition.cnn.com/2018/07/14/africa/google-ghana-ai/index.html
[19] See: http://www.universityworldnews.com/article.php?story=20180824092059418
[20] See: https://digestafrica.com/y-combinator-africa-startup/

mobile data traffic will continue to grow by 55% per year until then. Furthermore, the World Bank is at the time of writing (2019) investing more than US$ 1.2 billion in ICT infrastructure for internet connectivity in Africa.

Women in particular may benefit from these trends, especially given good progress in recent years in promoting gender equity. As was mentioned previously, in terms of internet penetration rates per gender, the 'digital gender gap' in Africa at 6,3% less than that in Europe (6,6 %) in 2017 (Badran, 2018). Furthermore, female representation in engineering and science, two fields important to support digital manufacturing, is high in Africa in comparison to other regions. In particular, in South Africa, some gender parity has been achieved (in 2013 women made up 49,1% of all science tertiary graduates). There are encouraging examples of specific initiatives in Africa to support women entrepreneurship in smart manufacturing (see *Box 4*), although these are not yet enough, and more of these initiatives need to be rolled out.

Box 4: the 3D-Printing Academy for Girls

The Youth for Technology Foundation runs a 3D-printing academy for girls in Kenya, Nigeria and Uganda. According to the Foundation, its mission is to empower marginalized youth and women in order to use new technology entrepreneurially.

See: http://www.youthfortechnology.org/programs/3d-printing-academy-for-girls/

More generally, to support the momentum of Africa's entrepreneurship start-up scene, governments and the international community should focus on enlarging the pool of finance for new high-tech ventures. Although the trend in VC depicted in *Fig. 6* is promising, it shows growth from a small base. In the relative context, total venture capital in Africa is miniscule in global terms. It is particularly important that the right kind of entrepreneurial finance be made available.

This is because the needs for finance – and the type of finance required – for high-tech start-ups can differ from non-tech start-ups: to be specific, high-tech start-ups tend to require more risk-tolerant, patient finance; and often can provide less collateral given that they are more often based on intangible assets. In such conditions, the personal, managerial and entrepreneurial competencies of the lead entrepreneur in a firm is of vital importance to financiers, whether venture capitalist or angel financiers. Thus, the development of managerial and entrepreneurial skills within Africa's emerging tech hotspots and entrepreneurial ecosystems should be a priority for governments and international donors.

It is useful to consider in this regard, like Bloom and Van Reenen (2010), that management itself a type of 'technology'. Managerial capacity is an important determinant of the extent to which technology penetrates into firms, with better managers being able to much more efficiently introduce technology into their firms and promote innovation (Bloom and Van Reenen, 2010).

Finally, governments need to underpin investments in their entrepreneurial ecosystems with a better system of social protection / insurance, including unemployment insurance, basic income grants, pension systems, business insurance, and credit schemes. Africa spends the least of any continent on social protection, and having such mechanisms in place will increase the propensity of entrepreneurs to make the risky investments, which success in the new industrial economy will require. Too many entrepreneurs in Africa currently enter into business as a form of insurance, and hence avoid overt risk taking (Nagler and Naudé, 2017).

While European countries such as Finland and the Netherlands are experimenting with basic income grants, the administrative capacity and financial means may be a current constraint in Africa at present. This may however not be for long, given the way in which mobile finance has made innovative strides on the continent. Africa may even leapfrog European welfare states in the utilising of mobile finance as a delivery vehicle for basic income grants and insurance.

6. How New Technologies and Vibrant Entrepreneurship will Impact on African Manufacturing

Up until this point, this report has shown that the new technologies associated with the new industrial revolution are simplifying manufacturing, making it more accessible to indigenous, small business and artisans; that these technologies complement the current growing market for retail goods and processed food; and moreover, that the surging tech-entrepreneurship scene can bring many new types of manufacturing to Africa. In addition, youth and women stand to benefit, especially if the right support is forthcoming.

In considering supporting the industrialization of Africa, in a manner that will maximise these opportunities for youth and women, it is necessary to consider the overall, broad impacts that the technologies of the 4th Industrial Revolution will have. It the remainder of this section, four implications will be discussed. To be specific, the results of the 4th Industrial Revolution in Africa will be:

- The boosting of the growth of manufacturing value added.
- A positive impact on net job creation.
- Stimulatulation of complex skills development.
- Encouragement of investment in supportive infrastructure.

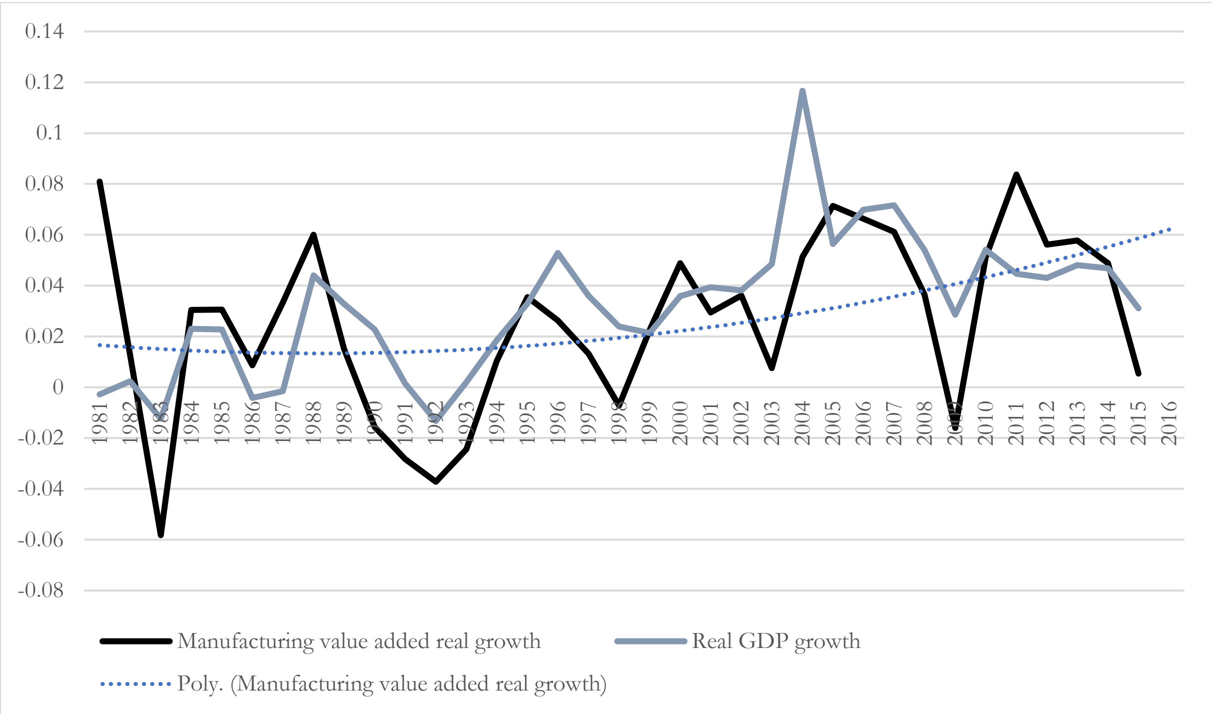
In the remainder of this section, these four implications or impacts of new technology and vibrant entrepreneurship on Africa's manufacturing future, will be elaborated on.

6.1 Manufacturing growth will be boosted

Since 1980, Sub-Saharan Africa has *more than doubled* the size of its manufacturing output in real terms. There are a number of reasons to expect that the size of African manufacturing will continue to grow in terms of value added as a result of new technologies and surging entrepreneurship.

The first is that manufacturing value added growth since the 2000s has been positive and accelerating, as *Fig.11* shows.

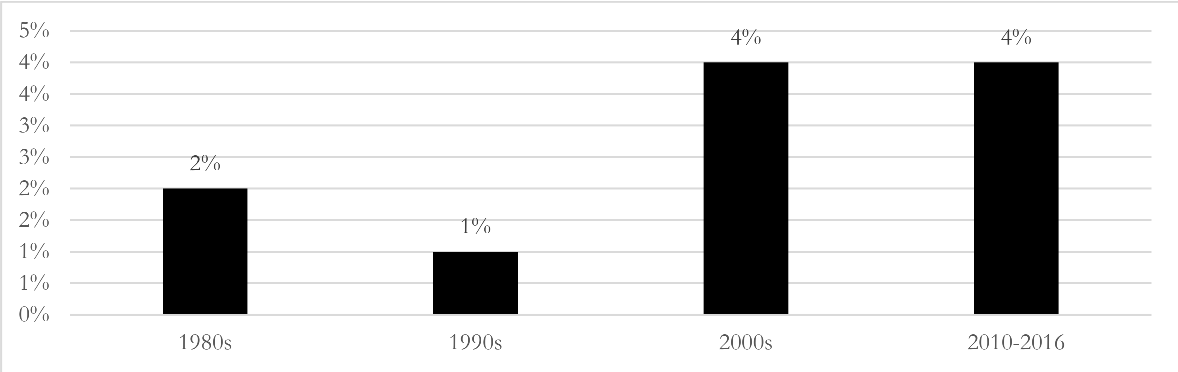
Figure 11: Growth in real manufacturing value added and GDP in Sub-Saharan Africa, 1980-2015



(Source: author's compilation based on data from the World Development Indicators Online)

The acceleration of manufacturing value added growth in Sub-Saharan Africa is clear from the fact that the manufacturing value added growth rates since 2000 have, on average, been more than double what they had been since the 1980s. This is shown in *Fig. 12*.

Figure 12: Average annual manufacturing growth rates in Sub-Saharan Africa per decade, 1980-2016



(Source: author's compilation based on data from the World Development Indicators Online)

A second reason to expect that the size of African manufacturing will continue to grow in terms of value added, is that the demand for manufacturers will continue to increase in Africa, purely because the population is growing fast, and urbanizing fast, and there is globally a strong link between the number of goods manufactured (more than 10 billion unique products) and the population.

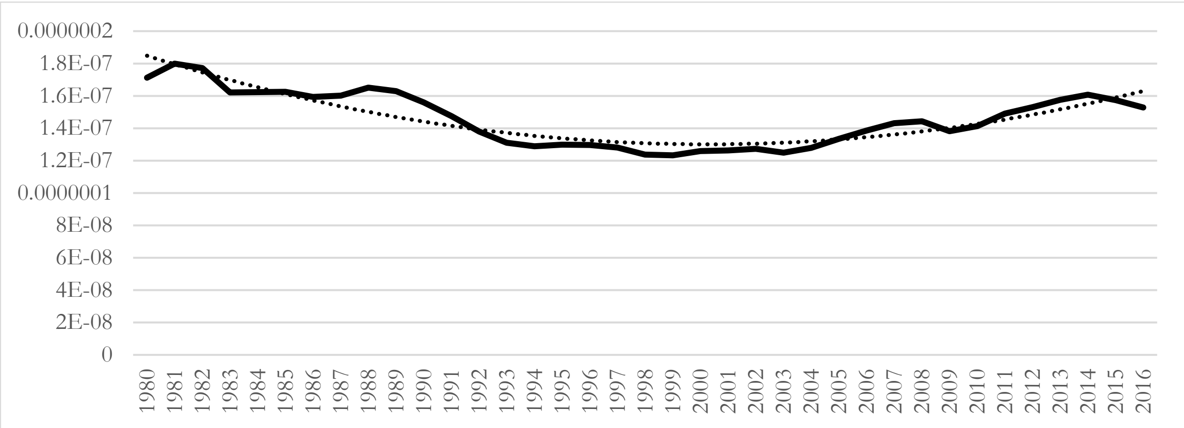
In his article '*What Africa will Look Like in 100 Years*', Kirk (2016) points out that 'Africa's population is booming. By 2100, it will be home to 4.4 billion people – four times its current population'. Most of these people will be living in cities, with the number of mega-cities in Africa having increased from one to more than 12. Even if the forecast of 4.4 billion (made by the UN) does not materialize, for instance if fertility rates decline to levels seen in other demographic transitions, the fact remains that Africa's population and urban populations will continue to grow, and exert a strong upward demand for manufactured goods. With more people in cities, the number of manufactured goods demanded per person will increase, offering a huge opportunity to local manufacturers.

There are indications that African entrepreneurs are more and more able to make use of this opportunity. For instance, as *Fig. 13* shows, since around 2000 the manufacturing value added per person in Africa has been growing steadily.

The promise of the new industrial revolution is that the simplification of manufacturing will enable African entrepreneurs to customize products to local demand (*Localized-Additive-Manufacturing-on-Demand*), thereby availing themselves of the opportunities that Africa's demographic trend offers.

Moreover, as Haraguchi et al. (2017) stress, in the recent past there has been a global concentration of manufacturing in a few locations (e.g. China, USA, EU, Japan) and this has caused some countries to think that manufacturing is less important, or in decline. However, the important aspect of the new industrial revolution is to potentially decentralize and deconcentrate manufacturing, and make it potentially easier for lagging industrial regions to manufacture more of their own products locally. As they conclude: "Achieving economic development by following the path of industrialization will likely remain important for low-income countries" (Haraguchi et al., 2017: 293).

Figure 13: Manufacturing output per person in Sub-Saharan Africa, 1980 to 2016



(Source: author's compilation based on data from the World Development Indicators Online)

While total manufacturing value added on a continent-wide level will continue to grow, and potentially grow quite fast in the coming decade, not all subsectors within manufacturing will grow, or grow equally fast, in future.[21] And not all African countries will enjoy similar growth in their manufacturing sectors.

The manufacturing subsectors in Africa that will gain most in coming years are most likely to be in food and beverage processing, and in the downstream and upstream industries that are most strongly linked to this, such as the manufacturing of machinery used in processing, including electrical and electronic equipment (e.g. *sensors, energy storage*), in transportation, and communication (e.g. *smart vehicles, drones, advanced materials, computers*), storage equipment, as well as in supporting customer services (*quality assurance, product tracking, timeous delivery, individualised design*).

As for the countries that are likely to benefit most from the new industrial revolution, the prediction is more difficult, given that the past is – especially in the case of these new technologies' impact – not a good indicator of the future. What is seen at present however, is that manufacturing is growing fastest in a relative small number of countries. As far as employment in manufacturing

[21] The experience of the USA is illuminating in this regard. Tassey (2014:28) documents how some of the "new" manufacturing sectors such as semiconductors, computers, pharmaceuticals, and medical devices grew on average by 27% per annum between 2000 and 2009, while more traditional subsectors such as chemicals, machinery, fabricated metals and plastics declined on average by 23% per year.

was concerned, most growth in the recent past has taken place in Ethiopia, Kenya, Nigeria and Burkina Faso. More generally, considering the current size of the manufacturing sector in various countries, and considering growth in manufacturing value added, the discussion in the following paragraphs attempts to identify which countries may, over the short-to-medium term, continue to grow their manufacturing sector.

It should be kept in mind that although all African countries for which time series data are available experienced growth in manufacturing value added over the past fifty years, there has been much heterogeneity in terms of the growth rates in value added and employment, as well as in the share of manufacturing value added in the total economy.

The **Appendix,** using the recent database compiled by Mensah and Szirmai (2018), shows the manufacturing value added (in real terms) in 18 Sub-Saharan Africa countries between the 1960s and 2015. Generally, three phases in manufacturing value added growth can be discerned.

First, the immediate post-independence period, roughly from the mid 1960s until the oil and debt crises of the mid 1980s, during which manufacturing value added generally grew fast: for instance in Burkina Faso, manufacturing production in real terms increased 9-fold between 1967 and 1984.

Second, the so-called lost-decade from the mid 1980s to end of the 1990s, when many African economies had to contend with structural adjustment programmes which included strong fiscal retrenchment and privatization components. During this period manufacturing output grew much slower and even stagnated in many countries. To take the example of Burkina Faso again, between 1985 and 1995 real output increased by only 18%, compared to an increase of 110% over the preceding decade.

Third, from around 2000, African economies and their manufacturing sectors tended to recover, and moreover some economies, such as Ethiopia, Tanzania, Kenya and others, experienced their most rapid periods of manufacturing output growth. Generally, the strength of the recovery period was such that the global financial crisis of 2008-2011 did little to dent the growth in African manufacturing[22]: as the Appendix shows, only South Africa and Namibia, two of the most financialized economies on the continent, showed any evidence of a decline in manufacturing output during the global financial crisis.

[22] The case of Lesotho is an interesting and somewhat unique one. In the Appendix it can be seen that from 1999 to 2005 the manufacturing output of the country more than doubled. This was due to the country's textile, apparel and footwear industries benefiting from the US's African Growth and Opportunity Act (AGOA). However, from 2005 the output declined substantially, reflecting the end of the Multifibre Agreement (MFA) in 2004.

6.2 *Net job creation will be positive*

The most feared threats of new emerging technologies for African economies are job losses (and jobless growth), and higher income inequality. The first may be the case if new technology displaces or replaces labor, and the second if new technology is skill-biased, raising the wage premium for workers with appropriate skills. The theoretical possibilities for job replacement and rising wage premia are well-established in the literature.

In an influential study, Frey and Osborne (2013; 2017) predicted that up to 47% of USA jobs could be automated in 10 to 20 years. Using a similar methodology, Bowles (2017) estimated that in case of the EU this could be even higher, at up to 54% of jobs.

Acemoglu and Restrepo (2017) calculated that one additional robot per 1,000 workers reduces the employment: population ratio in the USA by 0,37%, and wages by 0,25 to 0,5% on average. Using a similar approach, Chiacchio et al. (2018) model the impact of robotics on employment in six EU countries, finding that one additional robot per 1,000 workers 'reduces the employment rate by 0,16 to 0,20 percentage points'.

Scary as these predictions may be, the bulk of subsequent theoretical and empirical work has suggested that the negative impact of automation may be greatly overestimated. New technologies are unlikely to lead to mass unemployment.

Arntz et al. (2016; 2017) refined Frey and Osborne's (2013) method for predicting possible job losses due to automation in the USA for 21 OECD countries. They find a much lower likelihood of job losses in the OECD: only 9%.

Job displacement, rather than job replacement by new technologies, is more likely. Thus, many new jobs are likely to be created by new technology in other sectors, including jobs that may not at present exist.

Empirical evidence seems to bear out that this is already happening. Gordon (2018) finds that automation is having a 'evolutionary' rather than a 'revolutionary' impact on jobs in the USA, replacing workers "slowly" and 'only in a minority of sectors' (p.1). Indeed, Deloitte (2018) forecast more opportunities for jobs to arise in US manufacturing in the coming ten years and warn that the problem is not lack of demand for labor in manufacturing, but lack of skilled workers: concluding that up to 2 million manufacturing jobs in the US will not be filled.

Dauth et al. (2017), in line with the above, quoted findings finds in the case of Germany that no net jobs losses have taken place as a result of automation. Berriman and Hawksworth (2017) similarly reckon that in the UK there will be jobs at risk from automation (they estimate around

30%), but conclude that overall the net impact of automation on jobs will be neutral as a result of new jobs being created elsewhere in the economy.

New technology could lead to a decline in the price of the industry's good or service. If the product demand is price elastic, this will mean a rise in the demand for the good, an increase in its production and a rise in demand for labor (Bessen, 2018). Besson (2018) found that in most (manufacturing) industries over time, employment follows an inverted U-shape, with employment first rising and later declining. He explains this pattern as being due to changes in the demand elasticity: when an industry first expands the demand is highly price elastic, but at some point, it becomes less so, as consumers become relatively saturated with a product.

Therefore, new technologies will be more likely to lead to net job creation in an industry if "the technology is addressing large unmet needs affecting people with diverse preferences and uses for the technology", and that if automation introduces "entirely new products and services that tap into otherwise unmet needs and wants…there may be new and unanticipated sources of employment growth" (Besson, 2018: 14, 17).

While jobs that can be automated through a smart algorithm based on historical data may be lost, and these may include many dangerous, dirty and dull jobs, the growth in the services sector will lead to a higher demand for jobs where creativity, entrepreneurship, risk-taking and social skills are required, and which cannot be done 'algorithmically' (Makridakis, 2017:52; Deming, 2017).

In conclusion then, technological innovation (automation) does not pose huge risks for employment in Africa, as is sometimes imagined. Moreover, given the large unmet needs of the growing middle classes in Africa, the elimination of dirty, dangerous and dull jobs, and the new opportunities for female labor, the net impact of the new industrial revolution for Africa seems more likely to be positive than negative.

6.3 Technological and complex skills development will be stimulated

According to López-Gómez et al. (2017:15), in the near future 'manufacturing jobs will demand workers equipped with hybrid abilities involving deep technical specialization coupled with business awareness'. In Africa, as elsewhere, there is and will be a growing demand for workers with technology skills and with "complex" skills; particularly social and emotional skills.

Technology skills refer to skills that can be used with data, given that the new industrial revolution is putting a higher and higher premium on data[23] ('data is the new oil') and thus on skills that can

[23] See : https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data

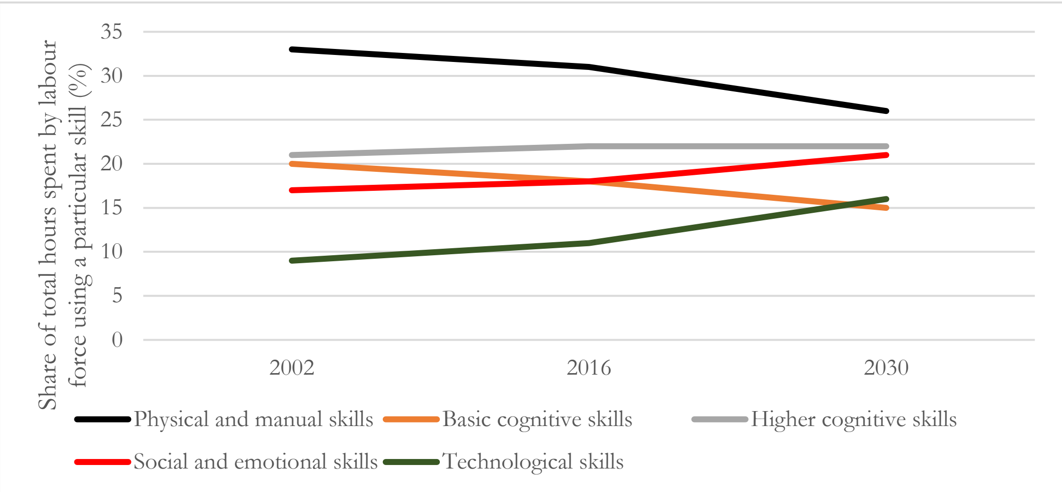
work with data (such as cybersecurity competency, data analytics and simulation modelling) and skills that can work with machines (Deloitte, 2018).

Moreover, with routine tasks being more likely to be automated, non-routine tasks, including complex social and emotional skills such as communication, persuasion, resilience and empathy are becoming more important. It was already mentioned earlier in this paper that the growth in the services sector will lead to a higher demand for jobs where creativity, entrepreneurship, risk-taking and social skills are required, and which cannot be done 'algorithmically' (Makridakis, 2017:52; Deming, 2017).

In the USA the share and wages of social skill-intensive jobs grew significantly since the 1980s. Deming (2017:3) found that in the case of the USA for instance, "the fastest growing cognitive occupations – managers, teachers, nurses and therapists, physicians, lawyers, even economists – all require significant interpersonal interaction". Moreover, the digitization of the economy is leading to all occupations becoming less routine over time so that in all occupations social and emotional skills will be more and more important (Deming, 2017).

Looking at how the skills demand is changing in the USA – the country at the world's technological frontier – may be instructive as a benchmark for African countries, given that many of the technologies driving the new industrial revolution are coming from the USA: especially those driving the digitization of the economy. For the USA, the predictions are that the next two decades will see a significant rise in the demand and use of technological skills, and social and emotional skills, and a decline in the demand for physical and manual skills, and even basic cognitive skills – see *Fig. 14*.

Figure 14: Actual and predicted changes in skills demand in the USA, 2002 - 2030



(Source : Author's compilation based on data from Bughin et al., 2018:7)

Fig. 14 uses a classification from McKinsey Global Institute's "workforce skills model" which classifies skills into five categories: physical and manual skills, basic cognitive skills, higher cognitive skills, social and emotional skills, and technology skills (Bughin et al., 2018).

Within occupations requiring more social and emotional skills, Bughin et al. (2018) predict that the demand for entrepreneurship and initiative taking will grow the fastest, and within occupations demanding technological skills, that the demand for advanced IT and programming skills will grow the fastest.

Given that these are the skills that are being demanded as the new industrial revolution unfolds, it points in the direction of the needed evolution in education curricula and educational institutions in Africa over the next two decades. Because Africa is lagging the USA in terms of technology adoption and industrialization, the changes depicted in *Fig. 14* will be different in Africa in coming years. Where will the biggest differences be?

One difference is that the share of occupations requiring physical and manual skills will not decline as fast as in the USA. Physical labor – in mining, agriculture and especially building and construction – will remain important in Africa given the need also for complementary physical (roads) and ICT infrastructure (such as broadband cables).

There may be a slower increase in technological and STEM-skills jobs in Africa. Two major reasons will be the current lags in terms of educational prowess in these areas, and the large international demand for these types of jobs, which will lead perhaps even to a brain-drain of tech-savvy workers from Africa.

As far as occupations with social and emotional skill requirements are concerned however, one should perhaps expect a faster growth in Africa. This is due to the demographics of the continent, discussed in section 2 of this paper. The demand for teachers, entrepreneurs, health care providers, lawyers and the like will grow; and grow even faster as urbanization continues.

This raises a huge challenge for educational investment and reform in Africa.

Firstly, all cognitive skills are already in short supply due to the fact that tertiary enrolment rates in Sub-Saharan Africa are the lowest of the world's regions: at an average of 7,5% over the period 2003 to 2012.

Secondly, only 25% of the already relatively small proportion of tertiary education enrolments in Africa are in STEM areas (UNECA, 2015). The lack of STEM skills can be a obstacle or bottleneck to the speed and extent to which Africa can benefit from the new industrial revolution. STEM skills underpin occupations such as robot engineers, industrial engineers, data analysts, cloud architects, and software developers (Frey et al., 2016).

Thirdly, given the growth in demand for occupations with social and emotional skills, it should be a priority to need boost management and entrepreneurial skills. Because entrepreneurship is resurgent in Africa at the moment: this momentum should not be allowed to run out of steam, but should be supported through investments in the entirely entrepreneurial ecosystem: of which entrepreneurial skills are one of the central most important elements (next to entrepreneurial finance). In this respect Naudé (2017) has argued for a more systemic approach towards development of business schools, and of lifelong education in Africa.

In both the cases of technological skills and social and emotional skills development, more collaboration between industry and education is needed. As the World Bank (2014b: 6) point out with concern: "there appears to be little knowledge transfer and collaboration between African academics and the corporate sector…especially for STEM disciplines". African countries need more initiatives that will bridge the gap between industry and education, instituting lifelong learning, apprenticeships, vocational and technical education, and support for entrepreneurship and small business management.

Having the private sector more involved in education may also be necessary, given that technological innovations are so rapid that Africa's public education systems are facing great difficulty to respond fast enough to provide labor with the type of skills that continue to complement and benefit from capitalization (Canidio, 2013). The private sector's involvement could be through for instance: advice on curriculum reform, internships, on-the-job training, and (co) funding of educational infrastructure – some examples of the learning environment that needs to be scaled up.

Finally, as the education system shifts towards producing more workers with skills in technology and social and emotional competencies, and delivers more and more STEM graduates from higher education, African governments will need to invest more in protecting their human capital – from disease, from conflict, and from exploitation. African countries need to ensure that there is a better nurturing environment for human capital on the continent that will protect Africa's knowledge base.

6.4 Investment in supportive infrastructure will accelerate

The importance of supportive infrastructure for Africa's industrial revolution cannot be overstated. Mehta et al. (2018) argue that digital infrastructure, such as broadband cables, mobile networks and internet access points, should be recognized as "a necessary universal resource for all". Other, more traditional kinds of infrastructure are also necessary, especially electricity, which is most often cited by entrepreneurs as their most serious constraint to doing business in Africa. 'Legal infrastructure', especially pertaining to supporting the digital economy, also needs to be upgraded in Sub-Saharan Africa: for instance in providing support for data protection, cybersecurity, electronic identification, and online work (Mehta et al., 2018; World Bank, 2018a).[24]

Finally, the internal infrastructure of the firm is a supportive infrastructure that will determine the speed and extent to which firms and entrepreneurs identify and adopt new technologies. It is futile to put all digital and physical infrastructure in place, if entrepreneurs and managers fail to adopt and use the new technologies to improve firm productivity and competitiveness.

The case for supportive infrastructure to enable Africa's industrial revolution is strong. For instance, Brynjolfsson et al. (2017) show that there can be significant lags before new technology will have beneficial impacts on GDP and employment growth. Emerging technologies associated with the fourth industrial revolution can have a significant impact on economic growth in Africa, but with a lag. Lags exist because (i) new technologies may require many complementary technologies, infrastructure and services first to be available[25] before they can be deployed be a firm; and (ii) the internal organization and management of firms (internal firm infrastructure) may need to change to be able to absorb a new technology, hence organizational inertia needs also to be overcome (Brynjolfsson et al., 2017).

There is growing evidence that these kind of implementation lags are preventing firms and countries from reaping the benefits of new emerging technologies – and will no doubt be the case also in Africa. For instance, surveys from the US have found that most firms do not have explicit strategies to deal with the acquisition and implementation of new technologies (Davenport and Mahidhar, 2018). Other studies have found evidence that the diffusion of technology at the firm level is slowed down by a lack of skilled labor (Bresnahan et al., 2002) and poor management (Bloom et al., 2017). One may assume that the same issues also characterize the situation in African countries. Hence investment in education, including of entrepreneurs and in building management skills, should be approached as a vital investment in Africa's manufacturing future.

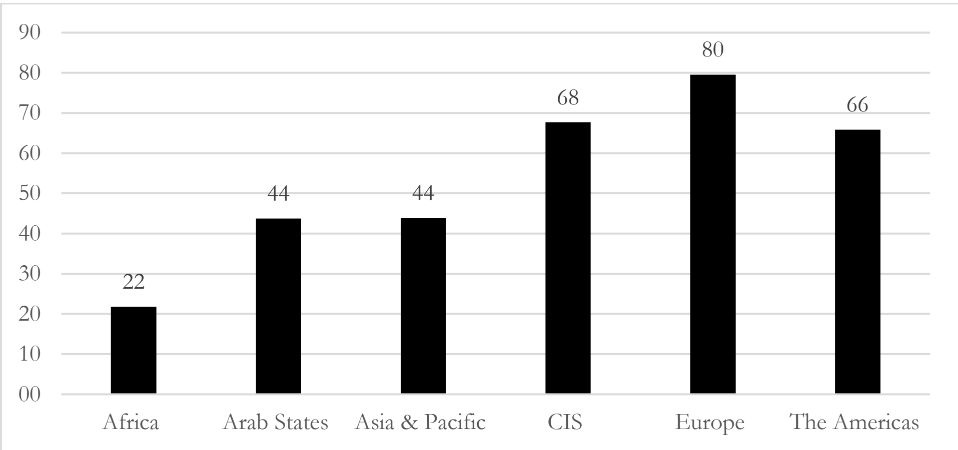
[24] Surveys of CEOs in Africa have found that businesses are more reluctant than individuals to adopt and use the internet for commerce as a result of fear of insufficient internet / data security (Naudé, 2017).

[25] For example, autonomous vehicles require the complementary technology of machine vision, and cloud computing makes the sharing of data, for machine learning, more widely available (Brynjolfsson et al., 2017).

Sub-Saharan Africa faces a gap both in terms of digital infrastructure and human skills/ organization infrastructure. How fast African countries can close these gaps will determine whether and how they benefit from the fourth industrial revolution. There are promising signs of progress.

In order to assess this progress and understand the challenge remaining, it is useful first to depict the current digital / technology infrastructure gap between Sub-Saharan Africa and the rest of the world. *Fig. 15* shows that internet use in Africa is at 22 individuals per 100 inhabitants – the lowest in the world, at about a quarter of the internet use in Europe.

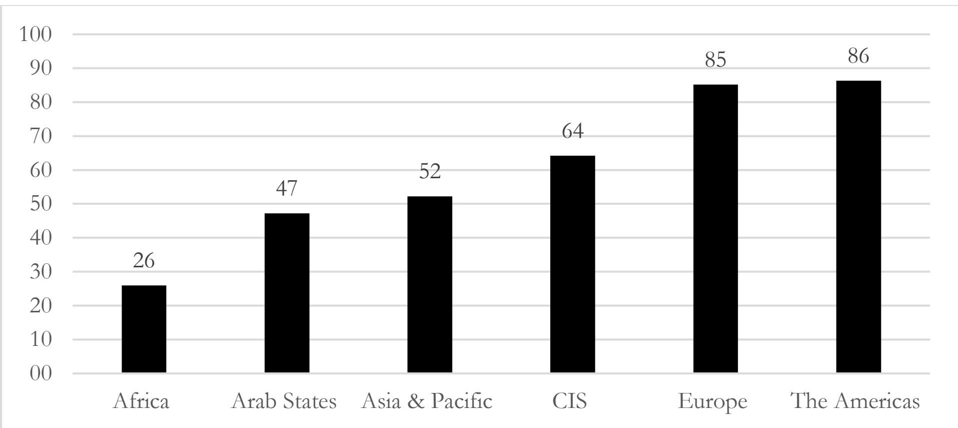
Figure 15: Individuals using the internet per 100 inhabitants, 2017



(Source: Author's compilation based on data from the ITU World Telecommunication/ICT Indicators database)

Fig. 16 shows that the same picture applies to the use of active mobile-broadband subscriptions.

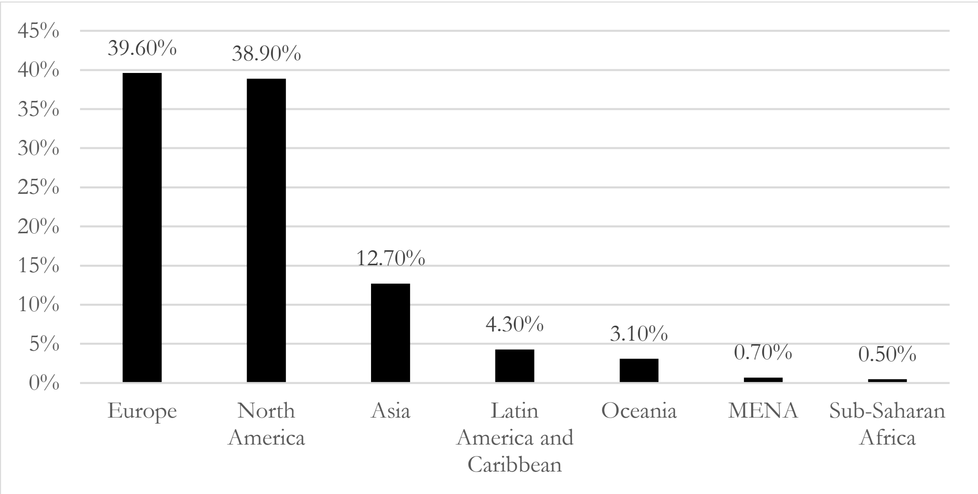
Figure 16: Active mobile-broadband subscriptions per 100 inhabitants



(Source: Author's compilation based on data from the ITU World Telecommunication/ICT Indicators database)

In terms of other indicators of participation in the digital economy, African countries do much worse however, suggesting that the gap in terms of contributing and helping to create the new digital economy, and obtaining value-added from it for economic growth and production, is much larger than the mere use of the internet or mobile-broadband. For instance *Fig. 17* depicts regional share in collaborative coding, and *Fig. 18* the regional shares in domain registrations.

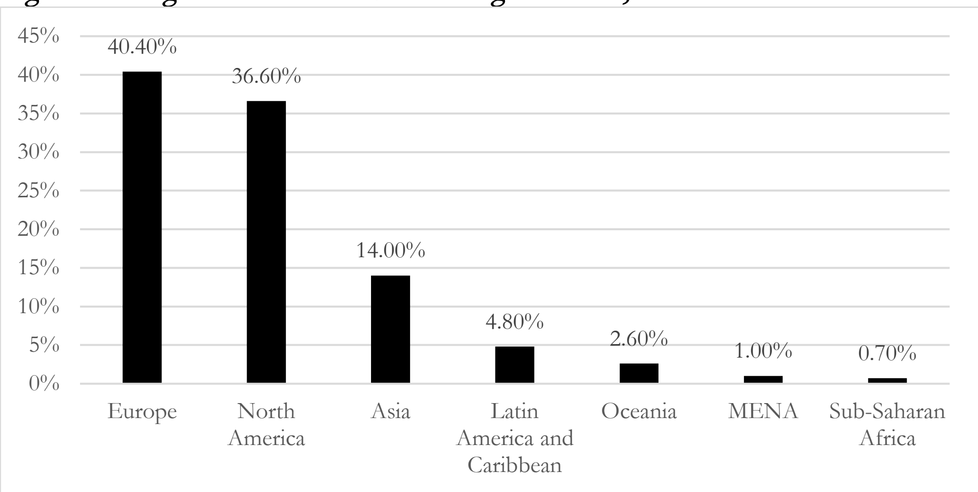
Figure 17: Regional shares in collaborative coding, 2017



(Source: Graham et al., 2017: 352).

Collaborative coding and domain registrations reflect the extent to which the online economy is co-created by a particular region. It is a measure of what has been called 'digital knowledge production' (Graham et al., 2017: 352). Collaborative coding has been measured by Graham et al. (2017) by the share of uploaded computer code on GitHub (the world's largest open-source repository), and domain registrations by the share of total domains (such as .com) being registered per region.

Figure 18: Regional shares in domain registrations, 2017



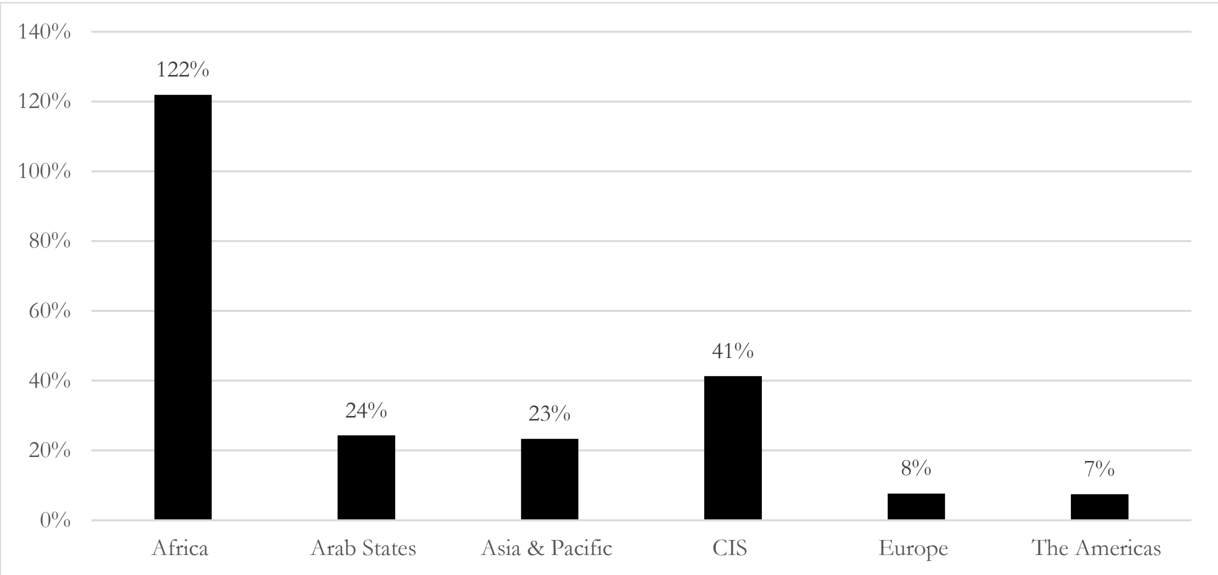
(Source: Graham et al., 2017: 352).

Fig. 17 and *Fig. 18* indicate that the digital gap that Sub-Saharan Africa faces is potentially much larger than that typically seen when only looking at standard measures such as internet penetration rates or internet use rates. In total, Sub-Saharan African countries are contributing less than 1% to worldwide digital knowledge production.

In reducing this gap, of course countries will have to start by expanding internet access and internet use. Just starting on this alone has been calculated to be able to deliver a huge 'digital divided' to African countries. Deloite (cited by Mehta et al., 2018) has calculated that if African countries can expand internet use to the same rate as that in high-income countries, they could create **140 million new jobs** and add US$ 2,2 trillion to GDP.

There are fortunately promising signs of progress in this regard. For instance as *Fig. 19* shows, the average annual growth in households with internet access at home has been growing the fastest in Africa, at 122% between 2005 and 2017.

Figure 19: Average annual growth in households with internet access at home per 100 inhabitants, 2005-2017



(Source: Author's compilation based on data from the ITU World Telecommunication/ICT Indicators database)

Similarly, Africa is experiencing the fastest growth in mobile-cellular telephone subscriptions (41% over 2005-2017), and in mobile-broadband subcriptions (170% over 2005-2017). Investment in digital infrastructure is rising, with for example the World Bank currently investing more than US$ 1.2 billion in ICT infrastructure for internet connectivity in Africa (Friederici et al., 2017:19). ICT company Ericsson predicts that by 2022, around 80% of mobile phone subscriptions in Africa will be WCDMA/HSPA, LTE and 5G, and moreover that mobile data traffic will continue to grow by 55% per year until then (Mamabolo, 2017).

The 'rapid transformation in the region's connectivity has encouraged politicians, journalists, academics and citizens to speak of an ICT-fueled economic revolution happening on the continent' (Graham et al., 2017: 346). This needs to be sustained and expanded in order for Africa to fuel its much needed industrial revolution. In particular, the promotion of open innovation, open platforms, appropriate IP rules, open data access, and education and training, have a role to play (see section 5.3), as well as stimulating new high-tech start-ups to enter the market (see section 5.6).

Dealing with data will also be important to strengthen Africa's ICT infrastructure, as it is claimed[26] that 'data is the new oil' – machine learning requires huge amounts of data. Hence this access to huge datasets is giving large online firms like *Amazon*, *Google* and *Facebook* huge advantages. Often smaller businesses, and businesses in developing countries, do not venture into AI development due to a perceived lack of data.

Cockburn et al. (2017) stresses the need for open access to data to avoid or limit wasteful investments by competing companies to each create their own proprietary database. For instance, car manufacturers whose autonomous vehicles need data to learn: if there is a common open dataset on which all potential car manufacturers could learn, it would lead to greater market entry, more transparency, more competition, and probably better outcomes for all.

Therefore, promoting access to free and open large datasets should be a priority. In this regard, it is also important to notice that governments should support innovation into the development of synthetic datasets, perhaps more reflective of African consumer demographics, with which algorithms can be trained. Such technology to generate synthetic datasets for machine learning has huge externalities, and hence would be a prime example of an area in which governments can provide a leading role.

Finally, given the need to expand internet use, participation and contribution to the digital economy, and of ensuring open access to data, African governments should desist from curbing and limiting access to the internet, and internet censorship. There are plenty of concerns that African governments are too often stifling freedom on the internet. Uganda has even introduced a tax on social media use.

Freedom House,[27] which publishes an annual "*Freedom on the Net*" report, details "the subtle and not-so-subtle ways that governments and non-state actors around the world restrict our intrinsic

[26] See e.g.: https://www.economist.com/leaders/2017/05/06/the-worlds-most-valuable-resource-is-no-longer-oil-but-data
[27] See: https://freedomhouse.org/report-types/freedom-net

rights online". According to the *Freedom on Net in 2017* report, in Africa only Kenya and South Africa allowed free internet use. After China, Ethiopia was ranked as the most abusive country towards internet freedom.

7. Summary and Concluding Remarks

Despite regular claims that Africa cannot industrialize, or that it should not, or that manufacturing itself is a thing of the past, this report has argued that the development of the manufacturing sector remains a high priority for many African countries: not least in light of the challenges posed by its demographics – a large and growing young population, still largely based in rural areas, and working in farming. Moreover, this paper contends that the future of manufacturing in Africa will be nothing like its past. The reasons are a combination of emerging and new brilliant technologies (radically transforming the nature of manufacturing), with a resurgence in start-up entrepreneurship.

This combination of new technologies and entrepreneurship offers the hope that African economies will at last be able to industrialize and structurally reform, and moreover in a way that creates new and better jobs – in particular for the bulging youth population – and that allows for the empowerment of women in the labor market.

Manufacturing remains important for Africa for a number of reasons. Even though African manufacturing has not broken into global markets and remains a *relatively* small contributor to output and jobs, in absolute terms and with respect to productivity growth, manufacturing has been significant.

This is often overlooked when only the share of manufacturing or its relative size in world production is concerned. In absolute numbers, manufacturing's importance becomes much clearer. For instance, total manufacturing value added (in constant US$) for Sub-Saharan Africa has almost tripled since 1980, and the total number of jobs in manufacturing in 18 of the largest Sub-Saharan African economies increased from an estimated 9 million in 2004 to over 17 million by 2014: an increase of 83%.

Manufacturing is also important as a driver of productivity growth in Africa. Between 2005 to 2014 for example, the countries with the highest manufacturing employment growth also enjoyed some of the highest growth rates in labor productivity.

In addition to providing output, jobs and higher productivity, manufacturing in Africa also provides better quality of employment than in other sectors. It was shown in this paper that in

Sub-Saharan Africa only 5.4% of the working poor were in industry between 2002 and 2012, compared to 16,4% in services, and 78,2% in agriculture.

Thus, moving more labor out of agriculture and into manufacturing can have a positive impact on job creation and poverty reduction.

The new industrial revolution, often referred to as Industry 4.o or the fourth industrial revolution (4IR), may offer an opportunity for African countries to further develop their manufacturing sectors.

What will be the implications (or impacts) for Africa of these technologies and trends?

The following four implications were discussed in this paper.

1. *Manufacturing will continue to grow in terms of value added.*
2. *Net job creation will be positive.*
3. *Technological and complex skills development will become central in education.*
4. *Investment in supportive infrastructure will accelerate.*

In the past, the development of African manufacturing was restricted due to, amongst others, geographical factors, low densities and lack of scale economies, the lock-in into global value chains at disadvantageous terms, and the smallness of the local and regional markets. This is set to change due to the new emerging and exponential technologies mentioned. The growth in regional trade, the growth of the African middle class, and the greater availability of the internet and internet-based education, are set to lessen these constraints.

Furthermore, although there have been a lot of scaremongering headlines in the international press about the destruction of jobs ("technological unemployment") due to the new technologies mentioned, the conclusion in this paper is that these do not pose huge risks for employment in Africa, as is sometimes imagined. Moreover, given the large unmet needs of the growing middle classes in Africa, the elimination of dirty, dangerous and dull jobs, and the new opportunities for female labor, the net impact of the new industrial revolution for Africa seems more likely to be positive than negative.

To ensure that the new industrial revolution does indeed bring to fruit the four implications discussed, a number of broad policy recommendations can now be made.

Industrial policy is of strategic importance to harness the benefits of the brilliant new technologies that are transforming manufacturing. Both advanced economies, such as in Europe and the USA, and recent industrializers, such as China, have taken strategic steps to benefit from these technologies and to limit possible negative impacts. López-Gómez et al. (2018: 20-22) provide a discussion of these recent industrial policies in China, the UK, Germany, Japan and the USA.

In light of the exponential impact of new technologies, and in light of the fact that all of the major manufacturing countries in the world are adopting strategic policies to leverage these technologies for their manufacturing competitiveness, Africa cannot continue under a business-as-usual scenario. African countries need their own industrial policies, and these need coordination and support on a continent level.

Given the nature of the new industrial revolution, the approach to industrial policy making needs to be different from the past. After gaining independence after the Second World War, those African countries where a deliberate industrial policy was followed, all attempted import substitution industrialization (ISI) strategies and the promotion of state-owned enterprises. When, after the oil price and debt shocks of the 1980s, many countries required structural adjustment policies, the imposed Washington Consensus promoted trade policy liberalization, fiscal retrenchment and privatization to supplant industrial policies in many African countries.

Now, with the opportunities from the new industrial revolution, beckoning a return to past policies hardly seems viable. Taking a new track, through entrepreneurial-innovation led industrial development, seems a more viable option. The changes in technology are so fast, and the accumulation of data so voluminous, that African policy makers cannot continue to rely on the essentially 19th century, top-down bureaucratic process of industrial policy making, anymore.

Based on the expected impact that the new industrial revolution and its technologies will have, that was discussed in section 6 of this paper, the following broad, generic policy recommendations can be made in Table 2, by way of a summary of the central messages of this report.

Table 2: Policy Recommendations to Enable Africa's Industrialization in an Era of Brilliant Technologies

Expected Impact	**Facilitating / Enabling Policies**	**Section in this paper**
Manufacturing will continue to grow in terms of value added.	• Demand-side policies. • Reaping demographic dividends.	6.1
Net job creation will be positive.	• Reducing skill mismatches. • Promotion of gender equality. • Education and skills.	6.2
Technological and complex skills development will become central in education.	• STEM skills expand. • Entrepreneurship and management skills. • Business school development. • Industry collaboration.	6.3
Investment in supportive infrastructure will accelerate.	• ICT infrastructure e.g. broadband. • Promote internet access and use. • Respect freedom of internet use. • Ensure data protection. • Improve electricity access and cost.	6.4

(Source: Author's compilation based on the discussion in the paper)

The success of its industrial policies will determine the competitiveness of African manufacturing in the coming decade. It is imperative therefore that the manufacturing sector itself as a collective should be engaging in policy advocacy to improve the entrepreneurial and innovation ecosystems for manufacturing on the continent.

In such a more systematic approach, promoting gender equality is a prerequisite. This paper has documented how the 4th industrial revolution will bring more opportunities for women and can further gender equality in Africa. However, an important condition for this is that both education and labor market policies should actively support women in terms of access to jobs and access to the education and skills they need. Countries should prioritize the removal of legal restrictions that discriminate against women and their opportunities of benefiting from future growth in manufacturing. It this respect it has been pointed out in the literature that "…the issue is not with the technology, but the policies".

Africa (and the world for that matter) still faces important gender gaps. The gender gap in higher education enrollment and employment in high-tech areas, including science and engineering fields, is a cause of concern, although there are very hopeful signs in Africa. For example, this paper has documented that more and more women in sub-Saharan Africa are qualifying themselves in science, technology and engineering fields, and also found evidence that in Sub-Saharan Africa, improvement in gender parity is correlated with more female participation in science and engineering. In South Africa, women already made up 49,1% of all tertiary graduates in science in 2013, thus achieving gender parity.

Investments in the skills of the workforce need to be complimented by investments in the infrastructure and capital that workers need to be productive and competitive. In this paper, calls were supported that: digital infrastructure such as broadband cables, mobile networks and internet access points should be recognized "as a necessary universal resource for all" on the continent. At present, internet use in Africa is at 22 individuals per 100 inhabitants: the lowest in the world, and about a quarter of the internet use in Europe.

In terms of other indicators of participation in the digital economy, such as collaborative coding and domain registrations, it was found in this paper that African countries do actually much worse however, suggesting that the gap in terms of contributing and helping to create the new digital economy, and obtaining value-added from it for economic growth and production, is much larger than in the mere use of the internet and mobile-broadband.

In reducing this digital gap, countries will have to start by expanding internet access and internet use. Just starting on this alone has been calculated by McKinsey to be able to deliver a huge "digital divided" to African countries, of 140 million new jobs and an additional US$ 2,2 trillion to GDP. There are promising signs in this regard: the average annual growth in households with internet access at home, mobile-cellular telephone subscriptions and mobile-broadband subscriptions, has been growing the fastest in Africa in recent years. Investment in ICT is rising, and ICT company Ericsson predicts that by 2022 around 80% of mobile phone subscriptions in Africa will be WCDMA/HSPA, LTE and 5G – and moreover, that mobile data traffic will continue to grow by 55% per year until then.

Given the need to expand internet use, participation and contribution to the digital economy, and of ensuring open access to data, this paper voiced concern that too many African governments are still curbing and limiting access to the internet and engaging in internet censorship.

One country has even introduced a tax on social media use to discourage participation in the digital economy. And only two countries on the continent, Kenya and South Africa, have been found to offer the citizens sufficient freedom on the internet. Relaxing such constraints, and rather focusing on regulations and provisions to support data protection, cybersecurity, and electronic identification, are recommended.

In addition to digital infrastructure, more traditional kinds of infrastructure and finance are also necessary: especially the cost and availability of electricity (which is most often cited by entrepreneurs as their most serious constraint to doing business in Africa), and entrepreneurial (risk) finance such as venture capital and business angels – which is growing fast, but still inadequate in Africa.

The investments made by African governments in education, physical infrastructure and entrepreneurial ecosystems is perhaps best concentrated in urban areas – in city formation. The urbanization of Africa is underway, and this will see the rise of at least 12 megacities in Africa by the year 2100.

The bulk of Africa's manufacturing will take place in these cities, which should be actively developed as "smart cities" – cities where urban planning is optimal to ensure connectivity, mobility, networking, learning, and utilizing new technology to improve living conditions in sustainable manner. The development of "smart" cities in Africa will provide a mutually reinforcing mechanism for the development of manufacturing.

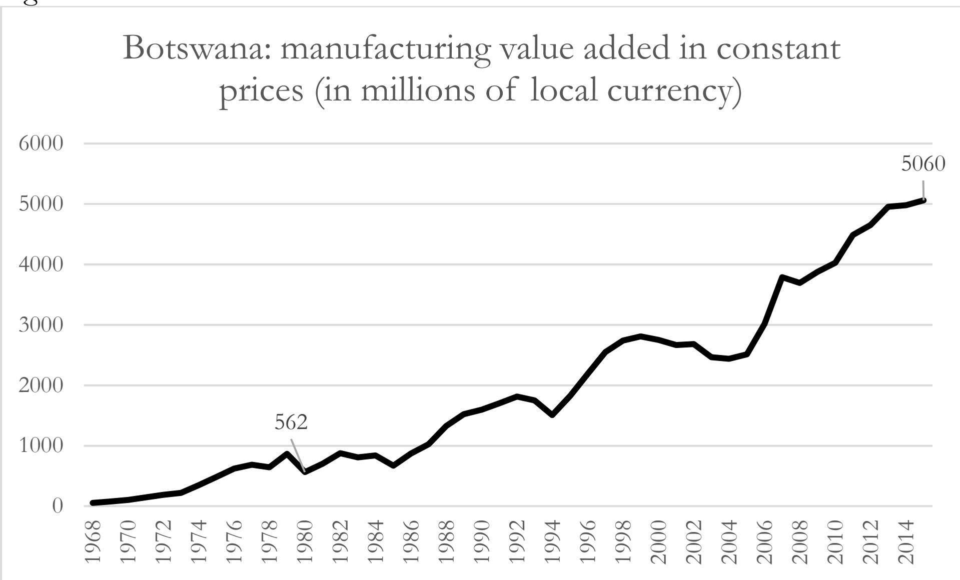
Finally, governments need to underpin investments in their entrepreneurial ecosystems and growing cities with a better system of social protection / insurance, including unemployment insurance, basic income grants, pension systems, business insurance, and credit schemes. Africa spends the least of any continent on social protection, and having such mechanisms in place will increase the propensity of entrepreneurs to make the risky investments which success in the new industrial economy will require.

The policy recommendations for investments in education, entrepreneurial ecosystems, infrastructure, regulations and smart city development are very broad recommendations, which should however be adopted and adapted on a country-by-country level. Africa is a very heterogeneous continent, and its large number of countries, some small, some landlocked, with different geographical constraints, would each need to fill in these broad recommendations with specific measures, objectives and time frames. This will mean that explicit industrial policy setting should be on the agenda of all countries, and coordinated at the level of the African Union.

Finally, policies matter. It is likely to become even more important in the future, given that industrialization will rely more and more on highly skilled labor and much venture capital: both factors that are very mobile. Countries that get it wrong will be quickly marginalized in a world economy where cheap labor and land will not be counting for as much as they did in the past.

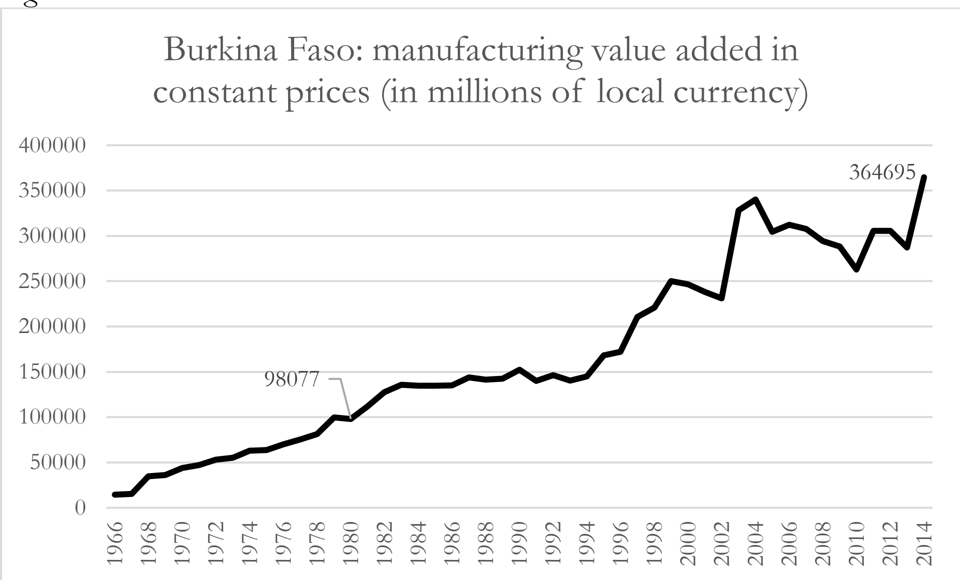
8. Appendix

Fig. A1



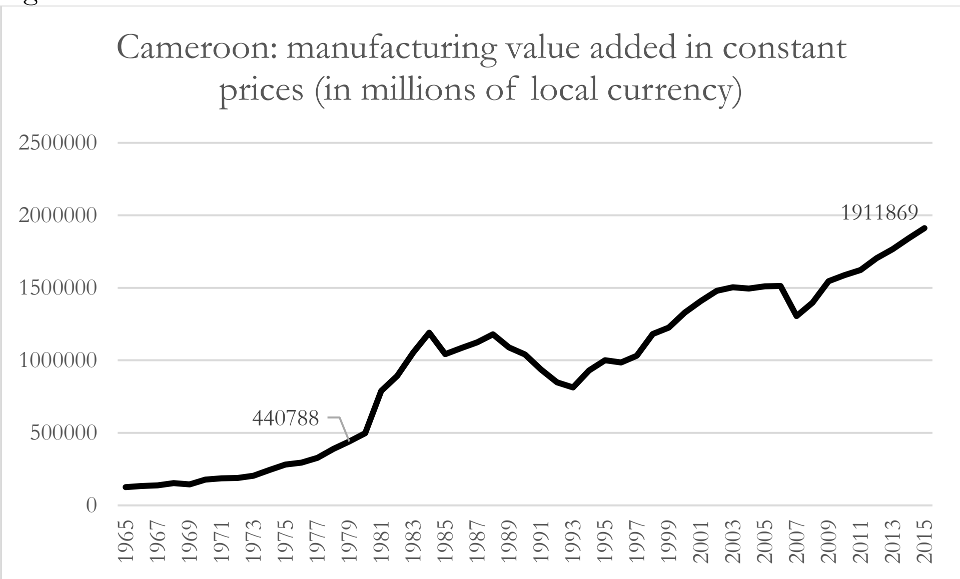
(Source: author's compilation based on data from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Fig. A2



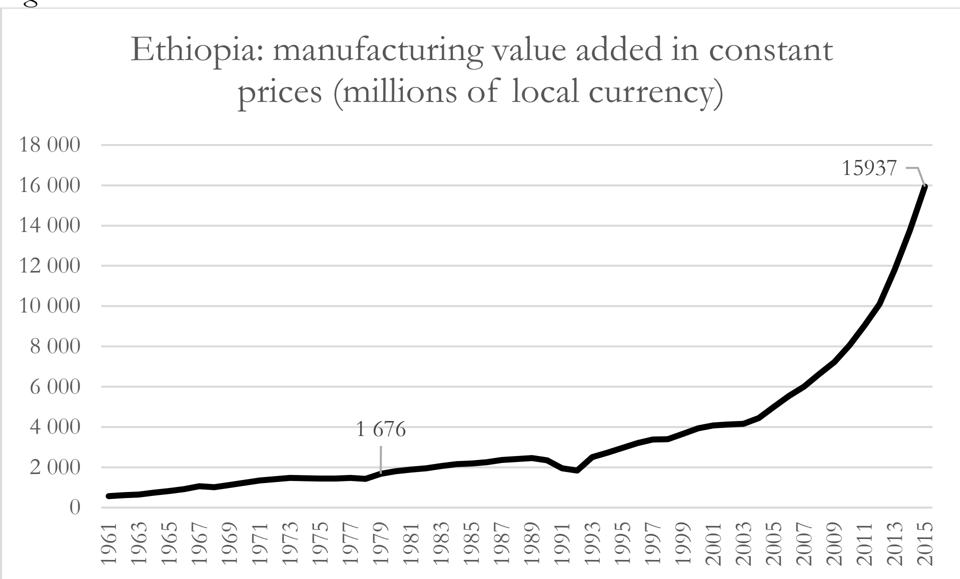
(Source: author's compilation based on data from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Fig. A3



(Source: author's compilation based on data from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Fig. A4



(Source: author's compilation based on data from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

Fig. A5

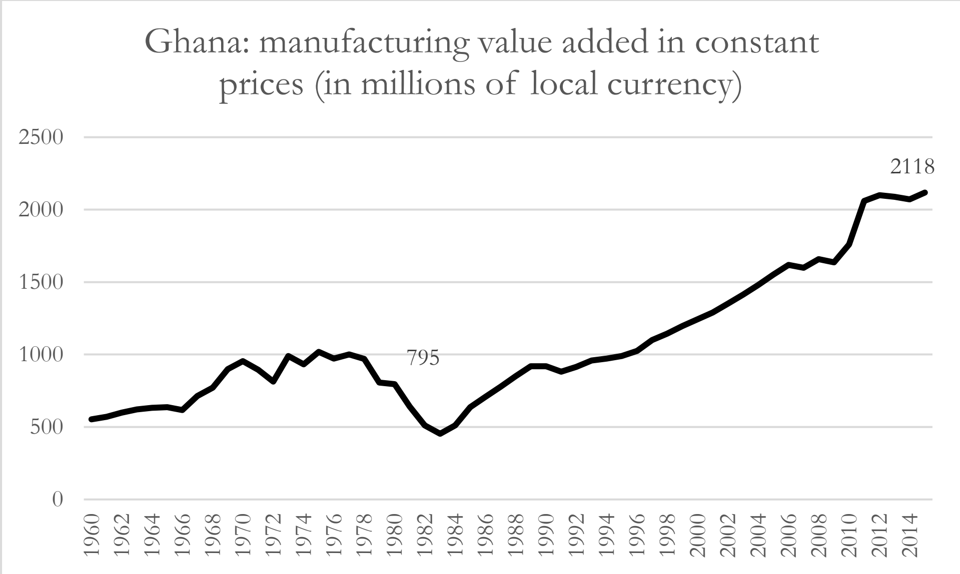


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Fig. A6

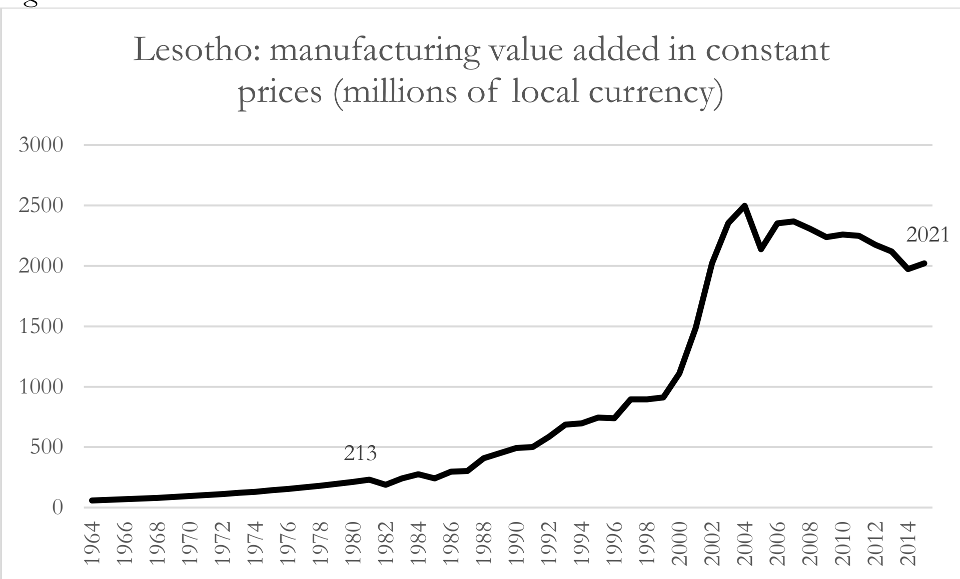

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Fig. A7

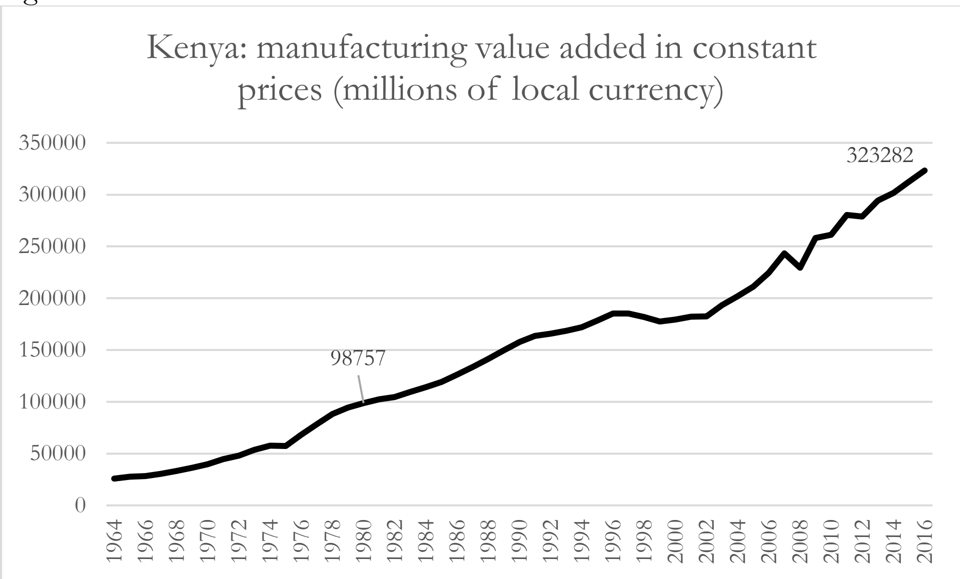

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Fig. A8

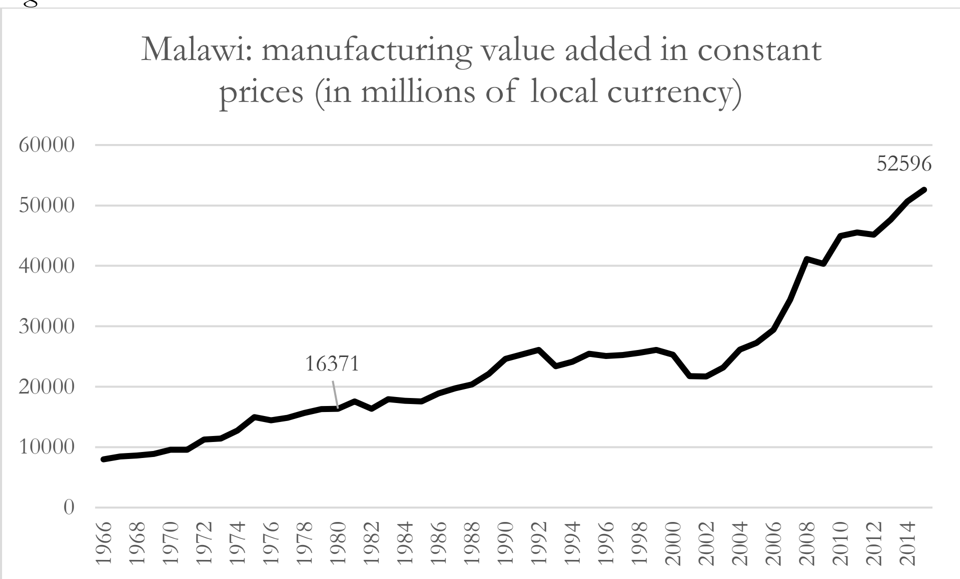

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Fig. A9

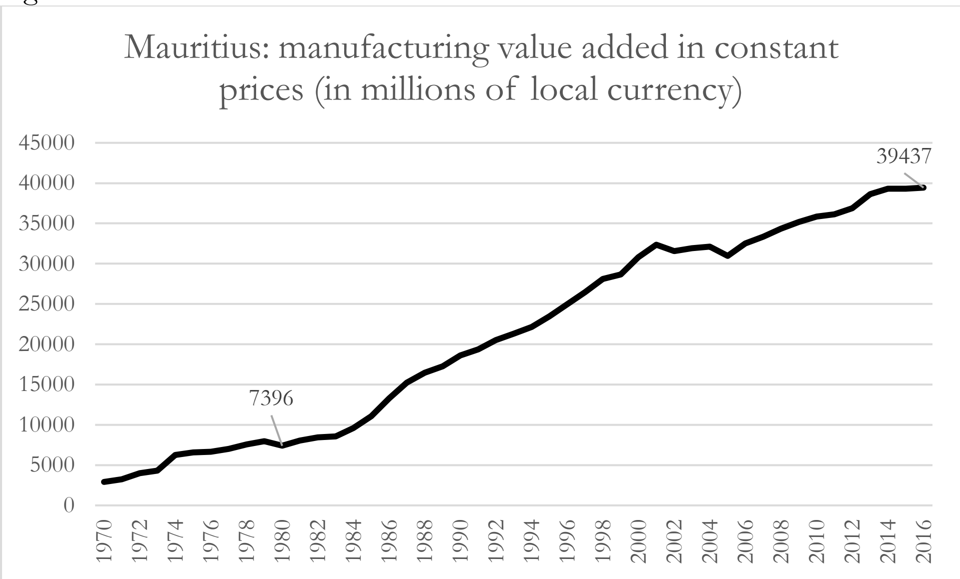

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Fig. A10

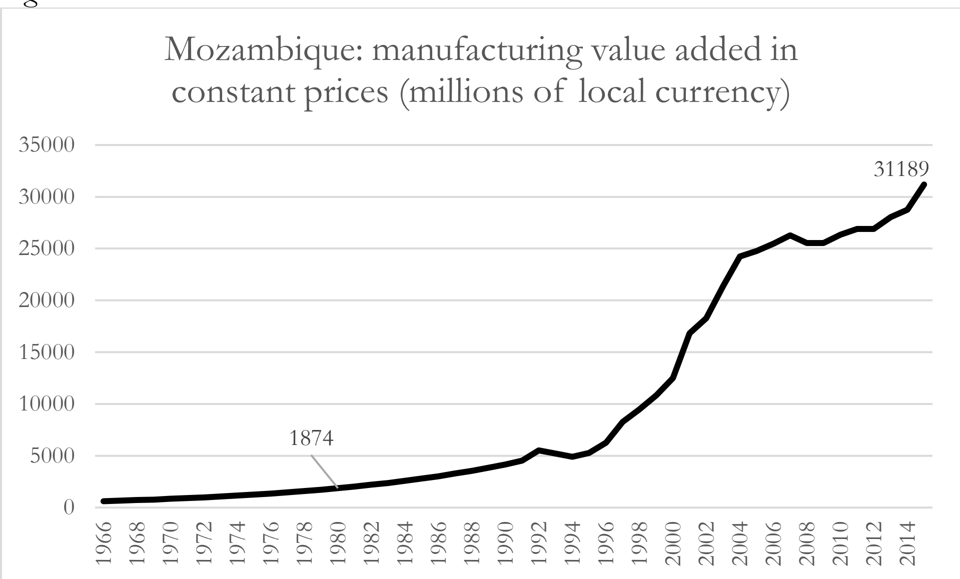

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Fig. A11

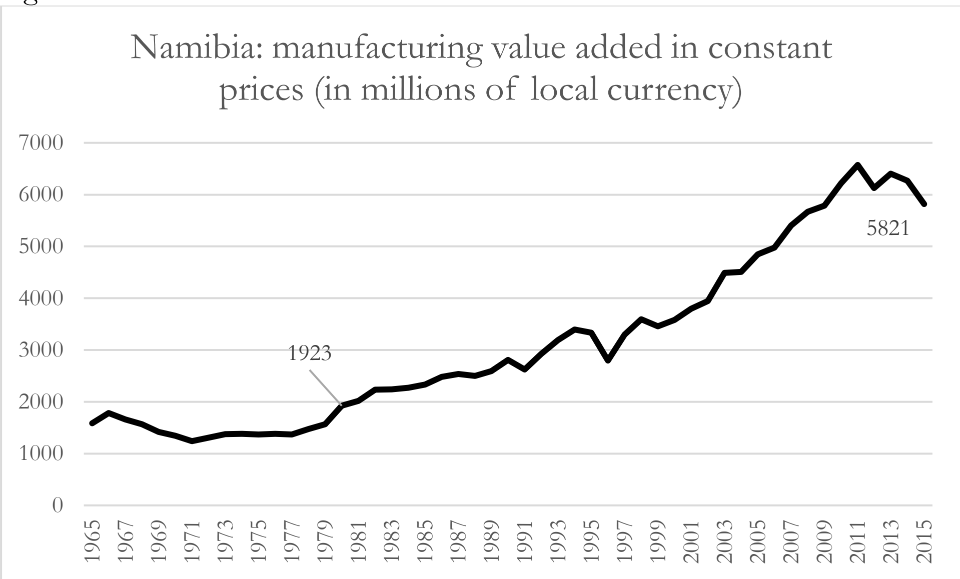

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Fig. A12

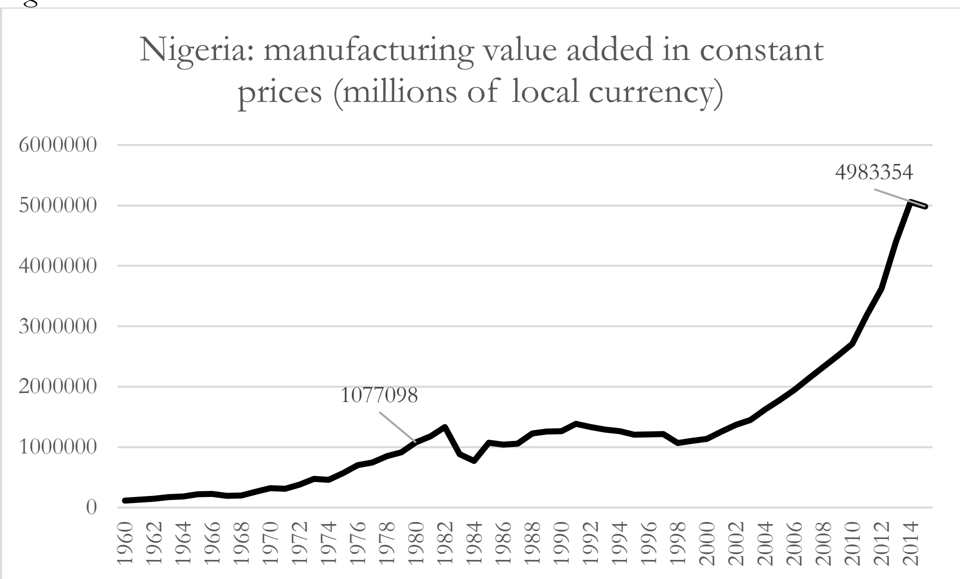

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Fig. A13

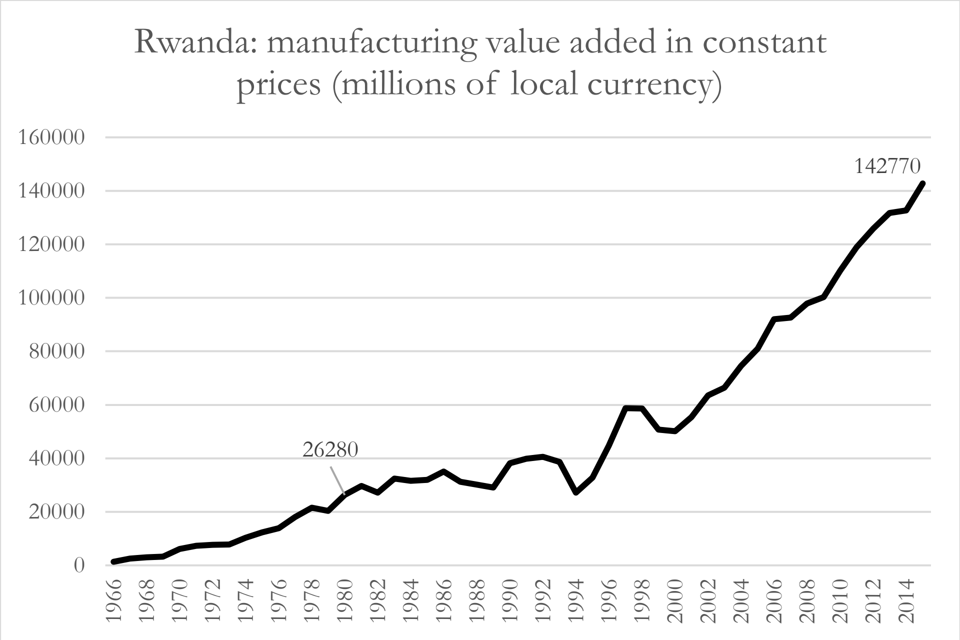

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Fig. A14

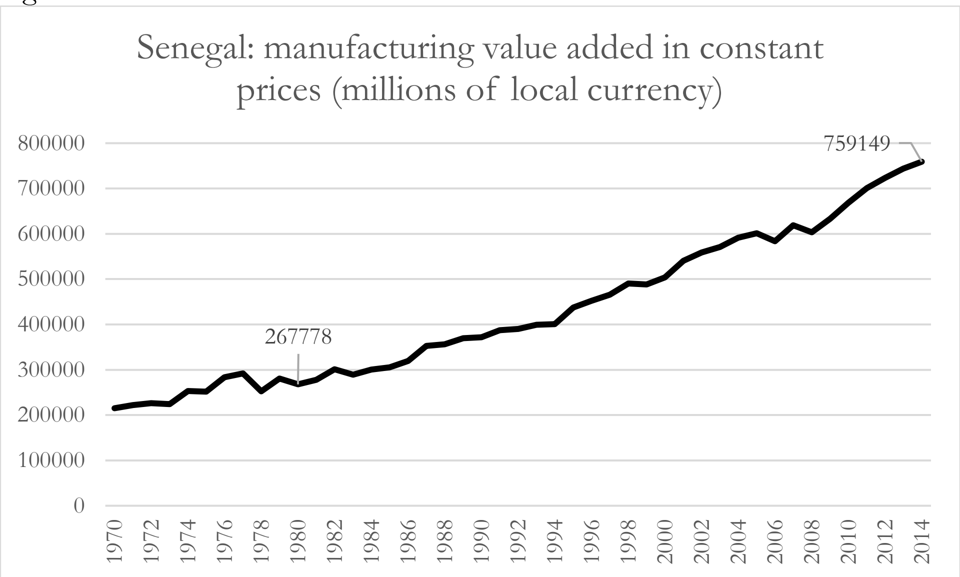

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Fig. A15

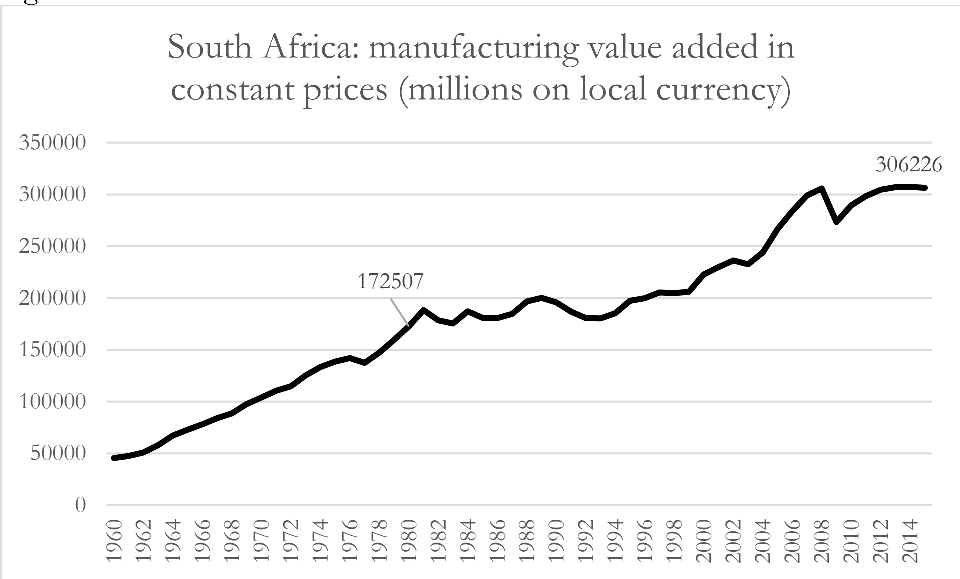

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Fig. A16

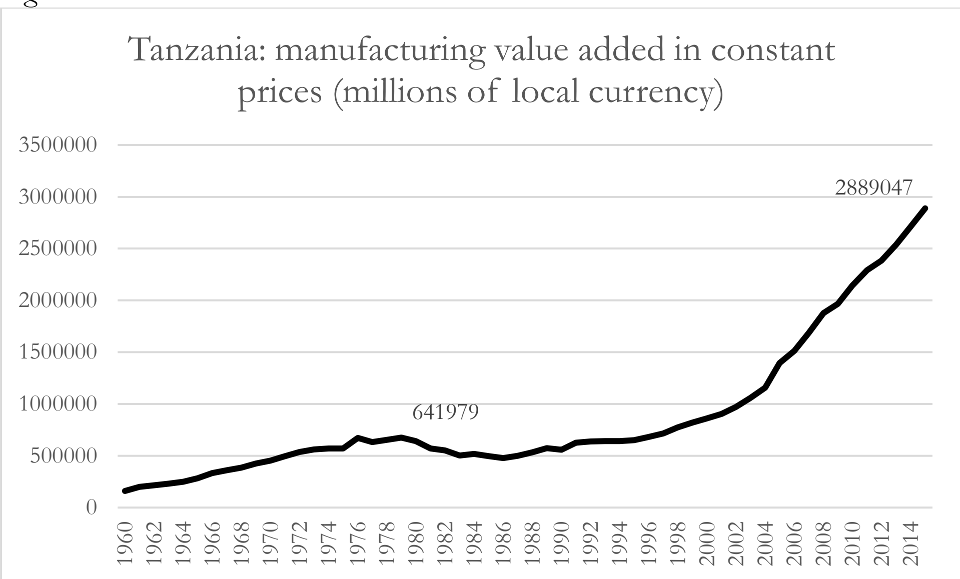

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Fig. A17

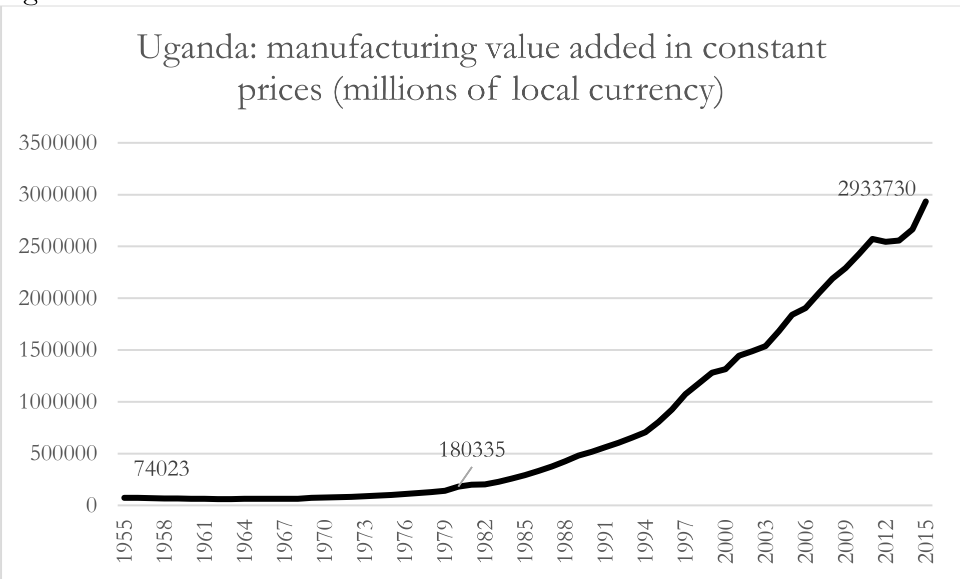

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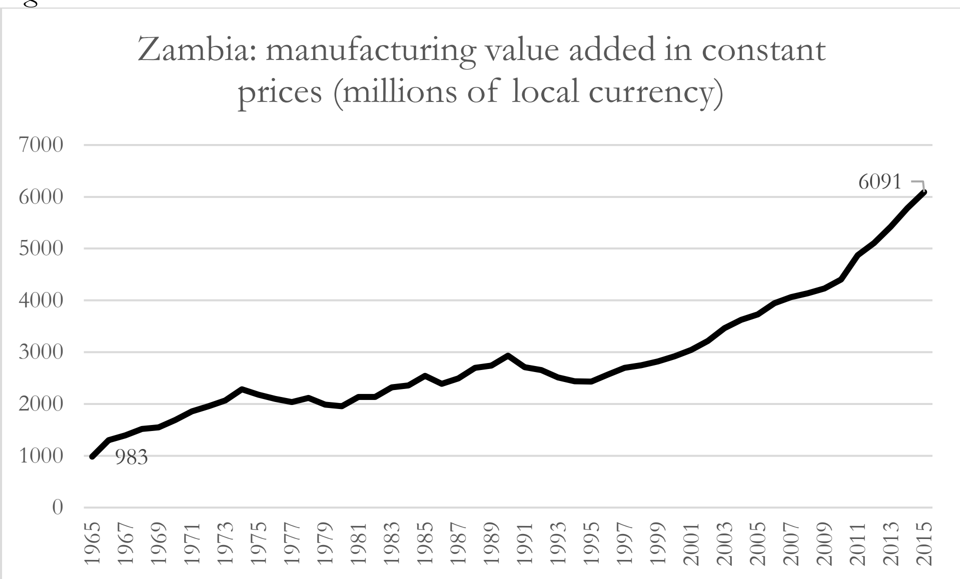
Fig. A18



(Source: author's compilation based on data from the Expanded Africa Sector Database (ASD) of Mensah and Szirmai, 2018).

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