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ABSTRACT

Entrepreneurship, Education and the Fourth Industrial Revolution in Africa

The Fourth Industrial Revolution (4IR) is impacting on the industrialization options for Africa inter alia through three interrelated sets of technologies, namely automation, additive manufacturing and the Industrial Internet. In this paper I set out the case for why Africa should industrialize. I then explore the opportunities and threats the 4IR pose for Africa. Threats include job-losses and the re-shoring of manufacturing to advanced economies. Among the opportunities are products-as-services, the sharing (collaborative) economy, and digital services and digital exports. These are markets that are currently underdeveloped in Africa but have substantial potential given Africa's geography, demography and on-going urbanisation. In order for the continent to benefit from the 4IR more needs to be done to improve entrepreneurship and education. A number of policy recommendations for 4IR-compatible entrepreneurship and education policies are made.

JEL Classification: O55, O25, O14, O33, L26, J24
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1 Introduction

Despite Africa's poor track record with industrialization, a renewed desire for (re) industrialization is animating development and policy debates. See for instance the African Union's *Agenda 2063*[1], the African Industrial Development Action Plan [2] and the 2017 African Economic Outlook[3]. This renewed desire is the result of a number of factors, one of which is the Fourth Industrial Revolution (4IR), which is driven by technologies such as automation, additive manufacturing and the Industrial Internet.

The 4IR indeed holds out opportunities for African (re-) industrialization. Among the opportunities are new business models of bringing goods and services to consumers. These include products-as-services, the sharing (collaborative) economy and digital services and exports. These are all markets that are currently underdeveloped in Africa but have substantial potential given Africa's geography, demography and on-going urbanisation. A further opportunity is that small scale manufacturing in Africa may become more competitive and efficient as a result of the mentioned technologies. But the 4IR also poses some threats to African (re) industrialization. The main threats are job-losses, the redundancy of the model of industrialization through attracting FDI based on low-cost labor in assembly-type manufacturing, and the re-shoring of manufacturing to advanced economies.

In this paper I investigate these the opportunities and threats. The key recommendation that I make is that in order to minimise the threats and avail itself of the opportunities, African countries need to improve entrepreneurship and education.

As far as entrepreneurship is concerned, policy makers should recognise that 4IR-compatible industrial policy requires promotion of entrepreneurial experimentation within an appropriate entrepreneurial ecosystem, characterised by live-and-let-die policies that will not support or keep inefficient firms alive; that will minimise rent-seeking and avoid government capture by entrepreneurs; that will provide entrepreneurs with smart government support; and that invests in entrepreneurial skills.

As far as education policies are concerned, I argue in this paper for industrial policies that promotes the (i) development of business schools and technical vocational colleges with a strong link to the commercial sector; (ii) raising of investment in technical and STEM skills; (iii) shifting of learning towards aquisition of complex, problem-solving skills; (iv) creation of a nurturing environment for human capital to better protect Africa's knowledge base from conflict and disease; (v) underpinning of investments in the knowledge base and entrepreneurial ecosystem with better social protection and insurance; and that (vi) promotes the efficiency of financial markets and access to finance, given that education is costly and subject to fixed costs.

The paper is structured as follows. In section two I define industrialization and articulate the need for Africa to industrialize. Section 3 provides a short description of the salient features of the 4IR. In section 4 the implications for Africa are explored. Section 5 considers the policy implications, specifically for entrepreneurship and education. Section 6 concludes.

[1] see http://www.au.int/web/en/agenda2063
[2] see http://www.au.int/web/en/ti/aida/about
[3] see http://www.africaneconomicoutlook.org/en/theme/Entrepreneurship-and-industrialisation

2 Why Africa needs to Industrialize

For purposes of this paper industrialization will refer to the process of structural transformation of an economy away from dominance by the primary sectors, to an economy where manufacturing plays a more prominent role in output and employment. It is important to note at the outset that technological progress (innovation) is necessary for successful industrialization.

In this definition of industrialization, there is no getting away from the fact that it entails the rise of manufacturing. Manufacturing refers to slightly narrower subset of activities than industry, as the latter also includes construction and energy. This does not imply that services are unimportant for industrial development. Certainly, many services provide for more productive employment that primary sectors. Indeed, the pattern of structural transformation in most advanced economies have been characterised by labour moving from primary sectors, to manufacturing and then to the service economy. In all advanced economies today services employ more people than manufacturing and contribute more to value added than manufacturing.

Services are also important for Africa's structural transformation, and industrial policies, for so far as their main aim should be on manufacturing, would be wise to incorporate an understanding of services. The manufacturing sector typically source between 20 and 70 percent of intermediate inputs in the form of services, such as research and development, maintenance, transport and finance. Smart services based on data analytics and using the Industrial Internet are re-shaping manufacturing. To an extent the nature of manufacturing itself is increasingly assuming a service orientation, for instance through being more directly aligned to consumer needs and preferences and through provision of products in non-material forms. An example is the recording industry's streaming of music through online channels, in addition to the manufacturing of physical compact discs and vinyl records.

Manufacturing development as an outcome is nevertheless justified, because this is typically the target of industrial policies and because de-industrialization is defined by reference to manufacturing. Manufacturing may also be special for Africa. Naudé et al. (2015) based on Szirmai (2012) lists a number of reasons why. One is that countries with a larger manufacturing sector tend to have more stable growth than countries dependent on production and exports of commodities. Africa's growth since the 1950s has typically been 'a story not of persistent failure, but rather of periods of growth, followed by reversals which often erase any gains that were made during the growth spurt' (Broadberry and Gardner, 2013). See also Jerven (2010). This is because of the dependence on agriculture and mining for growth (World Bank, 2014a). The growth rates of the past decades have been due to commodity extraction and imports which had further contributed to the de-industrialization of the continent and it being 'pushed further and further into underdevelopment and dependency (Taylor, 2016).

Another reason why manufacturing is a special sector is that a 'productivity bonus' can result when resources are transferred from agriculture to manufacturing, because value added per worker is higher in manufacturing than in agriculture (Szirmai, 2012). The size of the 'productivity bonus' has been calculated for some African countries. For example Vollrath (2009) found the marginal product of labour in industry to be over 10 times higher than in agriculture in Kenya, Malawi, Zimbabwe and South Africa. The movement of jobs from agriculture to manufacturing is moreover also desirable because manufacturing jobs tend to be located in cities and towns and not in rural areas like farming jobs. Hence manufacturing development goes hand-in-hand with urbanisation, and urbanisation is

associated with substantial increases in labour productivity due to locational and urbanization externalities (Owoo and Naudé, 2017). In Africa there is a strong negative correlation between the proportion of a country's population living in rural areas and its level of per capita income (de Brauw et al., 2013). Christiaensen et al. (2013) found that around 50 per cent of people who escaped from poverty in Tanzania between 1991 and 1994 did so by migrating out of agriculture into non-farming and into urban-based activities, including manufacturing.

Given these benefits it is regrettable that manufacturing has hardly developed in Africa. There is even evidence of (premature) de-industrialization in Africa, as defined by reductions in employment and value added in manufacturing (Timmer et al., 2014; UNECA, 2015; Rodrik, 2015a). For instance by 2013 manufacturing contributed 9,9 percent to the economies of Africa, less than in any other region of the world. Only 18.5 per cent of Africa's merchandise exports in 2013 were manufactures. Although the shares of Europe and North America are also relatively low, at 12 per cent and 15 per cent respectively, the share of manufacturing in Europe (and North America) were much higher when they were at a comparable level of development (Rodrik, 2015b). These countries also continue to export a higher proportion of manufactures in their merchandise trade: 73.9 per cent in the case of Europe and 66.8 per cent in the case of North America. Moreover in these countries, the share of manufacturing in GDP started to decline only *after* GDP per capita and employment in manufacturing had reached high (er) levels. In contrast, in Africa the share of manufacturing has been around 11 per cent already back in the 1960s, and unlike East Asia, industrial growth has never been the main driver of growth in Africa.

An estimated additional 170 million workers will be entering Africa's labour force between 2010 and 2020 (Fox et al., 2013). Where will they find jobs? The primary sectors, farming and mining, holds limited potential to absorb these work seekers. Farming is already characterised by surplus labor and low income growth[4], and productivity gains through mechanisation may in future limit further job creation. While the mining sector is by far the most productive sector in Africa it operates largely on the world technological frontier and is by nature heavily capital intensive. Most new mining technologies are job replacing. Mining thus cannot absorb much labour and despite high commodity prices jobs in mining has even declined in many of Africa's largest mineral exporters, for example South Africa. Most of the new job opportunities in future in Africa will most likely be in services sectors. While this will be welcome in terms of leading to (static) productivity gains by re-allocating labour out of farming, the longer-term weakness is that this may amount to what has been termed 'productivity-reducing structural change' (McMillan and Rodrik, 2011), because productivity growth is slower in service than for perhaps in manufacturing(de Vries et al., 2013). Hence, by pursuing industrialization African countries may hope to create jobs and dynamic productivity gains. Whether they will succeed in this will depend on whether it can grab the opportunities offered by the 4IR and minimize the threats.

3 The Fourth Industrial Revolution

The Fordist-type of mass-producing manufacturing of the late 19th and 20th centuries are increasingly obsolete in the 21st century. Technological innovations have heralded a Fourth Industrial Revolution (4IR). Schwab (2016) point out that the 4IR is driven technologies such as automation, additive manufacturing and the Industrial Internet. The *First Industrial Revolution*

[4] The agricultural sector in Africa has recorded the lowest growth in per capita incomes over the period 2005-2011, at 0.9 per cent per year on average (World Bank, 2014a).

was driven by steam and water energy; the *Second Industrial Revolution* by electricity; the *Third Industrial Revolution* by information and communication technologies (ICT) (Schwab, 2016). According to Schwab (2016) the exponential changes in new technology are characterized by 'a fusion of technologies across the physical, digital and biological worlds' that are leading to 'profound shifts across all industries, marked by the emergence of new business models which affects every aspect of society'.

The 4IR is different from earlier industrial revolutions in that whereas the earlier 'revolutions' saw technology replacing skilled workers (e.g. artisans in textile factories replaced by power looms) and compliment low skilled workers (e.g. the steam engine) in the 4IR technologies tend to replace lower-skilled workers while complementing higher-skilled workers. A binding constraint on whether an economy can participate in manufacturing in the 4IR then becomes whether it has enough relevant skills available[5]. Hence many low-skilled routine jobs in manufacturing, which Africa has a disproportionate share of, may be automated. Frey et al. (2016) estimate that up to 66 per cent of all jobs in developing countries are at risk. Even relatively poor African countries such as Angola and Ethiopia, there is a risk of having around 50 and 44 per cent of current jobs being susceptible to automation respectively.

A further threat is that there may be a reduced need for the advanced economies to offshore their manufacturing or assembly operations to countries only based on considering low-cost labour. Indeed, the 4IR is leading to a re-shoring of manufacturing to the detriment of low-wage labor in African and other developing countries. As remarked by Culey (2012): 'how important is low-cost labor when you dont actually need labor?'

As Frey et al. (2016) (p.8) also conclude, developing (African) countries will 'lose their cost advantage and potentially their ability of achieving rapid economic growth by shifting workers to factory jobs'. There are still however many scholars and policy makers who despite this, cling to the belief that as wages rise in China, this will create opportunities for Africa in manufacturing[6]. UNCTAD (2016) recently warned that robotics are driving a re-shoring of manufacturing and that this 'could turn global value chains on their head, and lead to their decline as a potential industrialization strategy for developing countries' (p.2).

These features imply a threat to African countries in terms of job-losses of existing low-skilled routine jobs in manufacturing, the redundancy of the model of industrialization through attracting FDI based on low-cost labor in assembly-type manufacturing and the re-shoring of manufacturing to advanced economies. But it also offers possible opportunities for African countries to develop 'new forms of manufacturing that would trigger a period of valuable growth' (Marsh, 2014). These 'new forms of manufacturing' refer firstly to new business models of bringing goods and services to the consumer. These include tools that will enable African entrepreneurs to provide to products-as-services, to establish and grow the sharing (collaborative) economy[7], and to deliver digital services and exports: markets that are currently underdeveloped in Africa but likely to have substantial potential given Africas geography, demography and on-going urbanisation[8]. These new business models will involve physical

[5] Skills that may become more relevant in the 4IR include social and creative intelligence, top management and leadership skills, as well as skills required for arts and entertainment (Brynjolfsson and McAfee, 2012a; Autor and Dorn, 2013).

[6] It has been argued that more generally, China's impact on African industrialization has been disastrous; see eg. Kaplinsky and Morris (2009) and Burgis (2016).

[7] Frey et al. (2016) estimate that the global revenue from the sharing economy will exceed USD 335 billion by 2025 with the best opportunities in peer-to-peer financing, online staffing, peer-to-peer accommodation, car sharing and music video sharing. The sharing economy is still in its infancy in Africa.

[8] To elaborate: Africa is huge continent characterized by large distances between and from markets; it is the

manufacturing but also manufacturing related and intensive services.

Secondly, the 'new forms of manufacturing' refer to small scale manufacturing that is now made more competitive and efficient through tools that enables additive manufacturing, mass customisation, cheaper automation and reduced input costs. Brynjolfsson and McAfee (2012a) mentions as example 'cheap robots-in-a-box that make it possible for small business owners to quickly set up their own highly automated factory, dramatically reducing the costs and increasing the flexibility of manufacturing'.

Thirdly, while the 4IR *per se* does not bode well for routine jobs in Africa, it is said to hold opportunities for certain types of skills, including creative, innovative and social skills, such as that associated with entrepreneurship (Brynjolfsson and McAfee, 2012b,a; Autor and Dorn, 2013). As Brynjolfsson and McAfee (2012a) pointed out 'There has never been a worse time to be competing with machines, but there has never been a better time to be a talented entrepreneur'. In section 4.1 I list some recent examples where this is starting to happen in Africa.

The new business models and the enabling of small scale manufacturing as mentioned in the previous paragraphs will potentially have positive spillover effects such as a closer alignment of the needs of African consumers with production, greater accessibility to goods and services, better use of natural resources, and less waste.

If the threats and opportunities of the 4IR are to be taken adequately into account in industrial policies in Africa then a thorough understanding of the implications of the 4IR for the continent is required. So far however, the literature and policy discussions have been limited in this respect. More work and more debate are needed to understand the likely impact of key emerging technologies like automation, additive manufacturing and the Industrial Internet on Africa's economies. The remainder of this paper will attempt to make a modest exploratory contribution in this regard.

4 Implications for Africa

The world in which Africa wants to pursue industrialization and development *anno 2017* is radically different from the post-independence world of the 1960s, and even post-Washington Consensus world of the 1990s. Most relevant for industrialization, the last decade has seen exponential changes in technologies that have changed the nature of manufacturing to its core. As was mentioned in the previous section these changes are described as heralding nothing less than a 4IR. As far as manufacturing is concerned, the 4IR is impacting on manufacturing among others through three major and interrelated sets of technologies, namely (i) automation, (ii) additive manufacturing and (iii) the Industrial Internet. The purpose of this section is to describe these technologies' impact on manufacturing, and to cursorily explore the threats and opportunities they hold for African countries.

continent with the most landlocked countries in the world; it is also the fastest urbanizing continent and the continent with the youngest population, meaning that its population will continue to grow for a long time into the future. Furthermore it is expected that climate change will have a disproportionately negative impact on Africa. All of these trends will create many problems and opportunities that the new technologies together with clever entrepreneurs can address.

4.1 Automation

Automation (including robotics and artificial intelligence) has made significant inroads into manufacturing in recent years. According to the International Federation of Robotics (IFR) an expected 1.4 million new industrial robots will be used in manufacturing worldwide between 2014 and 2019. The annual production of new robots has increased significantly from 2009 from 60,000 in 2009 to 322,000 in 2017. The reasons for this accelerating adoption of robots in manufacturing are due to declining costs of robotics and improvements in the abilities of the robots themselves. As a result, manufacturing industries are adopting robots and are seeing the greater efficiencies translate into increased labour productivity.

Frey et al. (2016) refers to a study by Boston Consulting that estimates that automation would raise labour productivity in manufacturing by between 10 and 30 percent over the next decade (p.67). Past experience indeed indicates that automation raises labour productivity. Graetz and Michaels (2015) studied the impact of automaton in 17 countries (none African) using panel data spanning 1993 to 2007 and found that it raised productivity growth by 0.37 percentage points per annum on average and that it did not contribute to higher overall unemployment in any of the countries studied.

Robots are particularly more efficient than humans in doing work that are 'dull, dangerous and dirty' and hence most industrial robots are used in three major manufacturing sectors: vehicles and transportation equipment, electronics and electrical equipment and machinery (Frey et al., 2016). These sub-sectors are where most imports of African countries emanate from, and also the sub-sectors where the Industrial Internet is expanding most rapidly.

Automation is hence both a threat and an opportunity for African industrialization. First, in terms of a threat it is clear that unless Africa adopt and use this technology where possible in its existing manufacturing plants, it stands to fall even further behind in terms of already large labour productivity gap with other countries. Moreover, the extent to which China is investing in robotics [9] (it is becoming the most significant market for industrial robots in the world with 40 per cent of global robot purchases) suggests that robots may pose an increasing threat to low-cost African labour.

If ultimately African entrepreneurs cannot seize the opportunity of producing at least some robots in Africa, the benefits of developing manufacturing on the continent will be relatively limited. Of course African firms can import robots, and they will have to do so increasingly as the standards in global value chains will require them to be compliant, but this will come at the cost of job creation. And African manufacturing will, as in the past, have to make do with the least valuable slice of the value chain. The point is that countries that manufacture and export robots will have the competitive advantage in manufacturing. This is the more so given that the sectors where robots (and the Industrial Internet) are most in use (transport, machinery, electronics) will remain important in virtually every economy in the world. At present the major producers of robots are in Germany, Japan, and the USA. There are currently no suppliers of industrial robots or cobots from Africa.

As an opportunity, robots may offer a less costly solution to overcome some of the current institutional and geographical constraints that hamper African manufacturing. One branch of

[9] In 2016 China spent more than USD 11 billion on take-overs of high tech German firms, most involved in robotics (see https://www.bloomberg.com/gadfly/articles/2016-10-24/maybe-europe-is-not-for-sale-to-china-after-all). According to the International Federation of Robotics (IFR) by 2017 there will be more robots in China than in the United States or Europe (Naudé and Nagler, 2015b).

robotics, namely the manufacturing and use of drones (unmanned aerial vehicles or UAVs) is of particular current interest in Africa given the continent's large distances, rugged terrain, lack of public transport, and conflicts. Drones are already being used in farming[10], surveillance[11], construction site monitoring, wildlife protection[12], and in deliveries[13]. These drones are all still imported, implying an opportunity for local entrepreneurs.

In Africa most robots in manufacturing are currently in use in South Africa's automotive manufacturing (Hendrikse, 2014). But given the need and potential there are a number of small, but growing initiatives to pilot the greater use of robots and most of these are driven by the private sector, with very little public sector support so far (perhaps illustrating that the issue is still below the radar for most policy makers and development agencies). For instance, in Ghana the *African Robotics Network* in 2016 boasted more than 380 members from 51 countries; in Uganda the 'Fundi Bots' initiative is teaching Ugandan schoolchildren about robotics, and in Egypt EG Robotics was launched in 2015 as an entrepreneurial initiative to promote robotic development in Egypt and more generally the MENA region. In 2014 Liberia piloted the first 'Ebola-fighting robot' (a robot that disinfects rooms and kills the Ebola virus) in a hospital in Monrovia, and in 2015 the DRC installed two traffic robots to control traffic in Kinshasa.

These are just a selection of some current initiatives reported in the popular press that illustrate that interest in robotics is alive and gathering momentum in Africa. Moreover, the potential for robotics to be adopted in Africa is becoming more and more feasible due to the continuing decline in the cost and flexibility of robots [14] (falling by around 30 per cent per year), improved robotic abilities (e.g. in machine vision) and progress in the evolution of co-bots (collaborative robots) that are easy to transport, can reprogrammed, can learn by doing, and are more affordable than robots (Friis, 2016).

4.2 Additive manufacturing

Additive manufacturing (industrial 3D-printing) uses laser printers to produce objects by printing very thin layers of material onto one another. It has gained momentum as a result of innovations in laser (3D) printing, materials science and computer aided design (CAD) software. It has shown to be potentially important for production of components and parts, for instance in jet engines and medical equipment (Rotman, 2013).

Additive manufacturing (3D-printing) has potential to open up opportunities for entrepreneurs to enter into manufacturing in Africa. This is due to the particular features of 3D-printing. For instance, 3D-printers are much more mobile than much other manufacturing machinery; the price of 3D-printers are declining; the energy requirements of 3D-printers are less than

[10] According to Weeden (2016) 'drone use has exploded in South Africa with drones being used increasingly by farmers to check fence lines, dam levels, windmills, livestock, wild game'.

[11] Nigeria's National Petroleum Corporation (NNPC) is using drones to patrol its oil pipelines to reduce theft.

[12] Google donated USD 5 million to the World Wildlife Fund (WWF) to buy drones to be used in Africa and Asia to protect wildlife from poachers. At the University of Maryland's Institute for Advanced Computer Studies, big data analytics are used to create algorithms that can predict where and when rhino poaching in African countries will most likely occur. These are combined with drones to reduce rhino poaching (see https://theconversation.com/satellites-mathematics-and-drones-take-down-poachers-in-africa-36638).

[13] Rwanda is building the world's first 'drone port to be used in deliveries of medical supplies and other goods in a country with a very rugged, mountainous terrain' (see http://qz.com/519849/the-worlds-first-airport-for-drones-will-be-built-in-rwanda/).

[14] Graetz and Michaels (2015) report that between 1990 and 2005 the average price of industrial robots declined by 50 percent.

that of traditional machinery in part-production; by printing spare parts and components using open source software the dependence of manufacturing and other activities such as farming on traditional transport and logistics are reduced (Juma, 2015).

Additive manufacturing (3D-printing) has promising applications for agricultural industrialization in Africa. A recent project that pilot additive manufacturing in this regard is the **3D4AgDev** project, funded by the Bill and Melinda Gates Foundation and GIZ and supported by the University of Galloway. According to the 3DAgDev website[15] the project use 3D-printing to provide women smallholder farmers the technology to 'design and develop their own labour-saving agricultural tools whereby '[...] local tool manufacturers (artisans, blacksmiths) can copy plastic prototypes and develop their own modifications.

The relevance of and potential for additive manufacturing in Africa is illustrated by the fact that Togolese entrepreneur Afate Gnikou won an international prize for manufacturing a prototype 3D-printer from recycled electronic waste in Togo, for less than USD 100 (and using crowd-funding to raise the capital for this) (Scott, 2015). Other 3D-printing initiatives being tested in Africa by the end of 2016 included the following (as examples) (see also (Scott, 2015; Juma, 2015)):

(i) Using 3D-printing, a project of the *Vanderbilt-Zambia Network for Innovation in Global Health Technologies* 3D-prints 'fully functioning molecular biology and chemistry labs' in rural Zambia for use in malaria testing.

(ii) The Youth for Technology has established a 3D-printing academy for girls in Kenya and Nigeria. It is aimed to provide opportunities for young women to design and 3D-print their own products, and assist them to develop their entrepreneurial skills to bring these products to market.

(iii) Using 3D-printing, South African entrepreneur Hans Fouch printed appliances such as a lawn mover and a vacuum cleaner, as well as shoes.

(iv) The South African firm *Rapid 3D* is reported to have become a leading supplier of 3D-printed components such as fuel nozzles, dental and medical equipment and jewellery in Southern Africa.

(v) In South Africa, the world's second-largest supplier of titanium ore, entrepreneurs in collaboration with government and research institutions, have developed 3D-printing systems to accelerate the additive manufacturing of titanium metal parts, including titanium hip joints. Production times are up to eight times faster than older technologies (Wild, 2014).

(iv) In Uganda 3D-printers have been introduced to print prosthetic limbs for amputees.

It is yet early days for this technology, and evaluations of the above mentioned example projects still remain to be made. The success or failure of 3D-printing in Africa depend on supporting infrastructure and capabilities such as energy (reliable electricity), fast and reliable access to the internet (for software, online sales, cyber-security) skills in the areas of design, computer aided manufacturing, and marketing, and finally greater collaboration and networking, including sub-contracting between large firms and the many potentially tech-savvy small manufacturers.

[15] See http://3d4agdev.org.

4.3 The Industrial Internet (and Internet of Things)

The Internet of Things (IoT) refers to the use of information and communication technologies to connect people to a variety of objects (things), not just their computers or smart phones, but also household appliances, motor vehicles, and households. Examples include autonomous vehicles, connected light bulbs, smart houses and even Wi-Fi connected teapots. It is estimated that by 2020 there will be 50 billion 'things' connected to the Internet (Accenture, 2015).

Whereas the IoT allows people remote control as part of their consumption of goods and services, and aims to improve the consumption experience, the Industrial Internet is the connection of the machines in manufacturing through ICT also described as cyber-physical production systems (CPPS). Hence, the *Industrial Internet* consists of machines at various stages of the manufacturing supply chain communicating with one another. For example engines, coolers, conveyer belts, transportation devices, quality controllers and other machines can share information through being equipped with sensors and connected to the internet. These 'smart machines are 'product-service hybrids that are capable of 'producing data for use in digital services' (Accenture, 2015) (p.31).

The volumes of information collected results in big data that can be utilised in prediction, which can lead to more timely maintenance and better designs of tools and equipment (Accenture, 2015). The aim of such communication and information sharing is to improve the efficiency of production.

Areas where the Industrial Internet is making an impact are in production of machinery, electrical and electronic equipment, and transportation equipment production; utilities (energy, construction) and healthcare services. It is estimated that these efficiency improvements in these sectors could amount to up to USD 15 trillion by 2030 (Accenture, 2015).

These sectors are also the sectors where most of Africa's imports are concentrated in, meaning there is a large and existing market[16] . To be able to manufacture some of these robotics-intensive goods within Africa, clustering and agglomeration economies would be key, and large-scale ventures involving public-private partnerships required. Here the options for small-scale, micro-entrepreneurs, even if 'gazelles', will be limited in this regard.

The Industrial Internet is in its infancy in Africa. But it has significant potential benefits to improve the competitiveness of African manufacturing. For instance, as Accenture (2015) notes smart technologies in manufacturing help reduce maintenance and repair costs; improves energy efficiency; reduce risks and improve regulatory compliance. These are all areas wherein current African manufacturing is lagging. Some pioneering applications of the Industrial Internet in Africa include (i) Lonmin using smart machinery in its largest platinum smelter in South Africa[17], and (ii) Siemens' monitoring South Africa's Passenger Rail Agencys train network[18].

Given the importance of Africa in supplying important mineral commodities to global manufacturing processes (e.g. bauxite, platinum), the need for the roll-out of energy smart grids and renewable energy systems, and the growth of healthcare and transport services in Africa, the question is whether or not African entrepreneurs can gain a foothold in producing

[16] According to UNECA (2015) Africa's top imports in 2013 included USD 69.3 billion of machinery, USD 48.8 billion in vehicles and transport equipment, and USD 47.7 billion in electrical and electronic equipment.
[17] See http://www.gereports.com/post/93771862550/this-software-is-worth-its-value-in-platinum/
[18] See http://www.africanbusinessreview.co.za/technology/2385/Siemens:-digitalisation-is-a-key-economic-driver-in-Africa.

and supply the smart machines and grids to be used in mining and electricity expansion, and in healthcare and transportation.

The availability of big data from the Industrial Internet, coupled with new technology in data analytical tools such as data storage, data mining and data visualization offers opportunities for African entrepreneurs to provide new business models and new management tools and digital services for improving the competitiveness of these sectors. Digital service development also allows a gateway into exporting of digital services, which is increasingly facilitated by the growth in global internet bandwidth[19] . For African entrepreneurs risk being side-lined from digital trade which according to Pepper et al. (2016) amounted to USD 2.8 trillion in 2014, and 'now generate more economic value than traditional flows of traded goods'.

The adoption of the Industrial Internet in Africa will most crucially depend on the availability of skilled labour and skilled entrepreneurs, in particularly to understand the nature of digital services and how to develop these given the nature of physical production. As Trabulsi (2015) outlines, the scaling up of the Industrial Internet will require, and especially so in Africa, progress in the development and use of Platforms-as-a-Service (PaaS). The PaaS market is estimated to be valued are around USD 8 billion by 2020, and more than 650 industrial internet companies were founded since 2015, mainly in the USA[20] and Europe (Trabulsi, 2015). None of these are in Africa, raising the fear that Africa is already lagging too far behind to ever catch up and become a role-player in the Industrial Internet.

The success or failure of the Industrial Internet in Africa will also depend on the availability affordable energy / electricity costs as well as fast, reliable and open Internet. In this respect there is consensus that connectivity in Africa need to be improved. As Friederici et al. (2016) document, the World Bank alone is currently investing more than USD 1.2 billion in ICT infrastructure for Internet connectivity in Africa. As the Internet is rolled out, an area where much progress is still needed in Africa is in data security and an appropriate regulatory framework for data capturing and sharing. This is important as 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 data security.

5 Policy Implications

As I argued in section 2, the continent needs to grow its industrial sector if it wants to develop. This is now having to taking place in a world where the 4IR is irrevocably transforming manufacturing (as outlined in section 3) posing both opportunities and threats. For Africa to grow its industrial (and specifically manufacturing) sector in the future, as indeed the African Unions *Agenda 2063* desires, would require that it develops industrial policies to participate in the 4IR.

In particular this would require new industrial policy thrusts on the country level that would see the continent's producers increasingly adopt automation, additive manufacturing, and the Industrial Internet. Such an industrial policy, given the speed of technological progress and

[19] Global Internet bandwidth increased from less than 50 terabytes per second in 2010 to more than 200 terabytes per second in 2014 (Pepper et al., 2016) .

[20] The dominant global firms working on the Industrial Internet and developing PaaS are all USA-based firms, such as GE, IBM, CISCO and Microsoft. The market value of these four firms far outstrips the market value of the five largest manufacturing firms in Germany (Trabulsi, 2015).

the risk-taking required, would need a significant refocus as compared to the past (and many still current) industrial policies that focuses on state-owned enterprises, import-substitution and government blue-prints. It would need a much greater involvement and facilitation of entrepreneurship, because of the nature of the 4IR where knowledge, skills and opportunity recognition are at a premium. As Marsh (2012) has pointed out, manufacturing is nothing but the combination of materials, energy and ideas. For Africa the most binding constraint to industrialization is not the materials or the energy, but the ideas. And it is here where entrepreneurship and skills are critical. In the following sub-sections I discuss the policy implications for entrepreneurship and education.

5.1 Entrepreneurship Policies

There is consensus in the literature that entrepreneurship in Africa is marked by two dichotomies: a dichotomy between entrepreneurs in the formal sector and in the informal sector, and a dichotomy between foreign entrepreneurs and indigenous entrepreneurs (Naudé, 2010). Most entrepreneurs in Africa are in the informal sector where enterprises are very small and rarely grow. These tend largely to be owned and managed by indigenous entrepreneurs (Nagler and Naudé, 2017). Against these, large firms in the formal sector are largely owned and managed by foreigners or are part of the state-owned enterprise sector. There is little interaction between the large foreign owned firms and the small informal indigenous-owned firms (Naudé, 2011).

In the past, African entrepreneurs did not feature significantly in industrial policies, which were more focused towards state-owned enterprises, foreign investment, and trade policies. Unlike in the industrial policies of China, South Korea or Malaysia for example African countries rarely aimed to promote indigenous ownership, joint ventures with foreign companies in manufacturing, or established venture capital funds to provide risk capital for entrepreneurs. As a result most African entrepreneurs today are self-employed workers primarily in services and trade sectors (Naudé, 2016).

How can this be changed? The challenge is compounded by the fact that there is no simple manual for policy makers who desire to promote industrialization through entrepreneurship. Nevertheless, from the existing literature and past experiences there are a number of broad guidelines. There are five dimensions of entrepreneurship that need to be stressed here for industrial policy purposes.

The first is that as Hausmann and Rodrik (2003) pointed out, entrepreneurs fulfill a 'cost-discovery' function by finding out what a country is good at manufacturing, as government does not possess that information. An industrial policy that that facilitates this cost-discovery function of entrepreneurs need to flexible, and moreover encourage experimentation. With a 'flexible' industrial policy is especially meant a policy that will stop support or intervention '*if it turns out not to be efficient*' (Aghion, 2009) (p.15). This is a weakness of African industrial policies where there have typically been very few mechanisms to get rid of inefficient protected firms. As identified by Campbell (2009) (p.1) most governments lack the strength 'to cut support to unsuccessful companies and industries' which are politically well-connected.

The second dimension of entrepreneurship that industrial policy should take into account, a bit related to the last point, is that policy makers and development agencies should not underestimate the dangers that entrepreneurs may pose. This refers in particular to the danger of regulatory and government capture, and even more serious forms of destructive entrepreneurship

such as looting, people smuggling, poaching and outright war. Consider three recent examples. Dreher et al. (2016) investigated the relationship between African leaders' birthplaces and the destination of Chinese-funded industrial projects in Africa between 2000 and 2012. Determining the location of 3,097 projects they concluded that 'when leaders hold power their birth regions receive substantially more funding from China than other subnational regions' (p.1). State capture by entrepreneurs has contributed to the destruction of the textile industry in northern Nigeria. Millions of garments with the label 'Made in Nigeria' is illegally smuggled across the Niger border, with the complicity of local politicians and entrepreneurs. The garments are in fact made in China (Burgis, 2016). And in South Africa, the state capture of President Zuma's ANC-government by unscrupulous entrepreneurs have rocked the country (Bhorat, 2017). These are only a few examples.

The third dimension of entrepreneurship that industrial policy should take into account is that entrepreneurial ability, and not so much the number of entrepreneurs matter. Nelson and Pack (1999) highlighted the role of entrepreneurial ability in the industrialization of East Asian[21] countries. They noted that highly able entrepreneurs played a key role in the assimilation of foreign technology, which entails significant risk-taking. Industrial policy should help build entrepreneurial ability, which requires, as Lazear and others have established, that good entrepreneurs need to be Jacks-of-all-trades with both knowledge and experience necessary in their skill set (Hessels et al., 2014). Apprenticeships, internships, on-the-job-training, lifelong learning, and vocational education are in this respect neglected dimensions of education in Africa.

It can be noted that when Singapore and Korea embarked on their industrialization, the entrepreneurial base was at the start judged to be lacking, as is now the case in Africa. As a result, the industrial policies implement by these countries was at first aimed to complement and strengthen the domestic entrepreneurial base, through better vocational and business school education, by only allowing in foreign entrepreneurs on conditions such as joint-ventures where knowledge spillovers could more likely take place, and by providing financial support to allow entrepreneurs to take on more risk in imitation and foreign technology adoption (Nelson and Pack, 1999).

The fourth dimension of entrepreneurship that industrial policy should take into account is that entrepreneurial innovation in industry is resulting in fast speed of change[22]. This creates an entirely different and unprecedented challenge for policy makers in designing and implementing effective industrial policy. African governments will have difficulty keeping up with the rapid pace of change, unless 'government' itself innovates and evolves. Over the next fifty years further technological innovations in ICT, the Internet and even in virtual governments are likely to induce significant changes to the nation state elsewhere, and African governments may not escape these pressures. These technological innovations have the potential, by improving government effectiveness and making it more customer-focused, to result in more inclusive societies and resulting in greater transparency. This will be good for industrial policymaking

[21] The policies that underpinned the diverse entrepreneurial routes of East Asia's industrialization had a number of commonalities. These were (i) export promotion, which stimulated international entrepreneurship and productivity gains of firms; (ii) attraction of Foreign Direct Investment (FDI) bringing in foreign technology and innovation, often through joint ventures, (iii) the imposition of macro-economic policies which encouraged savings and selective channeling of credit to entrepreneurial start-ups, (iv) the adoption of extensive education and skills formation programmes to facilitate the capacity of their economies to absorb foreign technology and know-how, including mandatory worker training schemes, vocational training, and lifelong-learning; (v) creation of venture capital funds to provide risk-capital and know-how support, and (vi) co-ordination of complementary investments including physical and ICT infrastructure (Szirmai et al., 2013).

[22] This rest of this section and what follows partly draws on Naudé and Nagler (2015a) and Naudé and Nagler (2015b).

and more generally public sector effectiveness (Naudé and Nagler, 2015b).

African governments can learn from the experience of other governments with crowd sourcing, open government, big data[23], virtual-citizen schemes (such as Estonia's e-residency[24]) and virtual currencies such as Bitcoin and the blockchains that are underpinning new trends in global finance and trade. Having access to large amounts of digital data will allow governments to assess and track changes more accurately and timely in their economies, changes in competitiveness, and measure in more detail the participation of their firms in the global economy. It is also relevant for African economies, not only the economies at the technology frontier. Peres (2014) cites a number of examples where developing countries in Latin America began to harness big data to improve economic sustainability in agriculture and processing, water use, traffic planning and surveys. These could be insightful for African policy makers.

The final dimension of entrepreneurship that industrial policy should take into account is that entrepreneurs can cause an increase in the demand for educated labour. This leads to an overall improvement in human capital in a country, in turn facilitating the imitation and adoption of foreign technology. A rapid expansion of skilled labour can only be absorbed if entrepreneurial ability is high. Without entrepreneurial ability the returns to physical and human capital are low (Nelson and Pack, 1999). Entrepreneurial ability therefore has positive externalities, which could justify support for it within industrial policy.

To conclude: the basic underlying lesson is that for entrepreneurs to drive industrialization, know-how and technology is key. Industrialization requires innovation and capability accumulation and learning, whether in the 1st or 4IR (Dosi, 2009; Fagerberg et al., 2007).

5.2 Education Policies

Given the nature of the 4IR, what African entrepreneurs require is for governments to help build the knowledge economy. Government investment in the African knowledge base is sorely needed, as it may be argued that the most serious (but not only) constraint to African entrepreneurs' making use of the opportunities of the 4IR, and which exposes workers to being replaced by automation, is the lack of skills and education. The need for schooling and re-tooling of the African labor force to find occupations less susceptible to automation, needs more recognition.

The lack of sufficiently educated entrepreneurs can be documented. UNECA (2015) (p.61) for instance found that 'A poorly skilled and educated labour force is the top supply bottleneck underscored by global executives when considering manufacturing investment decisions in Africa' as well as that the 'non-inclusive, jobless growth' has characterized Africa's recent economic performance is based on 'the misalignment of the educational curricula with the needs of the labour market' UNECA (2013) (p.6). Deloitte (2016) found from a global CEO survey that talent (skills) are the most important driver of manufacturing competitiveness. 90 per cent of South African CEOs surveyed by PWC in 2016 indicated that they are concerned about the lack of availability of key skills on their organisations' performance.

[23] Just as big data is raising the efficiency of manufacturing so it can make governments more efficient too. For instance it is estimated that the EU could save EUR 100 billion annually in operational efficiency through the application of big data (McKinsey, 2011).

[24] The government of Estonia introduced an e-residency scheme in 2014 in terms of which is 'a state-issued secure digital identity for non-residents that allows digital authentication and the digital signing of documents' (see https://e-estonia.com/e-residents/about/) (Naudé and Nagler, 2015b).

The lack of sufficiently skilled workers is further reflected in Africa having lower enrolment and completion rates in primary education than anywhere else, the lowest participation rate in tertiary education, and the highest pupil-teacher ratio in the world. Moreover the average African government spends only USD 131 per child on education per annum, which is a mere 10 per cent of the world average (UNECA, 2015).

Africa accounts for less that 1 per cent of the worlds scientific research output and only 29 per cent of all Sub-Saharan African research between 2003 and 2012 were in Science, Technology, Engineering and Mathematics (STEM). Moreover, this research declined by 0.2 per cent annually since 2002. Measured by citation impact the quality of African STEM research is 32 per cent below the global average (World Bank, 2014b). And only 25 per cent of tertiary education enrolments in Africa are in science and engineering (UNECA, 2015). South Africa, in the past the largest economy in Africa, has been described as having one of the worlds 'worst education systems' with 'the latest Trends in International Mathematics and Science Study (TIMSS) [...] had South Africa at or near the bottom of its various rankings' [25]. More generally, tertiary enrolment rates in Africa is by far the lowest of the world's regions, at an average of 12 per cent over the period 2003 to 2012 compared to 22 per cent in South Asia, and 65 percent in the EU.

This lack of skills, and of research in STEM areas is a signal that education and industry in Africa is not sufficiently coordinated and collaborating (World Bank, 2014b). As the World Bank (2014b) (p.6) point out with concern 'there appears to be little knowledge transfer and collaboration between African academics and the corporate sectorespecially for STEM disciplines'.

The World Bank (2014b) (p.6) reports that research in Africa has tended to focus on health and natural resources rather than on 'supporting knowledge-based economies and societies', due to following external funding trends rather than indigenous needs and priorities. This is a very similar skewing of investment away from physical infrastructure (also critical for the new industrial revolution) as a result of the international donor community's focus on the Millennium Development Doals (MDGs).

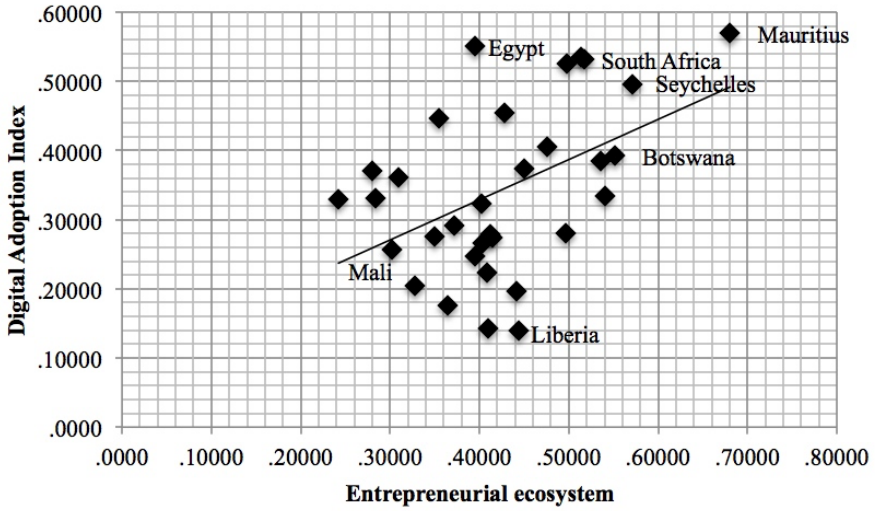
The African countries with the entrepreneurial ecosystem where better skills are available are also the countries with better digital / ICT adoption levels. Figure 1 plots the relationship in 31 African countries between a measure the entrepreneurial ecosystem, and the Digital Adoption Index for the country. The measure of the entrepreneurial ecosystem is also described as the compliments to the digital economy and has been calculated by the World Bank (2016) as an index consisting of three sub-components, namely the average of (i) entrepreneurial start-up rate, (ii) years of education of the workforce adjusted for skills, and (iii) the quality of institutions.

It can be argued that these three components provide a measurement of the ecosystem for entrepreneurs, as they need good institutional quality such as property rights, contract enforcement and finance to limited destructive entrepreneurship, and also a skilled workforce to absorb new digital technologies, and a dynamic environment for start-ups.

Clearly, it is a question of shifting the skills profile of the African labour force to be more suited to the type of entrepreneurial ecosystem that will minimise jobs losses due to automation and

[25] see The Economist on 'South Africa has one of the world's worst education systems' (7 January 2017) at http://www.economist.com/news/middle-east-and-africa/21713858-why-it-bottom-class-south-africa-has-one-worlds-worst-education.

Figure 1: Entrepreneurship and the Digital Economy in Africa



Data source: author's compilation based on data from the World Bank, 2016:30.

utilise the opportunities of the 4IR. The topic of education in Africa is however far from a new one, and already much resources are spent on education and training. There are however, in light of the above analysis a number of critical areas in the educational institutional set-up in African countries where radical and fast changes need to be made. I conclude this section by identifying six areas.

The first is the development of business schools and technical vocational colleges with a strong link to the commercial sector, wherein on-the-job training and career planning receives more priority[26]. 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 labour with the type of skills that continue to complement and benefit from capitalization (Canidio, 2013). The private sector's involvement, through for instance advice on curriculum reform, internships, on-the-job training, and (co) funding of educational infrastructure are some examples of the learning environment that needs to be scaled up (Lazonick et al., 2014).

It is also important to link education more strongly with the private sector, because management skills matter for entrepreneurial success. According to Bloom and van Reenen (2010) management practices and skills are similar to application of technology. They find evidence from a global dataset that more competent managers tend to better at identifying and introducing appropriate technology in their firms and to promote effective innovations (Bloom and van Reenen, 2010). Similarly McKenzie and Woodruff (2015) establishes from a sample of small firms in African countries such as Ghana, Kenya and Nigeria that business practices of their entrepreneurs significantly determines their firms' productivity.

There is as far as business schools are concerned, a huge gap between Africa and the rest of

[26] On the job training and predictable career ladders are vital, but under-appreciated conditions for innovation-lead industrial development, as Lazonick et al. (2014) (p. 13) point out. They discuss how collective and cumulative learning matters for entrepreneurship and innovation.

the world. The number of business schools in relation to the population is dramatically lower for some African countries even much less than what one would expect for their level of global connectivity. This means that access to a business school is basically out of reach for the populations in some of Africa's poorest countries.

The second area where urgent change is needed is to increase investment in technical and STEM skills. This is necessary to equip African labour market entrants for the 'jobs of the future' which include robot engineers, industrial engineers, data analysts, cloud architects, software developers, security analysts, health sector workers (Frey et al., 2016). This is also the type of skills and experience that entrepreneurs will need, in addition to soft management and social skills.

The third area for change in education institutions is that the emphasis need to shift towards imparting of complex, problem-solving skills: creative skills and social skills, including management, leadership, change management, collaboration, critical thinking, curiosity and risk taking, communication, marketing and sales, all which are also required for entrepreneurship. The WEF (2015) describe these ' 21st Century Skills' as nonroutine interpersonal and nonroutine analytical skills. In this regard some concrete measures which are needed include (i) making a start with re-training teachers to move to problem-based teaching methods, away from rote-learning, (ii) to improve the teaching of mathematics and science, (iii) making more use of mentors and champions from business and science in education outreach activities such as advertising, online and television programme, (iv) to teach entrepreneurship ideas, and economics and management at all levels of schooling, and as was noted before, to (v) encourage the creation of more business schools, as business schools offer more multi-disciplinary and trans disciplinary approaches towards learning that many other higher and vocational institutions where there is a tendency to focus or specialise more. Business schools are also more attuned to lifelong learning.

The fourth area is to create a nurturing environment for human capital to protect Africa's knowledge base. This includes improving safety and security, a clean environment, strengthening pollution control and urban design and development, expansion of housing and public utilities, including health, recreation and sporting facilities. Moreover a strong focus on ethical and regulatory issues with respect to privacy, online security and the legal environment will be essential to establish what Richard Florida has called the 'Creative Class'. In this respect urban development, design and management, including use of *Geographic Information Systems*, urban rail-transport systems, and sustainable city initiatives in Africa still leaves a lot to be desired, especially in light of the projections of continued rapid urbanisation. The scope of the task may be out of reach for most governments and external support, both financial and technical, is needed in Africa to address these challenges.

The fifth area for improvement is to underpin the above investments in the knowledge base and entrepreneurial ecosystem with a better system of social protection. This includes expansion of unemployment insurance, basic income grants, pension systems, business insurance and credit schemes. As Atkinson (2010) (p.3) outlines, social protection is vital for facilitating economic change while promoting social inclusion. He argues that social protection systems had their origins in establishing appropriate labour markets to support industrialization in Europe in the late 19th and 20th centuries: 'One of the motives for the introduction of the Bismarkian system of social insurance was to underwrite the modern industrial employment relationship' (Atkinson, 2010) (p.2).

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 delivery vehicle for basic income grants and insurance. Africa spend 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).

Finally, and related to the previous point, given that education is costly and subject to fixed costs, improvements in the efficiency of financial markets and access to finance may be important to give workers access to the education they may need to access and utilize the opportunities opened up by new technologies. In Africa underdeveloped financial markets and the lack of credit in poor rural areas prevent people to access opportunities in education or entrepreneurship. Credit market imperfections can constrain the occupational choices and labour market mobility of unskilled workers, entrenching higher income inequality, making the labour force more susceptible to automation, and preventing realising the opportunities of the 4IR. A central aspect of educational reform in Africa should thus focus on accessibility and finance of education (Nagler and Naudé, 2017).

In conclusion, to be able to make use of and participate in the 4IR, Africa will have to prioritise education, and massively upscale its investments in the quality of its workforce, as reflected by the type of skills needed absorb and use new technology, to generate and adapt and commercialise innovations, and that are less susceptible to future automation. The general gist of this section implies an active and evolving role for government in industrialization in Africa[27]. It requires a strong state with efficient capacity and good governance. From the 1st Industrial Revolution to the 3rd, in each successful case government played an important steering, regulatory and coordination role. It will not be different in the 4IR.

6 Concluding remarks

With only a 2 per cent share, Africa is marginalised in global manufacturing. Moreover in recent years the continent has been experiencing premature de-industrialization. Less than 6 per cent of the African labour force has a job in manufacturing. This is a problem because Africa needs growing job opportunities for the increasing number of entrants to its labour markets, and because manufacturing is a sector that offers many advantages and spillovers in economic development, including higher productivity, capital deepening, technological transfers, higher value added and more stable growth. Hence, most African countries pursue industrialization as a Holy Grail, and the African Union in its *2063 Agenda* reiterated the desire to industrialize the continent.

While Africa and the world can learn many potentially useful lessons from failed industrialisation and de-industrialization in the past and from the successful industrialization of China and other East Asian countries, these lessons are bound to be limited because the nature of manufacturing has irrevocably changed. If Africa is to industrialize in future it will have to do so in a

[27] The countries of Africa are of course very heterogenous, so that the type of approaches and priorities for promotion entrepreneurship and education will have to contend with this. One important aspect is the differing levels of development and state capacity. Acs and Naudé (2013) elaborates on taking into account stages of development in desiging entrepreneurial support policies for industrialization

Fourth Industrial Revolution (4IR) wherein new technologies such as automation, additive manufacturing and the Industrial Internet, are changing the essential nature of production and consumption.

The 4IR therefore poses both threats and opportunities. The main threats are job-losses of existing low-skilled routine jobs in manufacturing, the redundancy of the model of industrialization through attracting FDI based on low-cost labor in assembly-type manufacturing and the re-shoring of manufacturing to advanced economies. Among the opportunities are new business models of bringing goods and services to consumers. These include products-as-services, the sharing (collaborative) economy and digital services and exports: all markets that are currently underdeveloped in Africa but likely to be substantial given Africa's geography, demography and on-going urbanisation. A further opportunity is that small scale manufacturing in Africa may become more competitive and efficient as a result of the mentioned technologies.

In order to minimise the threats and avail itself if the opportunities, African countries need to invest in entrepreneurship and education, critical components of industrial policies. As far as entrepreneurship is concerned, policy makers should recognise that 4IR-compatible industrial policy requires promotion of entrepreneurial experimentation within an appropriate entrepreneurial ecosystem, characterised by *live-and-let-die* policies that will not support or keep inefficient firms alive, that will minimise rent-seeking and avoid government capture by entrepreneurs, that will provide entrepreneurs with 'smart' government support and that invests in entrepreneurial skills.

As far as education is concerned, what is recommended are (i) the development of business schools and technical vocational colleges with a strong link to the commercial sector, (ii) to increase investment in technical and STEM skills, (iii) a greater emphasis on imparting nonroutine interpersonal and nonroutine analytical skills; (iv) a nurturing environment for human capital to protect Africa's knowledge base, specifically improving human safety and security; (v) a better system of social protection ; and (vi) improved efficiency of financial markets and access to finance for educational purposes.

These recommendations will help promote an entrepreneurial ecosystem that is conducive to minimise job losses as a result of automation, and will facilitate entrepreneurs to enter into new innovative forms of manufacturing. Of course, these are far from sufficient requirements for Africa's re-industrialization. A comprehensive approach, including optimal support for a dynamic services sector, is ultimately needed to deal with a 'revolution'. This will as many observers and policy makers already know require deep improvements in the institutional and governance framework in Africa.

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