The Fourth Industrial Revolution and National Innovation Systems: Key Concepts and Snapshot of South Africa

Rachel Alexander

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DSI/NRF SOUTH AFRICAN RESEARCH CHAIR IN INDUSTRIAL DEVELOPMENT

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Abstract

In the context of the expanding Fourth Industrial Revolution (4IR), this working paper identifies opportunities and challenges South Africa faces relating to the emergence and spread of 4IR. Elements of 4IR can involve changes that range from minor adjustments to products' features to the creation of new sectors and technologies that transform how the economy operates and how people's daily lives are structured. 4IR is spreading around the world at different paces. This working paper is the first in a series of four. It introduces key concepts related to 4IR, innovation, and national development processes. The discussion highlights how key outcomes include general economic conditions and related environmental and employment factors. The paper also provides an overview of dynamics related to these outcomes and the spread of 4IR within in South Africa.

Keywords: 4IR, Industrial development, South Africa

JEL codes: O14, O25, O31, O33, L52

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The data collection involved a team of researchers, including Antonio Andreoni, Guendalina Anzolin, Marta Bengoa, Erika Kraemer-Mbula, Edward Lorenz, and Lotta Takala-Greenish. A previous publication was produced from the same data set in 2019, entitled *Report on the Adoption of 4th Industrial Revolution Technologies in South African Industry*, written by Edward Lorenz, Milene Tessarin, and Paulo Morceiro.

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1. Introduction

The global economy is expected to undergo dramatic transformations in the coming years. Technological and organisational developments, which have been called the Fourth Industrial Revolution (4IR), are becoming an increasingly important component in global production processes (Ayentimi and Burgess, 2019; Schwab, 2016). This industrial revolution is bringing opportunities for restructuring manufacturing systems, both in terms of the products that are produced, as well as the ways they are made and sold. It also has the potential to create wide-ranging changes in all aspects of how societies function. In order to explore related developments, this working paper series uses the human-centric definition of 4IR provided in the Report of the Presidential Commission on the Fourth Industrial Revolution (PC4IR, 2020: 25), "The 4th Industrial Revolution is an era where people are using smart, connected and converged cyber, physical and biological systems and smart business models to define and reshape the social, economic and political spheres".

The working paper series has two purposes. One is to explore the dynamics through which South African businesses are adopting 4IR technology and systems, particularly with the objective of identifying challenges and opportunities faced by businesses. Second, the working paper series considers the types of changes that may occur as 4IR spreads and seeks to identify opportunities and risks related to how 4IR systems are implemented. The papers have been prepared based on reviewing 51 interviews covering 25 South African firms and nine stakeholder organisations (see Annexure A), as well as relevant published materials.

To understand the dynamics faced by businesses related to the adoption and spread of 4IR, this working paper series examines South Africa's national innovation system. Through this exploration, barriers and opportunities faced by firms are identified. The concept of innovation systems is introduced in this paper, and the second working paper, *Assessing the Ability of the National Innovation System of South Africa to Facilitate the Fourth Industrial Revolution* (Alexander, 2022a), provides a more thorough assessment of the strengths and weaknesses of South Africa's system related to its ability to facilitate the spread of 4IR. These findings set the stage for all businesses operating in South Africa.

Paper three in this working paper series, *The Fourth Industrial Revolution in South African Manufacturing and Connectivity: Case Studies of Automotive and Mining Equipment Manufacturing, along with Transportation and ICT Infrastructure and Services* (Alexander, 2022b), focuses specifically on the experiences of two economic sectors. The first is connectivity services, which involve physical infrastructure as well as a variety of other services, such as logistics and cloud services. Connectivity services is a sector that is growing as a result of the expansion of 4IR. In addition, connectivity services enable 4IR developments for other types of businesses and non-business actors. As such, the strength of the connectivity services sector can be seen as part of shaping the national innovation system.

The second sector considered in the third paper is manufacturing. As will be discussed in this paper, manufacturing has historically been important in experiences of national economic development. However, 4IR may be changing the nature of the manufacturing sector, and these changes are important to understand.

In the third paper, these two broad sectors are explored through four case studies. Connectivity services are examined by looking at businesses involved in communication services and transportation. Manufacturing is investigated through focusing on the cases of South Africa's automotive and mining equipment industries.

The final paper of the series, *Key Opportunities and Challenges for 4IR in South Africa* (Alexander, 2022c), identifies key opportunities and challenges facing the spread of 4IR in South Africa and explores potential trajectories of the effects of 4IR. Specifically, changes related to how the adoption of 4IR systems may influence three important priorities for South African development are considered, namely the general economy, the effect of economic activity on the environment, and the effect of economic activity on employment. These are important considerations for ensuring that South Africa can reach the dream proposed in the PC4IR (2020) report: "South Africa will have a globally competitive, inclusive and shared economy with the technological capability and production capacity that is driven by people harnessing the 4IR to propel the country forward towards its social and economic goals, instead of falling behind".

This first paper acts as a background paper for the other papers in the series. The following section introduces theoretical concepts that are explored empirically in the other three papers. The third section introduces the empirical situation in South Africa. It provides a snapshot of the current situation in the country related to national economic development outcomes and the national innovation system. Finally, the fourth section provides a conclusion with an overview of the rest of the working paper series.

2. Key Concepts

A number of key concepts and research results can help with understanding how 4IR is spreading. This section provides an introduction to these topics. The first part provides an elaboration of elements of 4IR. Second, ways to understand innovation and development are presented. Third, outcomes that can arise from processes of innovation and technological development are discussed. Fourth, the concept of innovation systems is introduced. Fifth, the roles of public policy in stimulating change to productive systems are considered.

2.1 What is the Fourth Industrial Revolution?

4IR involves a range of new technologies and new forms of connections between actors in the economy. Particularly, digitisation and information and communications technology (ICT) is critical to 4IR developments. Schwab (2016) says that "major technological innovations are on the brink of fuelling momentous change throughout the world – inevitably so". 4IR technologies are disruptive by changing ways of sensing, calculating, organising, acting, delivering and creating value, which involve changing production systems for goods and services, processes of communication and collaboration, and individuals' interactions with the world (Schwab and Davis, 2018).

Modern economic activity involved in providing products and services has been described as consisting of production networks that encompass ongoing links between organisations (Coe and Yeung, 2015; Henderson et al., 2002). In some cases, 4IR is increasing processes of fragmentation of activities within these networks. It can also be seen to be strengthening ties and blurring boundaries between organisations. Notably, 4IR involves generating more data and new ways to use the data, such as predictive maintenance and increased data sharing. These changes can mean a decreasing ability for individual businesses to have all relevant knowledge in-house (Hidalgo, 2015). In addition, new types of industries and networks are being created, such as the development of online platforms that enable consumer-to-consumer exchange. Examples of systems and technologies associated with 4IR are provided in Box 1.

4IR systems and technologies across diverse sectors rely on having appropriate connectivity services in order to function. A key component of 4IR is digital infrastructure. While traditional infrastructure (e.g., roads, rail, water supply) created a substructure to support human settlements, digital infrastructure can provide the same services with enhanced features and also provide additional services to a population, such as internet access. PC4IR (2020) says that future infrastructure will be software-based, data-enabled and have cloud access.

A key facilitator of 4IR is the spread of the internet. PC4IR (2020) posits increased access to the internet as generating benefits by creating access to digital content, digital services and even augmented reality (AR) or virtual reality (VR). Digital services are depicted as providing benefits related to consumers saving time and money through systems such as mobile payments, digitally enhanced healthcare services, and applications of the internet of things (IoT).

Box 1: Examples of 4IR Systems and Technologies

- Electric-powered and autonomous vehicles
- Carrier ships powered by solar and wind energy
- Mobility as a service
- Wearables (e.g., smartwatches)
- Smart homes (e.g., internet-connected appliances, devices learning residents' habits)

- Smart cities (e.g., artificial intelligence to help control traffic)
- Advanced production and operations (e.g., digital twins, smart warehousing, robotics, augmented workforce, near-dark factories)
- 5G and edge computing, blockchain, quantum computing, artificial intelligence
- New materials, new energy sources and storage
- Virtual & augmented reality
- Circular economy, advanced green packaging, short-loop recycling, autonomous disassembly
- Logistics services enabled by the internet of things

Sources: Deonarain (2019); Gosh (2021); Hoque Essing et al. (2021); PC4IR (2020); Schwab and Davis (2018)

4IR can be seen as having multiple benefits at a national level. Some of these include enhancing national competitiveness, enabling production reshoring, enabling mass customisation, enabling internationalisation with lower risks due to production flexibility and decreased capital costs, increasing opportunities for start-ups, increasing employee satisfaction, and improving sustainability by reducing the use of natural resources (Cunningham, 2018a). 4IR developments can help those who have already benefited from the first industrial revolutions to further their development and can also enable development for those who have not received many of these earlier benefits (Schwab and Davis, 2018). If managed well, these technologies can help ensure more freedom, better health, more education and opportunities, along with decreasing economic insecurity (Schwab and Davis, 2018). However, these benefits are not inevitable.

In addition to the broad-ranging potential benefits of 4IR, numerous potentially harmful effects exist. A serious issue is that the distribution of benefits is not uniform. In many cases, transformations related to 4IR are driving increasing inequality (Schwab, 2016). For some actors, 4IR systems have decreased the costs needed to run or expand a business. For example, “information goods” can have very limited costs for storage, transportation and replication. Consequently, the “innovators”, who provide new products and services, and their shareholders are major beneficiaries. However, the flip side is that some categories of workers and businesses using older models can lose out. Notably, these changes can result in less employment opportunities, as companies rely increasingly on technology as opposed to human labour. This can explain the rising gap in wealth between people who look for waged work and those who make profit based on companies’ profit.

The trend of benefits being held by a small group of people is enhanced through the “platform effect”, which involves digital networks matching buyers and sellers (Schwab, 2016). This creates benefits for consumers who can get higher value and convenience for lower costs. However, it can concentrate power and the ability to make profit in the small group of people who own the platforms.

Another type of risk is related to the creation of broad societal harms. Examples of this type of risk can include artificial intelligence (AI) promoting systems that clash with human values; attempts at geoengineering creating irreversible damage to the biosphere; unscrupulous people getting access to sensitive digital data; and VR experiences enhancing the damage caused by online harassment (Schwab and Davis, 2018). Taken together, this wide range of potential benefits and challenges creates a complex situation that societies will have to deal with in the 21st century.

As global economic and societal systems experience dramatic shifts created through the spread of 4IR, it is vital to consider how national productive systems can cope with these changes, which create both challenges and opportunities. Schwab (2016: 13) writes, "The question for all industries and companies, without exception, is no longer 'Am I going to be disrupted?' but 'When is disruption coming, what form will it take and how will it affect me and my organization?'". He highlights the importance of determining shared values that can shape policies that will make these changes beneficial for all.

New institutions need to be created to manage the effects of 4IR (Schwab and Davis, 2018). To realise the potential benefits of 4IR, multi-stakeholder collaboration is needed to distribute the benefits of technology fairly, contain externalities and unintended consequences, and ensure that technology empowers humans. The changes that will accompany 4IR have the potential to help address complex challenges faced by society, but they also have the potential to exacerbate existing challenges or create new ones.

2.2 The Adoption and Spread of 4IR: Innovation and Development

As discussed above, the adoption of 4IR is not a neutral process. It has complex influences on society and economic structures. The outcomes of the emergence and diffusion of 4IR technology can be considered as taking place at the firm level and having an agglomerated effect that shapes national developments.

The adoption of and spread of 4IR can be seen to involve innovation. In this paper series, innovation is seen as involving the creation of new or better products (material goods or services) or processes (technological or organisational ways of producing goods and services) (Edquist, 2006). The change can be new to the world, new to a country or even new to an individual firm. The innovation process can include creation, adoption, adaptation, assimilation, and diversification (Zanello et al., 2016). In the contemporary world, new developments are constantly taking place and firms often have to participate in continuous processes of innovation just to keep up (Lundvall, 2016a). Sometimes these involve processes of gradual change with cumulative effects, and at other times they entail radical breaks with the past. The distinction between invention, innovation and diffusion can be blurry. In some cases, innovation can be seen as more of a process than an event.

This sub-section has two parts. The first part discusses the concept of innovation. The second part considers innovation at the firm-level. Finally, the third part considers national-level dynamics.

2.2.1 Types of Innovation

Innovation can be considered from a variety of perspectives. Edquist (2011) identifies six categories. One is the level at which something is "new". Innovation can be new to the world or it can be new to a firm, country or region, and it can be introduced through diffusion and absorption. A second consideration is whether an innovation is radical or incremental. While much of innovation is incremental, radical innovation can occur that leads to unexpected outcomes that may create significant breaks from the past, making older knowledge obsolete. Innovations can be classified as incremental or radical, based on technical or economic dimensions (Lundvall, 2016a). Sometimes incremental technical progress can have a large economic effect. Alternately, radical technical innovations may not have much effect, as society may not be ready to adopt them. A third consideration is whether the innovation is high-tech or low-tech. A fourth consideration is whether it is a product or process innovation. A fifth aspect is whether the innovation is related to a specific sector. Finally, a sixth factor is whether the innovation can generally be connected to a specific policy objective, such as economic, social, environmental or military priorities.

Innovations related to 4IR are diverse. Types of 4IR innovations can cross multiple variations across all the above-mentioned categories. For example, 4IR innovation includes new business models, such as urban bike-share schemes, and also includes AI systems helping with medical diagnosis.

Uncertainty is also an important aspect to consider related to innovation. Sometimes a new product can fail to be adopted by users or a product that was intended to address one need ends up being used for other purposes (Lundvall, 2016a). In some cases, relatively isolated niches within a larger productive system support the development of radical innovations (Geels, 2005). These innovations may break through and lead to system-wide changes or remain within their niche.

2.2.2 Firm-Level Innovation and Upgrading

One scale to explore the outcomes of innovation is at the firm level. Innovation can be considered as leading to four types of industrial upgrading, as defined by Humphrey and Schmitz (2002). One is product upgrading, which involves increasing the sophistication or value of products. A second is process upgrading, which involves improvements to businesses' internal workings. The third is functional upgrading, which involves firms adding new functions to their existing offerings, such as packaging. Finally, the fourth is sectoral upgrading, which involves firms bringing their skills into new sectors.

4IR technology and systems can involve all four forms of firm upgrading. Firms can develop new 4IR-related products, such as the examples outlined in Box 1. 4IR can also involve diverse new processes, such 3D printing and digital monitoring of production processes. New processes can also involve changing entire business models, such as digitally enabled customised production and new forms of product leasing. Functional upgrading is also occurring related to 4IR. A key type of 4IR functional upgrading is adding digital services. Furthermore, the versatility of digital technologies, including new products and processes, can help businesses expand the sectors to which they contribute. In addition, new firms are being created that can be considered as having a variety of upgrades compared to firms that have been founded in the past.

4IR can also change market structures related to the types of businesses that can compete (Primi and Toselli, 2020). One trend is the concentration of big players as large companies expand through engaging in sectoral upgrading, such as internet service providers adding financial services. Another dynamic is that the creation of digital platforms can allow more opportunities for start-ups.

2.2.3 National-Level Innovation and Industrial Development

While innovation can be explored at the firm level, looking at changes in national systems is another important level of analysis. A major issue in South Africa and other developing countries has been the process of industrialisation, which involves the growth of manufacturing. Globally, innovations spread with each wave of industrial revolution have changed what is involved in the process of industrialising. Consequently, the emergence of 4IR has the potential to change how and if countries industrialise in the coming years. To understand how 4IR may affect national economies, it is important to consider how industrialisation has affected countries in the past.

Historically, manufacturing has had strong ties with economic growth. The sector involves knowledge spillovers that can enhance non-manufacturing activities and produces products that can often easily be exported, thereby providing access to large global markets even when a domestic market is small (Altenburg and Rodrik, 2017). In fact, manufacturing has been the main channel through which rapid growth has happened in the past, with typical features including technological dynamism, unconditional labour productivity convergence, and the ability to absorb large levels of unskilled labour (Rodrik, 2013, 2016).

Benefits gained through building the manufacturing sector include skills development through learning by doing, technological gains in other sectors, the generation of foreign exchange, which relieves balance-of-payments constraints on growth, and the stimulation of other sectors through forward and backward linkages (Tregenna, 2015). For example, manufacturing can be connected to mining and agriculture through creating productivity-enhancing equipment and can be connected to service sector development related to areas such as engineering and research and development [R&D] (Bell et al., 2018). Furthermore, shifting from sectors with low productivity to those with higher productivity, which has been the case in switching from agriculture to industry, increases the national income and taxation base, thereby expanding the national ability to provide universal social services (Bell et al., 2018).

National industrial development has long been seen as a goal for countries seeking to achieve economic development. However, this is now contested. Reasons include growing difficulties with industrialising based on the production and consumption patterns of major global players (particularly China), the growing role of global value chains (GVCs) in manufacturing, differences between developing countries' levels of industrialisation and the competitiveness of their manufacturing sectors, and the diversity of dynamics found within their manufacturing activities and other sectors. These changes are making it difficult for low-income economies, which benefit from having low wages but also suffer from low productivity, poor infrastructure and limited technological advancement, to become competitive manufacturers (Tregenna, 2015). A key consideration related to 4IR is that new forms of manufacturing can have lower labour requirements, which can decrease the competitive benefit countries gain from having low wages.

Historical industrialisation processes have led to the divide between Europe and the United States and the rest of world, and have resulted in the catch-up and convergence of some countries (e.g., Japan, South Korea, Taiwan) (Rodrik, 2016). However, historical experience shows that countries tend to have a maximum contribution that manufacturing can provide to their gross domestic product (GDP), beyond which its share declines (Altenburg and Rodrik, 2017). A decline in industry has been described as the process of deindustrialisation.

Deindustrialisation is a phenomenon that has been observed widely across diverse countries in recent decades. While some definitions of deindustrialisation solely consider declines in the share of manufacturing in total employment, this approach does not take into account situations in which declines in employment are related to increases in productivity and thus do not actually indicate deindustrialisation. Tregenna (2015) proposes that deindustrialisation is only truly happening in cases where there is sustained decline in the shares of manufacturing in both employment and GDP.

In some cases, deindustrialisation may appear to be occurring when inter-sectoral outsourcing is taking place (Tregenna 2015). This is an important dynamic to consider, as 4IR often involves outsourcing. Another issue is that 4IR business models can involve transforming businesses in ways that blur the boundaries of traditional categories. For example, some manufacturing businesses are becoming service providers when they sell the service their product provides, as opposed to selling the physical product.[1]

The effects of deindustrialisation have been found to differ across regions and time periods. For advanced economies, the process of industrialisation has been followed by moving into a post-industrial phase that involves deindustrialisation (Rodrik, 2016). High-income countries have experienced deindustrialisation as involving a growth in the service sector, which often incorporates high-value services. For countries with advanced economies, service sectors can have characteristics that are typically associated with manufacturing, such as increasing returns to scale, scope for cumulative productivity increases, strong linkages with other sectors, and potential technological advancement (Tregenna, 2015). However, the process can also involve people moving from manufacturing employment into lower-income service jobs (Rodrick and Sabel, 2020).

Processes of deindustrialisation have been experienced differently for less-developed economies. Notably, deindustrialisation has started happening at lower levels of income per capita and with lower shares of manufacturing in employment or GDP (Tregenna, 2015). Overall, in most lower-income countries – with the exception of a few mostly Asian countries – the manufacturing share of employment in terms of income and real value added has been falling for decades, after these countries had built up some levels of manufacturing in the mid-twentieth century (Rodrik, 2016).

Premature deindustrialisation refers to the process beginning at lower levels of GDP per capita and/or at a lower level of manufacturing as a share of total employment and GDP compared to global norms. The point at which a country is termed to be engaging in premature deindustrialisation is not fixed (Tregenna, 2015). If the bar is based on divergence from norms, it is important to note that this bar has been moving over time, and countries now typically start to deindustrialise with lower shares of manufacturing than in the past. In some cases, countries have even experienced pre-industrialisation deindustrialisation (Tregenna, 2015).

Overall, a number of dynamics can result in premature deindustrialisation leading to negative effects (Tregenna, 2015). When countries cut short periods of industrialisation, they lose out on the many opportunities related to manufacturing growth that are described above. Notably, for countries in earlier stages of development, service-sector businesses that become prominent in cases of premature industrialisation are likely to be relatively low-skilled, low-productivity, and

[1] This process has been described as servitisation. It can involve firms contributing to production in value chains, such as chemical producers selling coating services. Alternatively, it can involve final products, such as office equipment producers leasing their products.

non-tradable activities (e.g., retail or personal services). While these activities may have an important role to play in job creation, they are unlikely to drive growth.

In addition, premature deindustrialisation is more likely to be a sudden process than what is experienced by more advanced economies because it is more likely to be the result of policy changes, and economies with low levels of diversification, as can be found in cases with low levels of industrialisation, are more susceptible to shocks (Tregenna, 2015). This is problematic, because rapid deindustrialisation means that firms have limited opportunity to adapt and may not survive. Rapid change can also create problems for workers, who may not have the skills needed to quickly find new jobs.

While growth in developing countries has continued since the 1990s, much of it – outside of a small group of manufacturer exporters – seems to have been driven by potentially unstable sources of capital inflows, external transfers, or commodity booms (Rodrik, 2016). A major risk is that, without manufacturing driving high levels of growth, lower-income countries may not be able to "catch up" to high-income countries (Andreoni and Tregenna, 2020; Rodrik, 2016).[2]

Deindustrialisation can also be considered specifically in relation to employment or output. Employment deindustrialisation has been a concern in high-income countries for decades, with issues of concern including the loss of good jobs, rising inequality, and a potential decline in innovation capacity (Rodrik, 2016). In contrast, output deindustrialisation is a less uniform experience. While the US has maintained a relatively stable share of GDP derived from manufacturing value-added, a contrasting example is provided by the UK, where the manufacturing value-added contribution to the GDP has fallen from about a quarter in the 1970s to less than 15% (Rodrik, 2016). Overall, however, industrialised countries have maintained a significant base of manufacturing as part of their output.

While evidence more clearly indicates a positive relationship between industrialisation and growth, deindustrialisation has been a more diverse experience that, nevertheless, shows a likely correlation with declines in growth (Tregenna, 2015). A number of factors have been found to be connected to deindustrialisation having different effects. One set of important factors is based on the condition of a country when the process begins. Specifically, the effects of deindustrialisation on growth can be shaped by the level of income per capita at which the process begins; the degree of industrialisation achieved, which can be measured by the share of

[2] Premature deindustrialisation can also have problematic political consequences (Rodrik, 2016). Historically, labour movements that developed through industrialisation played a big role in demanding rights for citizens. Without a strong role of organised labour, there is more potential for groups to organise based on other characteristics, such as ethnic divisions.

manufacturing in total employment and GDP; and the extent to which it is triggered by or accelerated by policy (Tregenna, 2015).

A particularly important policy area is trade liberalisation. When many developing countries opened their markets to trade after small, domestic manufacturing industries developed through protectionist policies, local industries could not compete with low-cost global manufacturing and countries became net importers (Rodrik, 2016). However, for some Asian countries that had already developed strong manufacturing industries, the opening of global markets provided a larger pool of customers for their more competitive products.

Knowing the cause of deindustrialisation can be important for understanding the effects (Tregenna, 2015). In addition to policy as a driver, processes of deindustrialisation can be driven by technological progress, leading to a decrease in the need for workers; rising incomes, creating an increased demand for services; and increasingly knowledge-intensive manufacturing processes, requiring specialised services such as engineering, information technology and finance (Altenburg and Rodrik, 2017). The growth of 4IR systems and economic models is a key factor to consider related to these drivers.

The types of activities that are contracting or expanding are also important to consider to understand the effects of deindustrialisation (Tregenna, 2015). Each sub-sector is composed of a different mix of activities, which can have different characteristics, such as technological intensity, scope for increasing returns and cumulative productivity increases, and linkages with other sectors. Different patterns of growth and decline across these elements can result in deindustrialisation having different effects across experiences.

All countries, no matter what stage of industrialising or deindustrialising they are in, have to deal with the effects of 4IR on production and economic systems. Overall, 4IR technologies and systems change the types of opportunities that countries experience related to industrial development. 4IR can involve dramatic changes in how economies function. Particularly notable is the increase in businesses that are based on service provision. These dynamics will change how countries experience industrialisation and may change the way the manufacturing industry affects societies. As 4IR spreads around the world, the changes it creates for processes of national industrial development are still being discovered.

2.3 Outcomes of the Adoption and Spread of 4IR

Both firm-level and national level developments related to the adoption and spread of 4IR can have broad societal outcomes. This sub-section considers the nature of key outcomes. Particularly, the first part considers national economic outcomes, the second part considers national environmental outcomes, and the third part considers national labour outcomes.

2.3.1 National Economic Outcomes

As discussed above, processes of industrialisation are linked to economic development, with levels of industry being connected to GDP. As national economies incorporate higher levels of economic activities that involves 4IR processes, the impacts on economies are yet to be determined. Countries can become more or less competitive and costs and benefits may be felt differently across societal groups. Key considerations are where and how new technologies are incorporated. The features of national innovation systems play a crucial role in determining how 4IR develops (see: Section 3 and Alexander, 2022a). Additionally, impacts can differ across industries (see: Alexander, 2022b).

2.3.2 National Environmental Outcomes

While, historically, industrial development has helped countries to increase their wealth, it has often also resulted in damage to the environment, particularly related to the use of fossil fuels and environmental destruction. This is not an inevitability. 4IR technologies and systems are changing the relationship between industry and the environment. New energy sources, energy-saving technologies, the adoption of new materials in manufacturing, and behaviour changes, such as using circular economy models, can remediate previous challenges posed by high levels of petroleum use and other environmental threats.

Although past experience has generally shown examples of countries exploiting the environment in their development processes, new practices are possible for countries that are currently undergoing or seeking to initiate periods of development. Altenburg and Assmann (2017: ix) note that almost all countries that have achieved high levels of development have done

> so by overstepping the world's bio capacity, whereas those countries that stayed within the Earth's limits so far invariably failed to provide the conditions for a high level of human development … not a single country worldwide provides a role model for achieving decent human development sustainably within Earth's bio capacity.

While this is a troubling precedent, they go on to say that

> economic latecomers to the globalizing world economy even have an advantage. They can build their cities, their manufacturing industries, their energy and transport systems and their institutions in new, more sustainable ways that take their distinctive national characteristics into account … latecomers are not as deeply locked into existing unsustainable infrastructures and century-old institutional routines that often hamper change in many ways.

Altenburg and Rodrik (2017) identify a number of economic benefits and trade-offs related to promoting a green economy. Key economic benefits include maintaining natural resources that support ongoing economic activity, reducing inefficiencies that cause pollution and waste, and increasing market demand for green products in the future. Moreover, the costs of switching to new systems may be higher in the future. A green economy can also promote external benefits (such as cleaner air reducing healthcare costs). Finally, green industrial policies can drive innovation. However, they note that there can be short-term costs, such as internalising costs that previously were externalised, and opportunity costs, where money could be spent on other items such as health care or housing.

4IR technologies have many opportunities for improving environmental outcomes. The World Economic Forum (WEF, 2018a) highlighted five 4IR technologies that can help with sustainability challenges. The first is advanced remanufacturing, which can involve robotic disassembly and advanced material sorting. The second is new material development, which includes new types of green packaging and replacements for a number of environmentally damaging materials. The third is advanced agriculture, which can involve automation, biotech, IoT, and data analytics, working with crop science to optimise farming systems. The fourth is more efficient factories that use lower levels of resources, while the last is improved traceability technology, which can help facilitate the verification of product information and data flows, and enable remanufacturing and recycling.

2.3.3 National Labour Outcomes

As mentioned above, past experience with industrialisation has resulted in the creation of large numbers of jobs, and processes of deindustrialisation involve changes in the types of jobs available. While overall job creation is an important factor, particularly in places with high levels of unemployment, an important factor to consider is whether jobs are providing “decent work”. The International Labour Office (1999: 13) describes decent work as

> productive work in which rights are protected, which generates an adequate income, with adequate social protection. It also means sufficient work, in the sense that all should have full access to income-earning opportunities. It marks the high road to economic and social development, a road in which employment, income and social protection can be achieved without compromising workers’ rights and social standards.

Decent work can be seen as providing “good jobs”. Rodrik and Sable (2020: 1) consider good jobs as

> stable, formal-sector employment that comes with core labour protections such as safe working conditions, collective bargaining rights, and regulations against arbitrary dismissal … enabl[ing] at least a middle-class existence, by a region’s standards, with enough income for housing, food, transportation, education, and other family expenses, as well as some saving. More broadly, good jobs provide workers with clear career paths,

> possibilities of self-development, flexibility, responsibility, and fulfilment. The depth and range of such characteristics may depend on context: the prevailing levels of productivity and economic development, costs of living, prevailing income gaps, and so on. We expect each community to set its own standards and aspirations, which will evolve over time.

Good jobs can have a number of societal benefits. In contrast, losing good jobs has been found to have diverse negative effects on communities (Rodrik and Sabel, 2020).

Employment-related changes deriving from the adoption of 4IR are an important outcome to consider. 4IR has been identified as having diverse potential effects on jobs. While countries benefited from large-scale shifts of labour from agriculture to export-oriented light manufacturing in the past, the development of labour-saving technologies means that similar opportunities are less available (Altenburg and Rodrik, 2017). Key changes that have been predicted are that new systems will redefine tasks, with digital technologies replacing humans for routine and not-routine tasks; new professions will arise; and there will be a growth in entrepreneurship (Primi and Toselli, 2020). With some changes expected to increase jobs and others to decrease them, the expected overall effect on the total number of jobs in the future is unclear (Balliester and Elsheikhi, 2018; Primi and Toselli, 2020). As 4IR is changing the nature of work, it is important to consider the quantity and quality of jobs that are being created.

2.4 Enablers of the Adoption and Spread of 4IR: Innovation Systems

It is also important to consider the ways in which innovation, firm upgrading and national development occur. Innovation can be seen as taking place within innovation systems. This sub-section introduces the concept of innovation systems and discusses specific dynamics that have been identified for innovation systems in developing countries.

2.4.1 Innovation Systems

An innovation system can be defined as being "constituted by elements and relationships that interact in the production, diffusion and use of new and economically useful knowledge" (Lundvall 2016a: 86). Learning, a social activity that involves interactions, is a central activity in an innovation system. Innovation systems are characterised by both positive feedback and the reproduction of knowledge of individuals and collective agents. Elements can either reinforce or block each other in promoting processes of learning and innovation.

Routine activities can be a major generator of innovation. Lundvall (2016a) asserts that technical advances take place primarily where firms or the national economy are engaged in routine activities. This is due to the fact that a key source of learning is participating in day-to-day activities related to production, distribution and consumption. Through such processes, innovation is the result of the experiences of workers, production engineers and sales representatives, who produce knowledge that contributes to the innovation process.

While learning from routine activities is important, organisations also benefit from engaging in purposeful activities intended to expand technical knowledge. For many organisations, purposeful innovation activities might occur only in unusual situations, such as when a business's survival is threatened. However, some organisations have divisions that specialise in such activities, such as departments conducting market research or R&D.

Lundvall (2016a) distinguishes “searching”, which is goal and profit oriented, from “exploring”, which is often a more open-ended activity. Searching and exploring can take place in private firms and can also take place in specialised public or private research organisations. Lundvall proposes that exploring can be particularly important due to its potential to produce unforeseen and potentially radically transformative outcomes. Exploring sometimes results in breaks in cumulative paths and creates the basis for new technological paradigms. Mazzucato (2018) also asserts the importance of open-ended exploration. She highlights that publicly funded exploratory research can lead to unexpected outcomes that are beneficial for society.

Key elements of innovation systems include the internal organisation of firms, inter-firm relationships, the role of the public sector, the institutional set-up of the financial sector, R&D intensity and organisation, and education and training systems (Lundvall, 2016a). These systems can differ between countries, and the structure of each element plays a role in shaping how the other elements function. In addition, various contextual factors can shape innovation systems, such as infrastructure, availability of inputs, and demands from markets and societies. To support 4IR, new social technologies are needed to manage these systems, in addition to the technological solutions that are needed for managing large volumes of data and new systems of works (Nelson, 2003). Both physical and social systems and networks play critical roles in shaping the strength of an innovation system.

Lundvall (2016a) proposes that historical analysis and theoretical considerations should determine which subsystems and social institutions should be included when assessing an innovation system. Constituents of innovation systems have been grouped in different ways. One way to understand an innovation system is to distinguish between components involving institutions (formal and informal rules of the game), organisations, and activities (Edquist, 2006, 2011).

Institutions, which can be considered at the scale of specific firms, constellations of firms or nations, are relatively stable over time (Lundvall, 2016a). Important institutional factors include market structures, competition regimes, laws, routines, or technological trajectories and paradigms, which guide or focus the innovative activities of scientists, engineers and technicians (Lundvall, 2016a, 2016b). Another way to look at these factors is that they create an industry regime that shapes how production happens. Geels (2014: 267) describes industry regimes as

> industry-specific institutions that mediate perceptions and actions of firms-in-an-industry towards external environments [which] contain four types of elements: (1) technical knowledge and capabilities, which enable and constrain what firms-in-industries can do, (2) mind-sets and cognitive frames, which constitute how actors perceive the nature of social reality, (3) values, identity, mission, which specify what actors see as appropriate, (4) formal regulations, laws, standards.

He describes the first three as forming institutional logics, and the fourth as being part of the governance system.

Organisations working with innovation systems are diverse. Innovation systems include both public and private organisations. Examples include firms (e.g., suppliers, customers and competitors), research institutes, universities, and government ministries. These organisations interact in different ways in different innovation systems.

Activities within innovation systems can also be diverse. Key activities include the provision of knowledge inputs (e.g., R&D or competence building), demand-side activities (e.g., creating new product markets or quality requirements), provision of constitutions (e.g., organisations, networks, institutions), and innovation support services (e.g., incubation activities, financing, or consultancy services). Activities can be seen as being performed by organisations or by individuals, with institutions providing various incentives and obstacles. Exploring the dynamics of activities, including the division between the public and private sector, can be helpful for understanding innovation processes and supporting policy design (Edquist, 2011).

Knowledge flows within innovation systems play a big role in facilitating innovation. This dynamic is particularly important for 4IR. The process of diffusion involves innovation and the related tacit knowledge spreading to new users, which can involve private and public organisations and individuals (Organisation for Economic Co-operation and Development [OECD], 2019a). Innovations can spread from leading firms to laggards within a national system through collaboration, networks and people moving between firms (Cunningham, 2018b). Technology diffusion has been seen as playing a more important role in determining firms' productivity than internally generated innovations (OECD, 1998). Knowledge diffusion, involving the movement of physical goods and data sharing, can be shaped by a country's physical infrastructure.

2.4.2 National Innovation Systems and Developing Countries

Lundvall (2016a) identifies the national level as an important scale to explore when assessing innovation systems, noting that common cultural and political systems can exist at this scale, while acknowledging that many nations are internally diverse. A lot of research exploring innovation systems has focused on the national level and has often concentrated on countries producing advanced technological developments. However, research on developing countries has identified some commonalities in how innovations systems function, in ways that can differ from those of advanced countries. The findings from the studies described below are important to consider for South Africa, but do not all necessarily apply.[3]

An important dynamic is that the bulk of technological activity in developing countries is related to absorption and the improvement of existing technologies, as opposed to innovation that is at the frontier of technological development (Lall and Pietrobelli, 2005). While a small group of firms in more advanced countries create the bulk of new-to-the-world technology, developing countries are often working on building the ability to use existing technologies in competitive ways (Lall and Pietrobelli, 2005; Zanello et al., 2016). Furthermore, the ability for firms in developing countries to upgrade in relation to 4IR has been seen to be more difficult than for more advanced countries (Lee et al., 2020).

Notably, national characteristics can affect diffusion processes. Zanello et al. (2016) identify six characteristics that affect the diffusion of innovation. These are found to create stronger challenges for developing countries. First, the nature of a technology shapes the ease with which diffusion happens. For example, high-tech equipment might need advanced skills to be adopted.

Second, technology may be designed for particular contexts. Consequently, its adoption in a new environment may require adaptation for local needs. Countries can vary in the level of skills they have related to the ability to adapt technology.

Third, communication and connectivity are needed to create awareness of new innovations. Channels of connectivity can involve transmitting information and goods. The connectivity services that are required for these processes are a key topic in this working paper series. Connectivity can be influenced by geographical and cultural distance, infrastructure, as well as policies that can shape the process, such as tariffs.

Fourth, the existing networks of interaction between firms and intermediaries, such as trade associations, government agencies, and staff moving between firms, facilitate knowledge diffusion. Particularly, these networks help to share tacit knowledge. High-income countries tend to have larger concentrations of firms strengthening these networks. Lower income countries tend to have less diversified sectors, fewer large firms and limited intra-firm worker mobility.

Fifth, the strength of the institutional environment can also shape diffusion. Political instability and weak law enforcement can discourage foreign investments. In addition, a lack of cooperation between the public and private sectors can limit domestic diffusion.

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[3] The second paper in this series, Alexander (2022a), focuses on exploring characteristics of South Africa's national innovation system.

Sixth, firms’ internal characteristics can also influence diffusion. These characteristics shape firms’ ability to absorb new technology. Characteristics of firms in developing countries often pose challenges for innovating, such as limited financial resources and a lack of specific skills.

The diffusion of innovation has been found to be a more heterogeneous process for developing countries compared to technologically advanced countries (Zanello et al., 2016). One factor to consider in a national innovation system is where innovation takes place. While innovation includes many activities outside of formal R&D, it is important to note that R&D happens differently in developing countries versus advanced industrial countries. In developing countries, the bulk of R&D takes place in public institutions, and often has limited connections to businesses (Lall and Pietrobelli, 2005).

The size of the middle class is another factor found to influence diffusion. A middle class has been associated with various definitions, with the term being seen to describe people who lead a comfortable life, are the source of entrepreneurship, and who form a consumer base that can buy large levels of goods and services (Kharas, 2010). Using an income-based definition, larger middle classes have been found to lead to higher levels of patenting for national residents (Weinhold and Nair-Reichert, 2009).

Another issue to consider is the fact that developing countries tend to have larger informal sectors. This characteristic can also play a role in shaping national innovation systems. For informal sector businesses, the characteristics of individual entrepreneurs may shape levels of the adoption and creation of innovation (Zanello et al., 2016).

A further issue to consider that is related to developing countries is the existence of what has been called the bottom of the pyramid (BOP) market. This market has been seen to consist of the large segment of the world’s population that lives on less than $2 per day, whose billions of members have a large level of combined purchasing power and often rely on being served by the unorganised sector (Prahalad, 2012). This market can be a source of radical innovation.

Innovation targeted to and created by the BOP can take different forms than other innovations. The process can be demand driven and facilitated through processes of learning by doing and learning by using (Zanello et al., 2016). Notably, innovation for this market has been called frugal innovation, which is a concept that has been hailed as a way to provide affordable products that can improve people’s lives and has been criticised for exploiting low-income and vulnerable communities (Zeschky et al., 2011; Knorringa et al., 2016; Weyrauch and Herstatt, 2017; Meagher, 2018). A key concern is that this group risks being seen more as a potential market, rather than as housing potential co-creators, because of a lack of strong formal sector elements in their innovation systems (Primi and Toselli, 2020).

Key drivers within countries are also important to consider. For some countries, a few actors, such as large and incumbent firms and local universities, are driving industrial modernisation. This has pros and cons (OECD, 2019a). This small group of actors can help with harnessing opportunities, such as those arising from automation and digitalisation. However, this situation creates a risk that developments are concentrated in specific areas and fail to spread to rural areas and disadvantaged groups.

For developing countries to “catch up” economically, building technological capabilities has been found to be crucial (Freeman, 2004; Fagerberg, 2010; Fu et al., 2011; Lundvall, 2016c). Knowledge creation and innovation diffusion are key to productivity and employment growth (OECD, 1996). At the global level, different countries can be characterised as relying on higher or lower levels of technology and innovation. For countries that currently use less-productive technologies, a process of catching up can occur through the diffusion of knowledge from more productive regions. However, this process faces several challenges.

One caveat related to processes of catch-up is that systems developed in different contexts may not be the best choice for countries currently going through development processes. A strong reliance on adopting globally developed technologies risks locking countries into technological pathways that can limit their experimentation with developing locally appropriate solutions (Primi and Toselli, 2020). A lack of existing systems can also be a benefit. In some cases, lagging countries can build new systems without the potential barriers created by already being locked into older technologies.

A growing phenomenon that has been experienced globally is the middle-income trap. This situation involves middle-income countries seeing lower growth than low- or high-income countries. The situation has been described as being “squeezed between the low-wage poor-country competitors that dominate in mature industries and the rich-country innovators that dominate in industries undergoing rapid technological change” (Gill and Kharas, 2007: 5). In this situation, countries have struggled with two often misplaced approaches (Gill and Kharas, 2015). On the one hand, they have tried to compete in labour-intensive exports, often facing challenges as their wages have risen. On the other hand, they have tried to compete in knowledge-intensive sectors, but often face challenges from having insufficient capacities.

Andreoni and Tregenna (2020: 324) highlight the importance of structural factors in creating a middle-income trap and explore what they call the “middle-income technology trap”, which they describe as “a specific structural and institutional configuration of the economy that is not conducive to increasing domestic value addition and to sustained industrial and technological upgrading”. Andreoni and Tregenna describe four phases of technology innovation development, namely research, development, deployment and operations. In advanced countries, governments tend to invest more in the research stage and the private sector invests more in the deployment and operations stages, leaving a gap in the development stage, which has been called the “valley of death”. This gap is larger in middle-income countries, with less investment in research and later-stage investment from the private sector, as well as total investment being lower at both stages (Andreoni and Tregenna, 2020). With lower investment in basic research, middle-income countries have less access to generic technologies, that typically emerge from universities, industrial research centres and laboratories, military and health system institutions, or large private companies, in collaboration with or funded by the public sector. Consequently, they rely more on external inputs of often expensive foreign technologies. In addition, access to infra-technologies (infrastructure technologies) can be limited.

The middle-income technology trap is seen to derive from three interdependent factors (Andreoni and Tregenna, 2020). First, countries constrained in terms of scale and technological competitiveness have difficulty “breaking into” the global economy. Global manufacturing is concentrated in a small group of countries, which have expanded to include some new entrants but remain a small group. Middle-income countries in particular have difficulty “breaking into” sectors that involve medium- and high-tech production activities. Key barriers faced in the 21st century are: realising global-scale economies; intellectual property rights; institutions and capabilities for technological development and innovation; and, the emergence of major national champions and globally operating multinational corporations creating new forms of direct and indirect (via global supply chains) competition in domestic markets.

Second, companies face challenges in “linking up” to GVCs and “linking back” to local production systems. When firms or economies “link up” to global value chains, they can engage in processes of upgrading (described above). In this model, firms can specialise in high-value niches without developing broader industries. However, this approach faces a number of challenges. Suppliers and manufacturers can struggle to upgrade and may face barriers from an industry’s lead firms. A focus on GVC participation can result in “de-linking” from local industry and creates risks of low productivity growth. This is a particular risk, as rising labour costs can cause lead firms to disengage and source from a lower cost location. However, a small number of middle-income countries have been able to “link up” to international companies while “linking back” to local producers and local supply chains. This process has resulted in cases of successful upgrading.

Third, countries can struggle with “keeping pace” with technological change and innovation. In order to “keep pace”, investments and capability-building efforts need to support the development of different types of technology. One type of technology is “generic technologies”, as described above. Another type is proprietary technologies, which are usually based on generic technologies and associated with specific products or processes (production technologies) generally developed by companies. A third type is infra-technologies, which facilitate the development of generic and proprietary technologies and can be relatively inexpensive or offered through public services. To “keep pace”, investments and capability-building efforts also need to target different stages of technological development (i.e., research, concept/invention, early-stage technology development, product development, and production/commercialisation).

Considering the role of innovation systems in supporting national development, costs and the need for coordinated efforts can be a challenge. Specifically, adopting new technologies can involve costs related to developing complementary institutions and the needed physical infrastructure (Cunningham, 2018c). Change in productive systems can be facilitated through a number of building blocks. These could include connectivity services, public policy and an ecosystem of support service organisations. As it is difficult to coordinate the creation of capabilities that do not exist, transformation tends to happen in relation to "nearby" goods because they need similar capabilities to those that already exist (Hausmann et al., 2008).

Some types of technology require multiple types of changes. For example, electric cars require users to buy new cars and for new energy infrastructure to be built. Making change at the individual level can be a difficult process. If changes require economies of scale beyond an enterprise's capacities, it may not be able to make an upfront investment in following through with a new idea or technological change that can come with risk and uncertainty (Cunningham, 2018c). Consequently, public policy can be needed for stimulating national upgrading processes.

Specifically, looking at countries' capabilities to take advantage of 4IR, Lee et al. (2020) highlight the importance of considering national levels of digital literacy, skill and education level compared to wage rates, population structure, domestic market size, GVC positions, and industrial policy strategy. They propose that effective investment in building an innovation and knowledge base can activate learning processes and facilitate leapfrogging over traditional forms of industrial development to directly adopt 4IR systems. In some cases, 4IR technologies are already creating opportunities for developing countries to rapidly address gaps and leapfrog, particularly through mobile digital services (Primi and Toselli, 2020). However, these opportunities are not universal. Countries do need a minimum level of capability to be able to leapfrog, with some companies and areas being locked out because of low levels of industrial development, informality, and subsistence-type business models (WEF, 2018b; Primi and Toselli, 2020). Countries' capacities to take advantage of 4IR can be seen to be related to the characteristics of their innovation systems.

Overall, as this sub-section has discussed, countries' individual situations are a key factor shaping how 4IR drivers and opportunities are experienced. A number of organisations have sought to make frameworks to assess whether countries are ready to adopt 4IR technologies. Each country has its own situation, with specific barriers and drivers. European countries have a shortage of young workers interested in technical trades, which can be a driver towards labour-saving technologies, whereas South Africa has a large level of unemployed youth with a need to find jobs (Cunningham, 2018a). A number of organisations have attempted to develop ways to identify whether a country, industry or firm is ready to adopt 4IR-type technologies, which include WEF and A.T. Kearney's (2018) *Readiness for the Future of Production Report*, WEF's (2019) *Global Competitiveness Report*, the Portulans Institute's (2020) *Network Readiness Index* (NRI), Cornell University, INSEAD and the World Intellectual Property Organisation's (2020) *Global Innovation Index 2020*, and Genesis Analytics' (2019) *South Africa in the Digital Age*. The second paper in this working paper series, Alexander (2022a), draws heavily on these reports in its assessment of South Africa's national innovation system.

2.5 Stimulating Change: The Role of Public Policy

While the discussion above has focused on the outcomes of technological change and the systems that support processes of innovation, an important factor to consider is that strong pressure for stability often exists in production systems (DiMaggio and Powell, 1983; Scott, 2013; Geels, 2014). Current technological systems can be entrenched and change can be difficult. Pressure for stability can come from multiple sources, such as norms shaping interactions and the behaviour of diverse actors, high initial costs needed for changes, and pressure from actors who benefit from current systems.

Change occurs when pressure for change is stronger than pressure for stability (Geels and Schot, 2007; Alexander, 2021). In many cases, change needs to be facilitated through coordination between multiple actors, and such coordination may be difficult to achieve. Also, change can emerge through different paths and can be sudden or slow. Technological change can be propelled through technological push mechanisms, such as the results of R&D, emergence within insulated niches, or learning during routine behaviour; market-pull mechanisms, such as commodity prices or consumer behaviour and preferences; external pressure created by public policy, crises, social movements or trends acting as drivers; or the introduction of globally developed innovation through foreign direct investment (FDI), trade and other global connections (Geels, 2005; Pietrobelli and Rabellotti, 2011; Lundvall, 2016a; Deonarain, 2019; Alexander, 2021). Change can be a result of combinations of multiple processes.

As depicted in Figure 1, innovation systems can be seen to lead to innovation and, regardless of the drivers of change, the innovation system shapes how actors respond. In turn, innovation can lead to diverse impacts and outcomes. The type of innovation that this working paper series is particularly concerned with is the emergence and adoption of 4IR systems and technologies. The key focus is how innovation related to 4IR results from South Africa's innovation system, and the potential of 4IR to shape South Africa's societal impacts and outcomes.

A key concern related to societal impacts and outcomes is how much of an impact is created by an innovation. For instance, some innovations can be adopted by a very small group and have a very limited impact. On the other hand, some innovation can create large-scale change. The size of the impact could be considered as being shaped by the process occurring through the second arrow in Figure 1. Also, as discussed above, the impact can be felt in different dimensions, such as within the sphere of technological systems, or spread to have broader economic, as well as social and environmental, ramifications.

Considering change related to 4IR, Schwab and Davis (2018) assert that top-down governance cannot ensure that society benefits from 4IR technologies and, alternately, that an unregulated system will not result in a fair distribution of benefits, free from harm and empowering for all members of a society. To seek to ensure positive outcomes, they propose that multi-faceted institutional change that is based on four key principles can help. First, it is important to consider systems-level issues as opposed to specific technologies. The systems in which technologies are used will shape how they affect society. Second, instead of having a perspective that technology will shape choices and change human behaviour, systems should be designed to give people more choices, opportunities, freedom and control over their lives. Third, instead of accepting the trajectory of changes that are happening, future systems should be designed consciously. Fourth, technologies can have values embedded within them. These values should be debated at every stage of innovation processes.

Public policy is an important factor that shapes national innovation systems and that can stimulate changes within these systems. In addition to public policy, a variety of additional pressures can contribute to change processes. Examples include social movements, technological developments, and businesses' activities. Nevertheless, this working paper series focuses on public policy as being a key driver shaping national systems. In addition, public policy is also an ongoing process that can be changed and developed in response to the variety of additional pressures experienced by an innovation system and country. Policy development can also seek to incorporate the perspectives of multiple stakeholders in order to address the complexities involved in how 4IR is integrating into and influences economic, social and environmental systems. The rest of this sub-section focuses on roles that can be played by public policy.

Figure 1: A Model of an Innovation System Contributing to Change

2.5.1 Purposes of and Need for Public Policy

This working paper series is particularly concerned with policies that shape innovation systems. Creating a suitable innovation system is seen as a way to promote innovation. Important considerations are the type of innovation that happens, the way it is organised, and the types of impacts it creates. In particular, the working paper series considers outcomes related to general economic development, as well as environmental and labour outcomes.[4] These are seen as key issues for South Africa, and are discussed further in Section 3 of this paper and in the final working paper in this series, Alexander (2022c).

A range of national programmes and policies across different parts of government shape the elements of innovation systems. In particular, the relevant policies can be framed as industrial policy, productive development policies, structural transformation policies or innovation policies. Relevant policies can also be based in other domains, such as education, labour and the environment. Countries often create national development plans and sectoral development plans that frame objectives for policy setting. When considering the functioning of a national innovation system, it is important to think about how a wide variety of policies intersect.

While some policy best practices are discussed below, it is important to consider the national context. When assessing potential changes to national development pathways, key factors to consider are a country's current innovation system and the types of technologies that are being used in the national productive system. Knowing the specific systemic context is important to avoid creating policies that may reproduce existing weaknesses in the national innovation system and to be able to introduce mechanisms that are compatible with the logic of the existing system (Lundvall, 1992).

While policy can be developed with multiple goals and implemented in diverse scenarios, one perspective is that certain conditions in particular call for policy interventions. Hausmann et al. (2008) describe three types of market failure that necessitate industrial policy. The first is self-discovery externalities, which involve the fact that the costs of research can be high for one actor but the benefits may be spread out to a broader set of actors. The second is coordination externalities. These are related to the fact that investments may need to be made simultaneously for different parts of a productive system, a process that may not happen without coordination. The third is missing public inputs. This failure involves a type of coordination externality that results in businesses lacking the required inputs, such as legislation, accreditation, R&D, transport and other types of infrastructure, standards and certification. A number of factors can be identified as leading to missing public inputs (see Box 2).

Box 2: Factors that can Lead to Missing Inputs

- Poor performance and governance of existing organisations
- Lack of incorporation of new technological developments that may need specific organisations, policies and capabilities
- Inadequate resources allocated

[4] It is important to note that policies can also be targeted specifically to achieving the outcomes that are desired by using methods that are not directly related to innovation systems (e.g., redistribution policies). However, this report is focused on policies that are intended to shape the elements of the innovation system.

- Poor policy design and measurement of impact
- Mismatch of policy and industry needs
- Overlap and fragmentation both within and between departments
- High coordination costs and low trust between public and private sectors
- Lack of data on and analysis of factors shaping private sector behaviour related to incentives to innovate, invest and upgrade
- Too many competing demands on public budget
- Lack of awareness of weak signals or demand in some sub-regions or sub-industries
- Pressure to show short-term results when longer term efforts may be needed to promote technological change and capability development
- Pressure from lobbying groups overshadowing other interests
- Individual agencies pursuing their own interests outside of a nationally coordinated effort
- Limited public sector management capability related to meso-policy

Source: Cunningham (2018c)

2.5.2 Policy for Industrial Development

A number of lessons on good industrial policy can be drawn from existing research. Good industrial policy involves collaboration between private actors and the government. For governments to make effective policy, they require the cooperation of firms and entrepreneurs to provide relevant information about the obstacles and opportunities they face (Hausmann et al., 2008). Important questions to ask when designing policies are, “Have we set up the institutions that engage the bureaucrats in an ongoing conversation of pertinent themes with the private sector, and do we have the capacity to respond selectively, yet also quickly and using a variety of updated policies, to the economic opportunities that these conversations are helping identify?” (Hausmann et al., 2008).

Industrial policies can cover many aspects related to innovation systems. Altenburg and Rodrik (2017) highlight the importance of successful East Asian countries having created policies that support technological learning and capacity building, especially in manufacturing, along with institutions to manage structural change, provide coordination for new economic activities, nurture entrepreneurship and invest in education and skills. Countries’ abilities to manage structural change in ways that enhance productivity and that are socially inclusive can shape their prospects for economic development.

There are no sweeping best practices for innovation system policies, as they need to be specific to their context. Learning from other countries is possible, but their contexts need to be understood (Lundvall, 2016a). The East Asian experience shows that an approach based on small, gradual and cumulatively transformative change through identifying challenges and using processes of self-correction can have highly positive outcomes (Hausmann et al., 2008). Not only do national policymakers need to understand domestic dynamics, but they also need to consider how their economies interact with global systems. A number of principles of successful industrial policy have been identified (see Box 3).

Box 3: Principles for Successful Industrial Policy

- Conscientious targeting, with continuous oversight and upgrading
- Engaging in collaboration with the private sector and labour when necessary
- Adequate resources available
- Corruption and rent-seeking prevented
- Policies are coherent and aligned
- Broad agreement across government that innovation and dynamism are needed
- Channelling entrepreneurial search processes towards societal objectives
- Combining regulations, market-based instruments and financial incentives
- Ensuring public services are delivered effectively
- Coordinating mandatory and voluntary measures to achieve the best result

Sources: Altenburg and Assmann (2017); Department of Trade and Industry (DTI) (2018)

Altenburg and Rodrik (2017) highlight three basic principles that should be considered when designing and implementing industrial policy. The first is embeddedness. Close interaction between public and private actors is needed to ensure that industrial policy provides benefits and remains targeted at ensuring continuous matching with changing conditions related to how economic sectors function, businesses' priorities, and where bottlenecks exist. The second is discipline related to ensuring that government actions do not get captured by private interests, which can be accomplished by using tactics such as clearly defined objectives and measurable performance indicators; unbundling the roles of policy formulation, funding, implementation and evaluation; and using public tenders, clear rules, conditionality and sunset clauses. The third is accountability for policymakers and implementing agencies, which can be created through reporting requirements, public disclosures, audits, political parties, independent courts and a free press. Furthermore, Aiginger and Rodrik (2020) outline 10 lessons for industrial policy in the 21st century (see Box 4).

Box 4: 10 Lessons for Industrial Policy in the 21st Century

1. Manufacturing remains crucial for growth and well-being

While employment in manufacturing is shrinking in middle-income and advanced economies, it remains crucial for development and well-being. Manufacturing is strongly linked to technological progress, which can increase the chances for better national living conditions and international leverage of a country. Structural change is needed to overcome poverty or change relative income status (e.g., middle to high income). Decline is often related to premature deindustrialisation or relying on inward investment and foreign technology.

2. Industrial policy has to be systemic, not isolated, or delegated to specialists

Successful industrial policy harnesses synergies with policies such as competition policy, trade policy, regional and tax policy. It should focus on specific sectors, while also seeking to improve general business conditions.

Responsibility should be held by the entire government as opposed to specialised actors, and led by heads of state or regional leaders reporting and responding to the needs of government actors, citizens, experts, and firms.

3. The optimal scale of the industrial sector depends on capabilities, ambitions, and preferences

Contributions from worker representatives, media, NGOs, and general citizens should be heard.

4. Industrial policy has to take the high road

Industrial policy should enable structural change within manufacturing. Manufacturing is an activity with blurred boundaries, including industry-based services and many input and output relations with private and public actors. Policy should support quality and sophisticated products, including 4IR elements. High-quality education, strong innovation systems and well-developed clusters facilitate high-quality industrial policy. Low costs, low standards, subsidising ailing industries and import protection do not support a high-road strategy. Focus needs to be placed on eradicating poverty and on economic development.

An over-reliance on resources, cheap labour or specialising in products with low income elasticity (lower than proportionate increase in demand as income increases, such as staple food products) can create development traps. Industrial policy should be conscious of promoting pathways to premature deindustrialisation. Rising incomes will change internationally competitive sectors, levels and types of education and innovation, and gender relations. Exploiting nature and high rural to urban migration can cause problems by leaving agricultural regions behind.

5. Redirecting technical progress and preparing for less growth

Current technical progress focuses on reducing labour instead of capital, resources and energy. This is not an inevitable dynamic. The direction of technological progress has been biased by distorted incentives. Labour is often very expensive due to the high levels of taxes, whereas pollution and transportation are generally not taxed in relation to their impacts on society. Furthermore, fossil fuels are subsidised and capital costs have been held down since the financial crisis. Redirecting technical progress through changing these incentives can improve welfare and reduces the need for growth.

6. Societal goals should be paramount, moving beyond the correction of market failures

The goals of industrial policy should include market shaping, mission orientation, and providing new basic technologies. These goals are wider than a narrow focus on correcting market failures. Societal goals involve climate, health, poverty prevention, the creation of good jobs, and reducing inequality. Progress towards these goals should be tracked. Notably, when industrial policy leads to regions being left behind, social challenges can occur, such as the development of populist movements.

7. Search process in an unknown territory

When industrial policy has ambitious and open-ended goals, government may have little information about how to reach the goals. Industrial policy should be open to new solutions, experiments, and learning, which should involve public-private dialog. As firms may provide biased information, the government should engage in conscious seeking to pick out the important information.

8. Asian countries demonstrate how to combine planning with market forces

Industrial policy can have a light (supporting business environment) or a heavy touch (top-down planning). Successful East Asian countries have prioritised sectors and technologies through cheaper credit and subsidies, while also incorporating market forces related to having open economies, special economic zones and favourable conditions for multinational enterprises.

9. Industrial policy can mitigate populism

When industrial regions lose dominant firms, along with emigration due to the loss of job opportunities, these "forgotten regions" can become averse to new immigrants and have limited appeal for new businesses. This dynamic has been driven by industrial policy that favours dynamic and growing places. "Forgotten regions" should seek to have former citizens return with the new skills they have acquired, improve infrastructure, prioritise new types of firms that may be small- and medium-scale enterprises (SMEs), promote teleworking, and provide lodging that integrates generations. Such a combination of policies may reduce one of the root causes of populism by increasing well-being. An important consideration is the creation of "good jobs" (see: Rodrik and Sabel, 2020).

10. An international forum for industrial policy shaping responsible globalisation

An annual international forum for industrial policy, which could include political leaders, civic organizations and firms, could enable global efforts to transform economies in more sustainable directions, develop agreements related to the compensation of losers from technological change, and seek to address international issues such as decreasing military spending, improving development assistance and preventing resource grabbing. The forum could benefit from incorporating inputs from experts, industry groups and citizens, but would need to be wary of being highjacked by special interest groups or populist priorities.

Source: Aiginger and Rodrik (2020)

Funding available to government actors tasked with engaging in industrial policy can also be a challenge. Hausmann et al. (2008) propose a solution for problems related to resources not being available for governments to provide missing public inputs to industry. They suggest creating a centralised budget that can be allocated to public entities as needed (e.g., for infrastructure, for improved phytosanitary services, or for a new regulation). In essence, the budget would be used to buy the necessary services from different government entities. This proposal is justified by contrasting money allocation in markets, which is determined by a profit motivation, to this case, where the industrial policymakers are seeking to be responsive to the group of private actors with whom they are engaging. This mechanism would ideally promote improvements in service providers' offers as they compete for funding.

Industrial policy needs to consider new products, processes, geographies of production, and specific country characteristics. With these considerations in mind, multiple options exist for the direction of industrial development policies (Tregenna, 2015). One approach is that countries can promote industrial development by seeking to build vertically linked processing activities related to primary sectors, such as agro-processing or mineral beneficiation. Another approach is to seek to enter into existing global value chains. As some countries have experienced successful economic development through connecting with global value chains, many international organisations have promoted building such connections as a path to development. More research needs to be done to better understand the influence of participation in GVCs on national development, particularly as the nature of productive systems shifts in relation to 4IR. Thirdly, organisations can actively seek to source inputs from domestic manufacturers.

Hausmann et al. (2008) broadly split industrial policies into two levels of scope. The first level comprises policies described as working "locally" to support existing industries. For these types of policies, the government faces three problems. One is related to a lack of information on what inputs it needs to provide. The second is that, even if the needs are known, adequate incentives for policymakers to provide these inputs may not be in place. The third is that resources may not be readily available to provide the needed inputs.

Hausmann and co-authors identify a number of ways to overcome these obstacles, which include developing a mechanism to promote inter-firm collaboration on identifying coordination failures and possible solutions, budgetary procedures that increase public sector responsiveness to the needs of industry, and monitoring procedures that ensure discipline and continuous improvements. They also identify a set of beneficial operating principles (see Box 5). These include using measured amounts of transparent direct transfers to the private sector, which include co-financing requirements, in order to help solve free-rider problems.

The second level of policies has a broader scope and they are described as working "globally". They involve making strategic bets on new industries that require national capacity leaps. In contrast to "locally" focused policies, these policies require identifying particular goals (industries or activities) and then providing the inputs and subsidies needed to entice private businesses. This type of policy requires a new set of institutions that can stimulate capacity-building "jumps" and can answer questions related to what customised sector programmes are designed and how coordination is ensured between complementary inputs.

Hausmann et al. propose that venture funds can play this role. These can be newly developed institutions or part of an expanded role of existing development banks. In contrast to private sector venture capital, which functions in a competitive marketplace, these funds are likely to be monopoly players responsible for generating project ideas, as opposed to choosing among them. The role of the funds would switch between organising coalitions to support projects and developing new projects. However, the lack of competition can lead to political as opposed to economic motivations shaping practices. To avoid this scenario, public venture funds should base decisions on clear frameworks.

With such an approach, many projects will fail, but the successes should make up for the failures. Hausmann and co-authors (2008: 12) write that "the absence of failure is a sure sign that the government's industrial policies were too timid. The ultimate test of whether industrial policy is working is not whether a government can reliably pick winners (no government reliably can), but whether a government is able to let losers go. The objective should be not to minimise the risk of mistakes, but rather to minimise the costs of the mistakes that inevitably occur on the way to success".

Box 5: Operational Principles for "Locally" Focused Industrial Policy

- Allow open dialog and private sector self-organising
- Promote transparency to limit rent-seeking and increase legitimacy

- Prioritise public inputs
- Interventions should focus on increasing productivity, not compensating low-productivity sectors
- Establish clear criteria for success and monitor and address performance challenges
- Use sunset clauses to define when funding ends or becomes part of specialised institutions' budgets
- Streamline decision-making and execution processes
- Ensure accountability and have clear guidelines for deciding when to cut off failing projects
- Build a formal process, including a quality review, for re-designing or expanding initiatives to increase benefits

Source: Hausmann et al. (2008)

Industrial policy can be targeted at addressing a variety of specific challenges, some of which have been discussed earlier in this paper. Notably, as discussed above, deindustrialisation is a growing phenomenon that has been connected with problematic outcomes. A number of policy measures can be used to slow, avoid or reverse deindustrialisation (Tregenna, 2015). Countries can promote manufacturing by developing targeted industrial policies. It is also important to note that industrial policy needs to have supportive macroeconomic policy, especially regarding interest rates and exchange rates; and complementary trade policy, technology policy, labour market policy and skills and education policies.

Rodrik (2016) outlines alternative development paths that may be pursued in place of relying on industrial development. One is services-led growth. Services that are high productivity and tradable could play a similar role to manufacturing in stimulating growth, such as information technology and finance. However, these industries rely on high-skill employees and cannot provide jobs for large low-skill workforces in the same way that manufacturing did. Other services face the challenge of not being technologically dynamic, or being non-tradable.

Focusing specifically on the issue of technology diffusion, which is a key factor when exploring 4IR, the OECD (1998) identifies four types of policy approaches. One is supply-driven, which involves transferring and commercialising publicly developed technology to the private sector. This can also involve public policy promoting globally developed technologies to national businesses. The second approach is demand-driven, which aims to identify and assess private sector technological needs and opportunities, often focusing on SMEs, and seeking to complement private sector mechanisms for diffusion. This can involve supporting firms' ability to incorporate technology through assistance with managerial, training, and financial problems. The third is network-based, which focuses on creating and strengthening networks to promote information flows. This can involve the creation of innovation centres, which act as intermediaries. The fourth approach is infrastructure-building. This approach aims to increase the diffusion capacity of the national technology infrastructure by combing the supply, demand, and networking approaches.

Additionally, seven types of government-led national efforts that can facilitate adopting and diffusing production technologies can be identified. These are outlined in Box 6.

Box 6: National Diffusion Mechanisms for Technology and Innovation

- Building awareness by communicating the importance of national initiatives and programmes to industrial policy, and by sharing success stories and lessons from technology and innovation adoption journeys of pioneering companies
- Establishing financial incentives to support companies' acquisition and development of 4IR technologies
- Creating a robust legal framework to regulate impact of new technologies (e.g., intellectual property, data protection, cross-border flows)
- Spurring accreditation of companies that successfully adopt 4IR technologies, nationally and internationally, thus supporting the technology and industry ecosystem
- Expanding connectivity and data security protection
- Promoting innovation for 4IR technologies applied to production
- Setting up new training and education programmes adapted to the future of the production workforce

Source: WEF (2018b)

Considering the situation in which middle-income countries face a middle-income technology trap, Andreoni and Tregenna (2020) identify three policy paths. First, upgrading in value chains can be facilitated through public technology intermediaries providing support to reach needed product quality standards. Second, as promoting technological upgrading in manufacturing requires building a solid productive and technological capability foundation, institutions need to evolve to respond to quickly changing innovation challenges. Third, "linking up" and "linking back" need to be done together and promoted through coordinated and coherent, yet flexible and dynamic, industrial policies. These policies need to be customised to country context, go beyond the manufacturing sector, and support innovation and technological upgrading.

In recent years, countries have launched national industrial policies that are focused specifically on 4IR. Between 2012 and 2018, eight of the top 10 manufacturing countries launched 4IR strategies (Cunningham, 2018a). Examples of such policies include China's Made in China 2025 policy (declared funding 2,2 billion euros), South Korea's Manufacturing Innovation 3,0 (declared funding 1,6 billion euros), and France's Industry of the Future (declared funding 1 billion euros) (Roland Berger, 2018, as cited in Cunningham, 2018a). These approaches are designed specifically for their own national contexts. Zanello et al. (2016) suggest that, when countries have low levels of capacity, 4IR policies should focus on incremental innovation involving existing technologies that are new to domestic firms. However, government policies that incentivise innovation can support companies to limit the risks of innovating (Cunningham, 2018b; Mazzucato, 2018).

The direction and implications of technological changes are important factors that should shape policy objectives. While a key objective of much industrial policy has been economic development, these policies have wide-ranging implications. Aiginger and Rodrik (2020: 193) highlight that "steering technological change in a direction that is friendlier to environment and labour must be a key element of new industrial policies". They go on to say that policies should not necessarily copy the paths of leading economies, but should consider domestic issues and priorities, such as "supporting vulnerable groups, gender equality, reduced fossil energy use or the development of green technologies for new types of agriculture, housing, and transport". As mentioned above, this paper is specifically considers environmental and labour outcomes related to the spread of 4IR. The following two sub-sections discuss how industrial policy can be designed to consider these outcomes.

2.5.3 Environmental Implications of Industrial Policy

Environmental outcomes have been considered specifically through discussions framed around "green industrial policy", which has been a growing area of concern (see: Altenburg and Assmann, 2017). Green industrial policy, which can overlap with environmental policy, has been defined as "including any government measure aimed to accelerate the structural transformation towards a low-carbon, resource-efficient economy in ways that also enable productivity enhancements in the economy" (Altenburg and Rodrik, 2017: 11). Green industrial policy is seen as going beyond traditional industrial policy in a number of dimensions. These dimensions include considering environmental externalities; prioritising technologies based on their environmental impacts; being shaped by time pressures related to emerging environmental outcomes; decision-making involving uncertainty based on future technologies and markets, political priorities, and ecosystem dynamics; coordination needed across multiple policy areas; and consideration of global outcomes, which might not be aligned with national interests (Altenburg and Rodrik, 2017).

Currently, there are many economic incentives to damage the environment. However, this is not inevitable and these can be changed. Policies such as incorporating environmental costs into prices, as well as increasing regulations and removing subsidies for fossil fuels and other unsustainable goods and practices, can create incentives for behaviour with less negative environmental consequences (Altenburg and Rodrik, 2017).

2.5.4 Labour Implications of Industrial Policy

In addition to green industrial policy, it is also important to consider how industrial policy shapes labour systems. Key considerations are the creation of jobs and the need to ensure that employment involves decent work (International Labour Organization, 1999). A key aspect that is important to consider is who gets access to which types of jobs, particularly with a focus on considering opportunities and experience for minorities and historically disadvantaged groups.

Rodrik and Sabel (2020) note that many companies do not currently have individual incentives to create good jobs, but that public policy can change the incentive system by providing tailored public services or through creating tax incentives. Overall, these authors propose an approach to promoting the creation of good jobs across an entire economy through a system of public-private collaboration that has three mutually reinforcing components. One is improving jobs in current enterprises by increasing skill level and productivity through extension services or cooperative programmes to improve technology. The second is increasing the number of good jobs by supporting start-ups, expanding existing firms and encouraging investment by outsiders. The third is implementing programmes to support workforce skills development, with a particular focus on at-risk groups.

3. A Snapshot of Key Economic Development Indicators and the Adoption of 4IR in South Africa

This section provides a snapshot of key outcomes related to the spread of 4IR in South Africa. The first three parts present characteristics of key economic development outcomes. The areas covered are general economic outcomes, related environmental, and related employment outcomes. These outcomes can be shaped by the spread of 4IR, a topic considered further in Alexander (2022c), the final paper in this working paper series. This section ends with a snapshot of South Africa's adoption of 4IR, which includes an overview of key features of South Africa's national innovation system and innovation policies.

3.1 Economic Profile and General Economic Outcomes

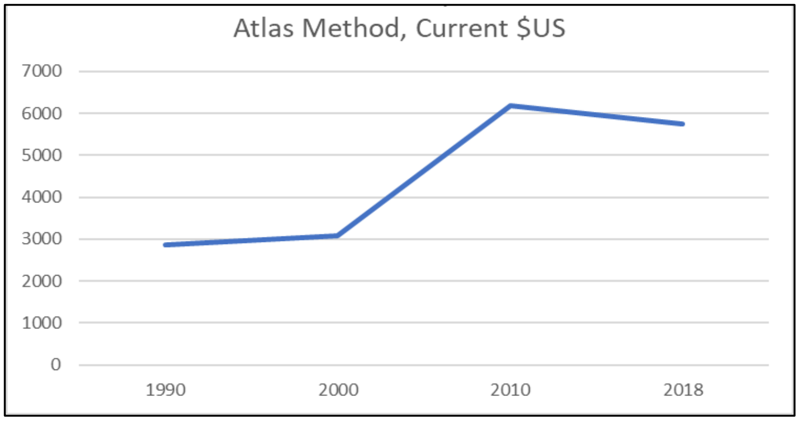
Economic development and reducing economic inequality are key issues facing South Africa. As discussed above, the adoption of innovation and 4IR has the potential to shape economic outcomes. This sub-section provides an overview of the nature of South Africa's economy and the status of key economic indicators.

3.1.1 Economic Development

South Africa is classified by the World Bank (2021) as upper-middle income, with one of the highest inequality rates in the world. Income per capita has risen substantially over the last 30 years (see Figure 2). However, over 30 million people (55%) lived below the national poverty line in 2014 (World Bank, 2020).

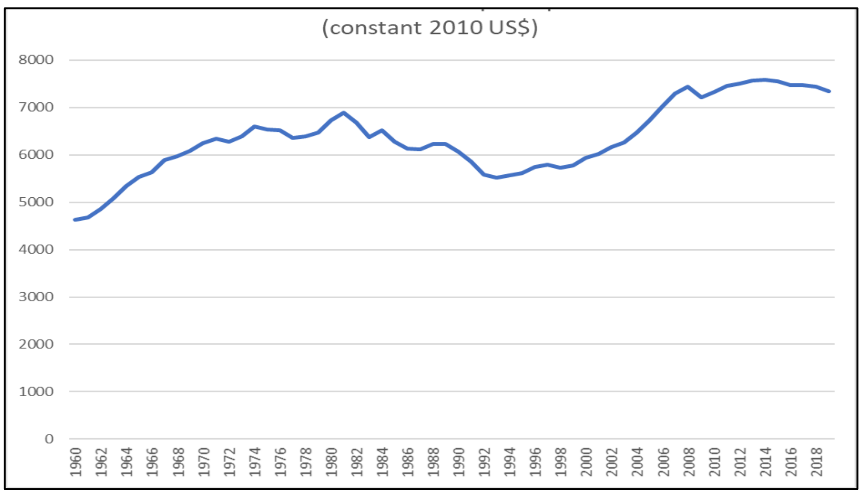
South Africa has worse economic performance than other upper middle-income countries. From 1994 to 2016, industry value added grew at an average of 1,6% and GDP growth was 2,9%, while the average for upper middle-income countries was 5,5% average industry value-added growth and 5% GDP growth (Bell et al., 2018). South Africa's GDP per capita growth has not recovered since the 2008 financial crisis and has been declining since 2014 (see Figure 3). Since the financial crisis, there has been limited new entry into South African markets and, compared to its peers, FDI has been low, and spending on R&D has been low (World Bank, 2018a).

Figure 2: GNI Per Capita



Source: World Bank (2021)

Figure 3: South Africa's GDP Per Capita



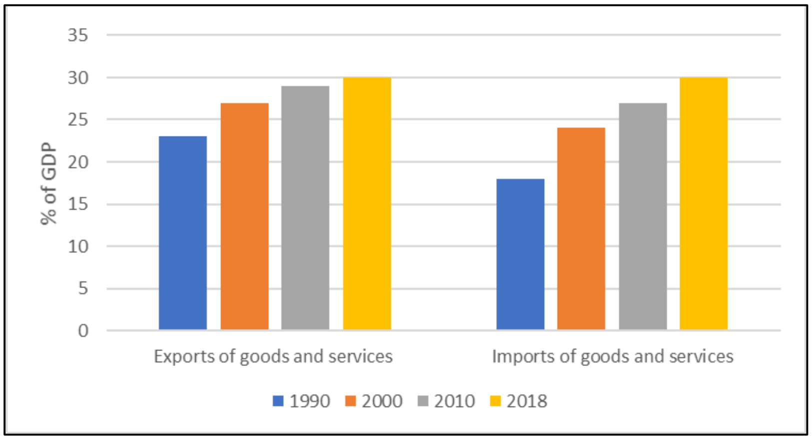
Source: World Bank (2021)

3.1.2 Structure of Economy

Overall, South Africa's involvement in trade ranked poorly on WEF and A.T. Kearney's (2018) Readiness for the Future of Production Assessment, at 69th out of 100 countries. Specific elements contributing to this low ranking included trade as percentage of GDP (68th), trade tariffs (68th), and prevalence of non-tariff barriers (58th). However, trade is becoming more important to South Africa's economy (see Figure 4).

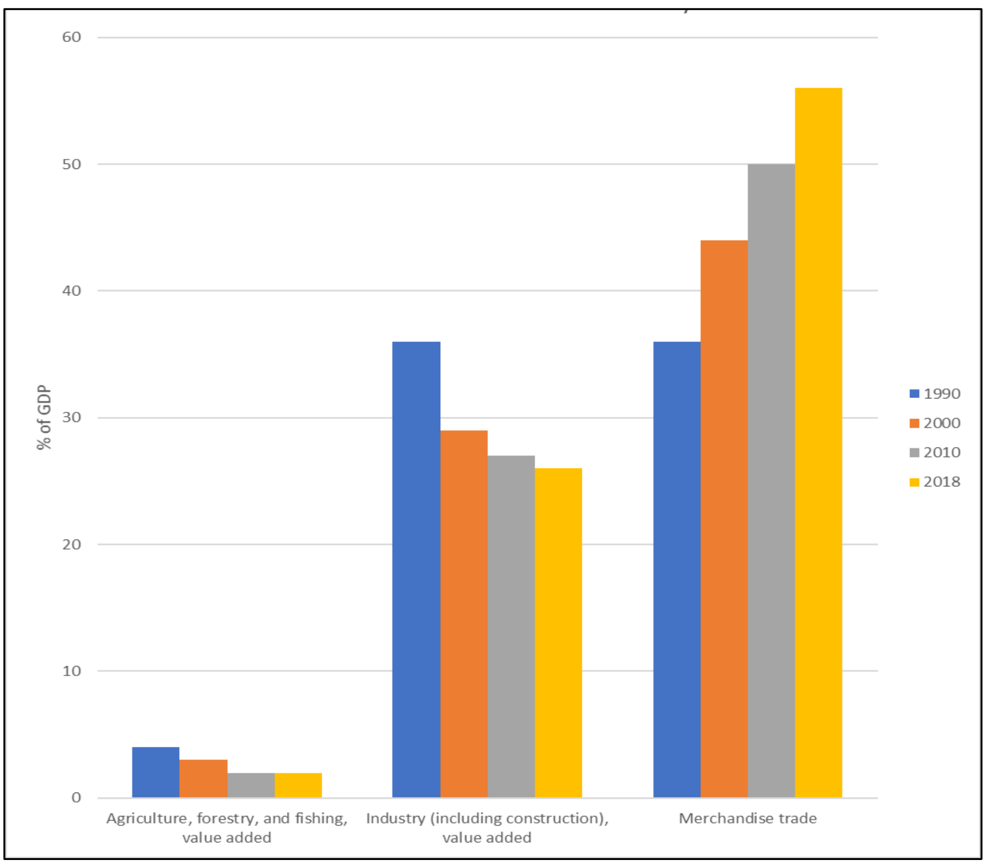
The make-up of South Africa's economy has changed quite significantly over the last 30 years. Successive post-apartheid governments have focused on market liberalisation, which has driven a path towards lower productivity (Bell et al., 2018). As discussed above, the growth of a manufacturing base can be pivotal to wider development processes. In South Africa, the contribution of industry to GDP has been declining since 1990 (see Figure 5). Manufacturing total value added dropped from 16% in 1990 to 13% in 2018, while services in total value added grew from 58% to 69% (United Nations Industrial Development Organization [UNIDO], 2021).)

Figure 4: Export and Imports



Source: World Bank (2021)

Figure 5: Features of South Africa's Economy



Source: World Bank (2021)

Overall, shifts in the structure of South Africa's economy have involved moving towards lower productivity and resource-based activities. Growth in value added has been strong in mineral and resource-based sectors, and these sectors dominate the export basket, accounting for 60% of merchandise exports (Bell et al., 2018). In a global comparison, the content of medium- and high-tech manufacturing value added ranks 63rd out of 128 countries, and this level has remained relatively stable from 2000 to 2017 (UNIDO, 2021). In 2018, high-technology exports made up only 5% of national exports (World Bank, 2021), and the NRI (Portulans Institute, 2020) ranked South Africa's high-tech exports 76th out of 134 countries.

3.1.3 Economic Needs

A number of key needs can be identified through this economic profile. These include raising incomes, decreasing inequality, diversifying exports and focusing more on manufacturing. All of these issues can be addressed through the appropriately implemented expansion of 4IR.

3.2 Key Environmental Outcomes

This sub-section provides an overview of key environmental outcomes. Environmental outcomes in South Africa are shaped, in part, through the nature of economic activity. Businesses' behaviours that affect the environment can be modified through the adoption of innovation and 4IR technologies and systems. However, it is important to note that related changes could be positive or negative. Considering these environmental outcomes is an important factor that should shape how policies promote the adoption of 4IR.

3.2.1 Environmental Challenges

In terms of environmental issues, South Africa ranks poorly compared to other countries (see Figure 6[5]). Notably low rankings are found in affordable and clean energy and carbon dioxide (CO_2) intensity level, where South Africa was in the 10th decile. Wastewater treatment was the only category in which South Africa was in the top half of global countries.

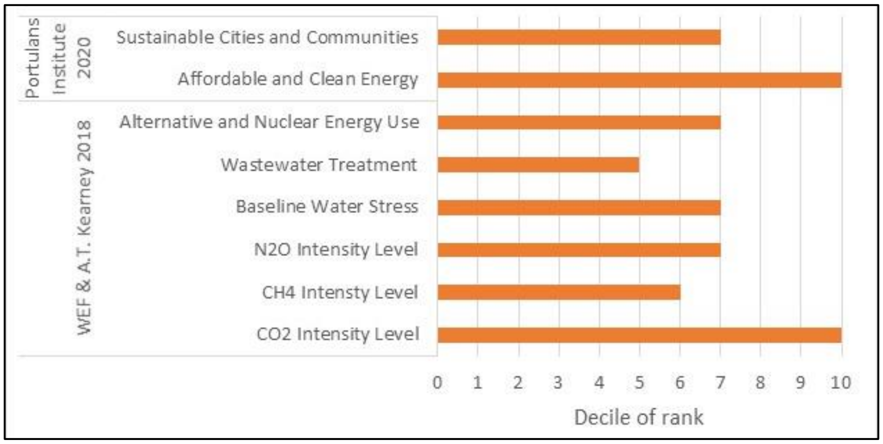
Greenhouse gas (GHG) emissions are a key challenge created by economic activity in South Africa.[6] National CO_2 emissions have remained relatively steady over a thirty-year period (see Figure 7). CO_2 emissions from manufacturing per unit of value-added rank 110 out of 128 countries (UNIDO, 2021). A key challenge that South Africa faces is a reliance on coal for mining and as an energy source (World Bank, 2018a). South Africa's energy intensity (units of energy per unit of GDP) was the fourth highest globally in 2016 (World Bank, 2018a). It also exports large amounts of coal (28% of production), making it the fourth-largest global exporter (World Bank,

[5] This figure shows deciles which categorise how South Africa ranks compared to other countries. For example, the first decile represents the top 10% of countries.

[6] GHGs include CO_2, CH_4, N_20 and fluorinated gases.

2018a). Overall, fossil fuel and fossil fuel-related exports account for 10% of export value (UNIDO, 2021). Moving away from coal is not a simple process, as many jobs are currently supported by the industry.

Figure 6: Global Rankings of Environmental Issues in South Africa

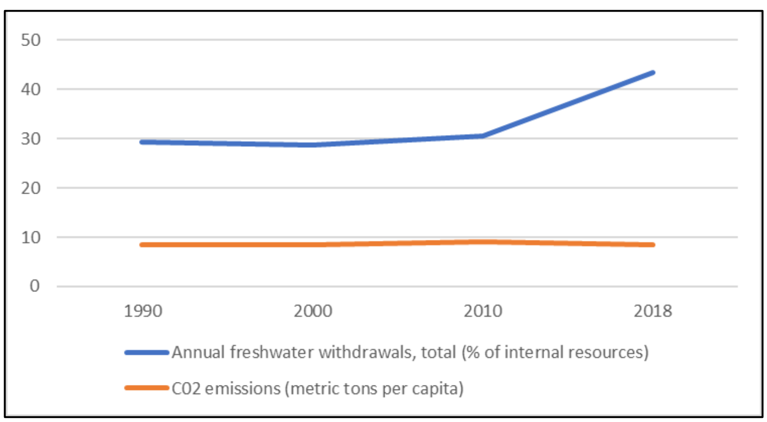


Sources: WEF and A.T. Kearney (2018); Portulans Institute (2020)

The transport sector is also a key contributor to GHG emissions. This sector contributes 11% of all emissions (Gain Group, 2020). Notably, road transport is responsible for 91% of this.

Another key challenge is the high use of water compared to the available levels. Water demand is growing because of population growth, urbanisation, and economic expansion (World Bank, 2018a). Fresh water withdrawal has seen a substantial increase in the last decade (see Figure 7).

Figure 7: Environmental Indicators



Source: World Bank (2021)

3.2.2 Environmental Needs

From this environmental profile, it can be seen that industrial development needs to involve developing systems with reduced environmental impact. Key needs can be seen as reducing CO_2

and other greenhouse gas emissions, and reducing freshwater use. These are challenges that 4IR systems have the potential to address.

3.3 Key Labour Outcomes

This sub-section provides a profile of key labour issues facing South Africa. The relationship between labour outcomes and 4IR is not straightforward. Notably, some of the challenges described in this sub-section can be alleviated through 4IR developments, and others, such as the lack of sufficient technical skills, may make the spread of 4IR more difficult.[7]

3.3.1 Levels of Employment

Compared to other countries, South Africa's labour participation rate is low (World Bank, 2018a). A major challenge faced by South Africa is high levels of unemployment. This challenge is experienced unequally in the population, with high levels of inequality associated with education status (see Figure 8), population group (see Figure 9[8]), and age (see Figure 10). Problematically, from 1994 to 2014, the share of black youth in skilled occupations decreased (Bell et al., 2018). Another challenge is that people with disabilities are minimally represented in the job market (World Bank, 2018a). Furthermore, of the people who are employed, 5% are underemployed (would like more work) (World Bank, 2018a). Nevertheless, poverty of those with a job is less than a third compared to those without a job (World Bank, 2018a).

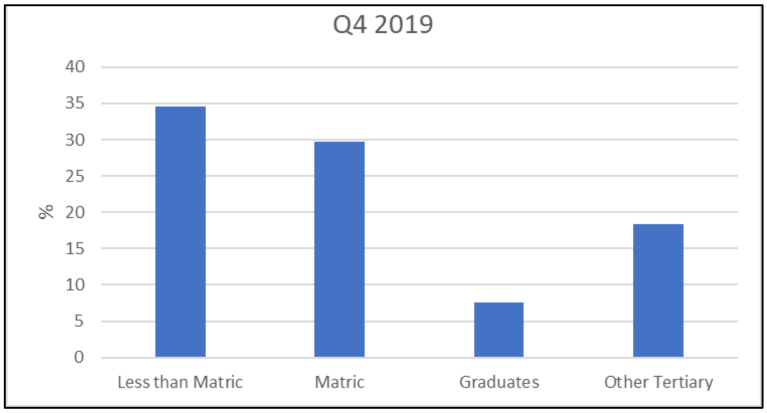
As mentioned above, from the early 1990s to 2018, there was a shift from manufacturing to services. This shift involved manufacturing in total employment dropping from 17% to 11% from 1991 to 2018 (UNIDO, 2021). Figure 11 shows recent changes in employment distribution. As part of this shift, jobs have been lost in manufacturing. For example, from the beginning of 2008 to the beginning of 2010, manufacturing employment dropped from 1 988 000 to 1 755 000, a loss of 233 000 jobs (Stats SA 2008, 2010). The largest losses have been experienced in diversified manufacturing industries, where strong growth would create jobs – directly and in related industries (Bell et al., 2018).

At the same time, in the period from 1991 to 2018, services in total employment grew from 60% to 72% (UNIDO, 2021). The bulk of employment is now in community and social services, trade, and finance (see Figure 12). This move to services has not been a positive change (Bell et al., 2018). Growth in communications and financial services has not been linked to employment growth. Notably, the movement towards services has involved a trend towards lower value and lower productivity services, including jobs such as security, cleaning services and retail.

[7] Alexander (2021a), the second working paper in this series, discusses labour as an economic input more thoroughly.

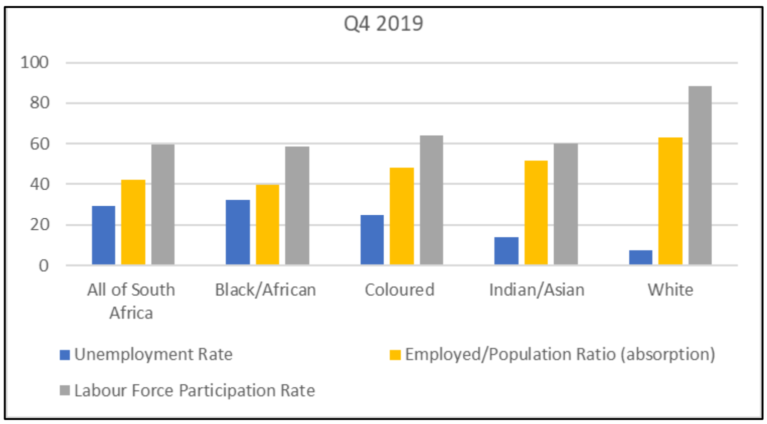
[8] For population 15 to 64 years old.

Figure 8: Unemployment Rate by Education Status



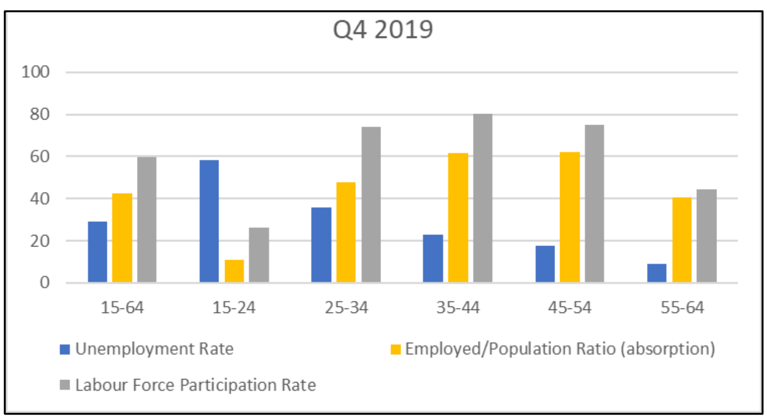
Source: Stats SA (2021)

Figure 9: Labour Force Characteristics by Population Group



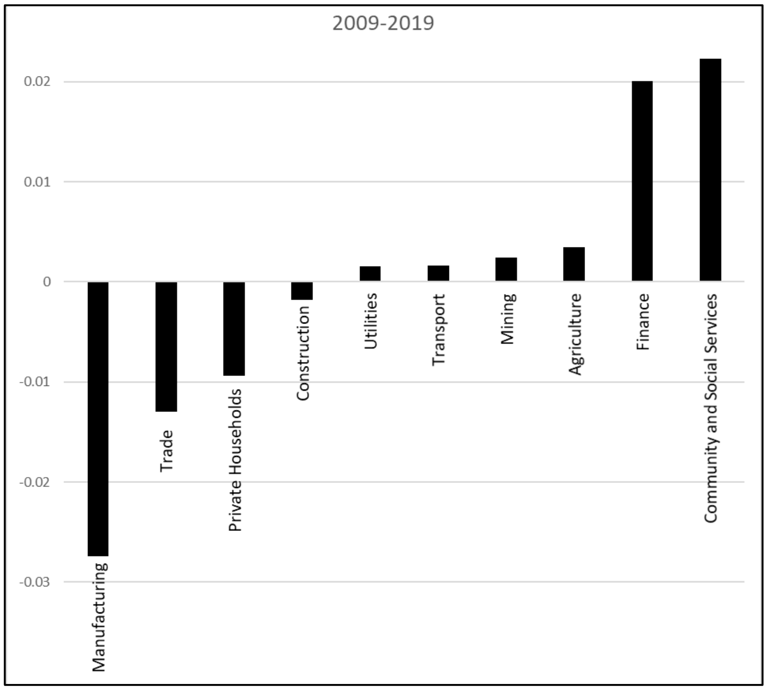
Source: Stats SA (2021)

Figure 10: Labour Force Characteristics by Age Group



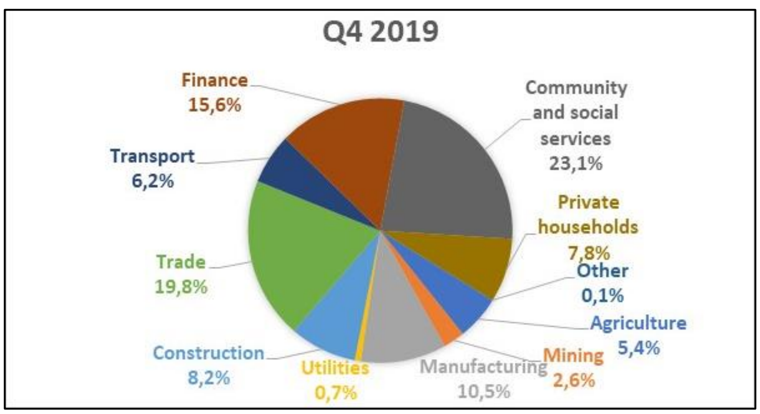
Source: Stats SA (2021)

Figure 11: Change in Proportions of Sectoral Employment



Sources: Stats SA (2010, 2020)

Figure 12: Employment by Industry



Source: Stats SA (2021)

While South Africa experienced export growth in the 21st century, it was not accompanied by the same level of employment growth (Calì and Hollweg, 2017; World Bank, 2016).[9] Export growth has generally been associated with growth in jobs and wages. However, the labour content of exports has declined because of both a higher import content of exports, and exports becoming more capital intensive (Calì and Hollweg, 2017). Calì and Hollweg propose that this may be due

[9] Calì and Hollweg (2017) also note that exports have declined relative to domestic production. Employment in exports provided a smaller share of total employment in 2011 compared to 2004.

to labour-saving technologies or due to policies or circumstances that favour capital over labour. They also found that there were a rising number of jobs in capital-intensive exports and a declining number of jobs in labour-intensive exports. They suggest that policy could be used to switch preferences between capital and labour input for exports.

Calì and Hollweg (2017) also show that the composition of exports can explain job patterns. A large proportion of export growth was in minerals, a sector that is not job intensive and with few backward linkages to the economy. However, this sector did experience some job growth. Notably, more than half of the growth in labour income from export during the 2000s went to manufacturing-affiliated services. Manufacturing exports were found to create a high number of jobs in related services, with indirect employment almost 4,5 times higher than direct manufacturing employment. Also notable is the fact that manufacturing employs about two-thirds of export-oriented workers, whose jobs primarily are in the service sector. As labour-saving technologies spread and the introduction of new technology creates a need for more skilled workers, growth in employment opportunities may sway towards skilled labour.

Considering job available across all sectors, job creation picked up in the early 2000s, but stalled following the global financial crisis in 2008 (World Bank, 2018a). While approximately 4,1 million net jobs were created between 2000 and 2016, compared to economic growth, job creation was slightly less than that of peer countries (World Bank, 2018a). One challenging factor is the type of jobs that have been created. From 1994 to 2015, the number of skilled jobs grew while the number unskilled and semi-skilled jobs decreased (World Bank, 2018b). Overall, since 2010, an average of 250 000 jobs have been produced every year (World Bank, 2018a).

Job creation can be impacted by public policy. Notably, Industrial Development Corporation of South Africa (IDC) funding has been associated with job creation (DTI, 2018). Specifically, IDC funding of the priority industries South Africa's Industrial Policy Action Plan (IPAP) (automotive; clothing, textiles, leather and footwear; metal fabrication, capital and rail transport equipment; agriculture and agro-processing; forestry, timber, paper and pulp, and furniture; plastics, pharmaceuticals, chemicals, and cosmetics; primary minerals beneficiation; green industries; marine manufacturing; aerospace; and, electro-technical and white goods industries)has been found to be associated with having created or saved between 400 and 62 000 jobs per sector between 2008 and 2017.Entrepreneurship can be an import source of job creation. The Global Entrepreneurship Monitor's (GEM's) survey covered issues related to South African entrepreneurs' motives (Bosma et al., 2020). A very large proportion (85%) of respondents who had engaged in entrepreneurial activity agreed with a statement saying they started their business to make a difference in the world, which was among the highest in the world (Bosma et al., 2020). In addition, South African entrepreneurs have among the highest reported levels of agreement with the statement that their motivation was to build great wealth or a very high income (79%), and that their motivation was to earn a living because jobs are scarce (90%).

Almost half of the entrepreneurs expected to employ one to five people, and more expected to employ over six people compared to those who expected not to have employees.

Overall, DTI (2018) describes that South Africa's economic structure is not well suited to the creation of a large number of jobs at the appropriate skill level, and ascribes this challenge to a number of factors. First, within labour-intensive sectors, such as manufacturing, growth is not fast enough to create a large number of jobs at lower skill levels, for which South Africa has a large number of available workers. Second, the development of higher-value productive sectors creates more jobs in the tertiary sector, for which South Africa has fewer workers. Third, legal and illegal imports create economic leakage. Fourth, population distribution remains shaped by apartheid, which creates challenges related to worker travel logistics.

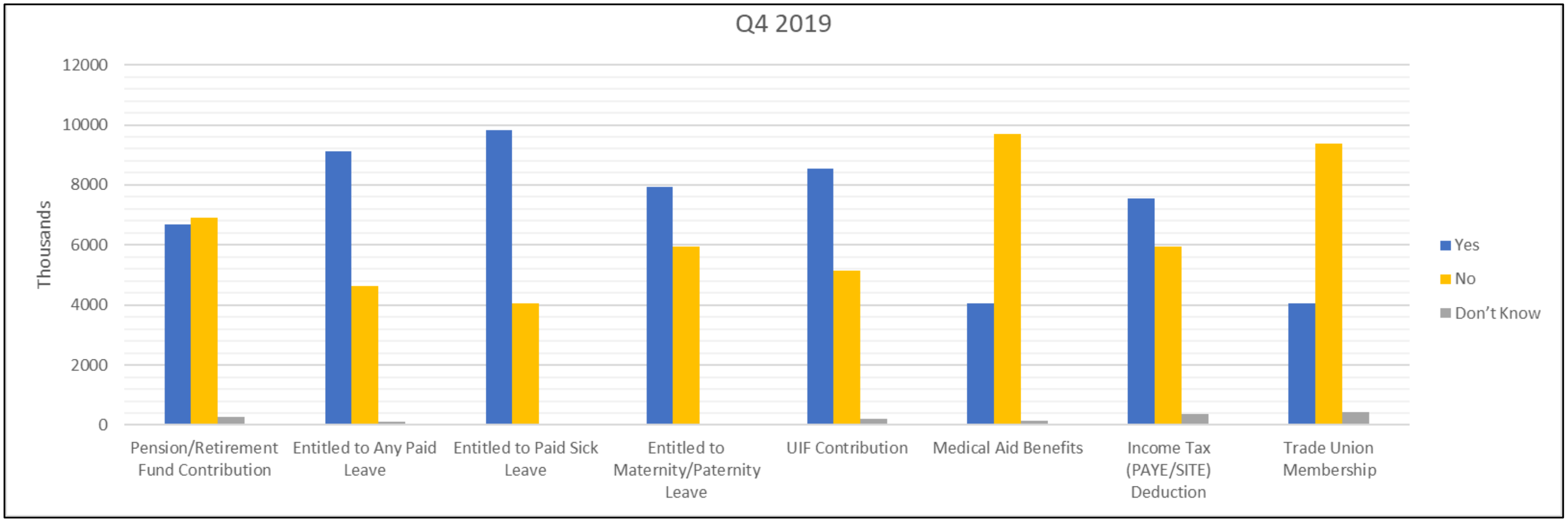
3.3.2 Working Conditions

Another important factor to consider is the types of jobs being provided. Workers in South Africa have varying conditions of employment (see Figures 13, 14, 15, and 16). Notably, slightly less than half of workers reported having retirement or pension fund contributions, and less than half reported having medical aid benefits. Also, about 39% of workers were in jobs with a limited or unspecified duration. Informal employment is concentrated in retail and other low-skill sectors, and more prevalent in the former homelands (World Bank, 2018a). Overall, South Africa ranked well related to workers' rights in the Global Competitiveness Index, at 26th out of 141 countries (WEF, 2019). Also, it is notable that self-employment accounts for 14,4% of employment in South Africa, which is close to the OECD average of 16,4%, and much lower than the 50,4% found in developing countries (World Bank, 2018a).

South Africa's Department of Employment and Labour (2021) runs a number of programmes with the purpose of supporting strong industrial relations and promoting South Africa's interests in international labour matters (see Box 7). It also supports the National Economic Development and Labour Council (NEDLAC) and the Commission for Conciliation, Mediation and Arbitration (CCMA).

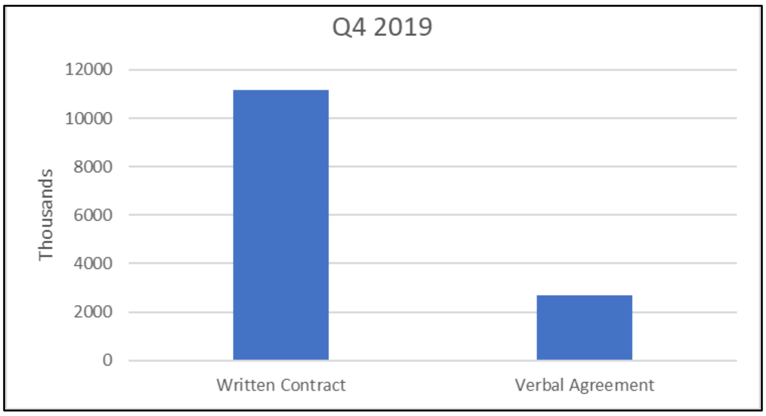
However, access to decent jobs is limited by people's levels of connectedness to economic opportunities. People in underserviced townships, informal settlements, and former homelands have less access to electricity, water, sanitation, internet, good public clinics, school, and financial services, and often live far from job opportunities, with expensive commutes (World Bank, 2018a). Another problem with job opportunities in South Africa is that large numbers of rural residents move to urban areas in search of jobs. Rural-to-urban migration has been significant and can reduce poverty; however, it also puts pressure on public services and raises tensions through new arrivals competing for jobs, services, and businesses (World Bank, 2018a). Long-term plans to densify cities sustainably are in place, but in the meantime, many South Africans remain in more remote areas (World Bank, 2018a).

Figure 13: Conditions of Employment



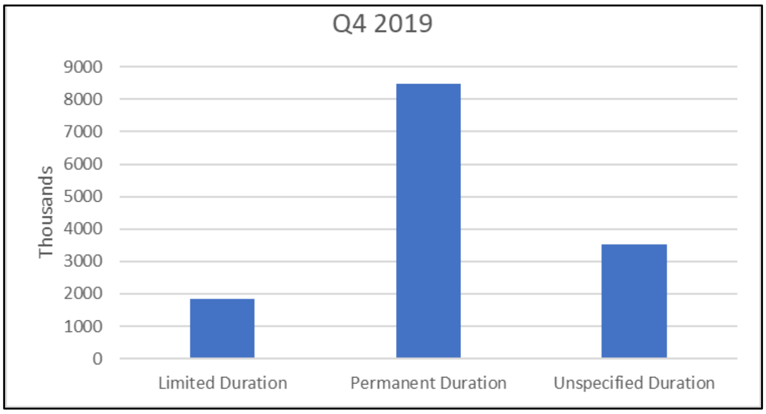
Source: Stats SA (2021)

Figure 14: Employment Agreement



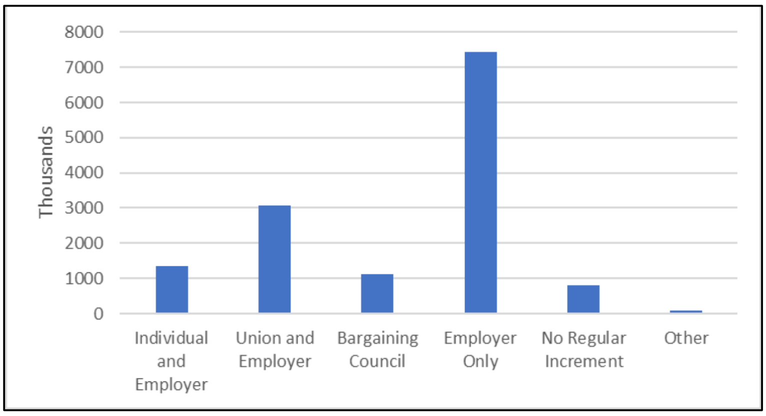
Source: Stats SA (2021)

Figure 15: Nature of Contract/Agreement



Source: Stats SA (2021)

Figure 16: How Annual Salary Increment is Negotiated



Source: Stats SA (2021)

New forms of work, which are often a part of 4IR, are also an emerging issue for South Africa. However, the impacts may be in the early stages, as, for example, the NRI (Portulans Institute, 2020) ranked the prevalence of the gig economy at 85th out of 134 countries.[10] Policy is

[10] NRI (Portulans Institute, 2020) uses data from WEF's Executive Opinion Survey that defines the gig economy

starting to address this phenomenon, with a large but declining gap identified related to labour regulation covering emerging types of work (Genesis Analytics, 2019).

Box 7: The Labour Policy and Industrial Relations Programme

Strengthen civil society:

Provides funding through transfers to the Development Institute for Training, Support and Education for Labour (DITSELA), the Workers' College Natal, the Congress of South African Trade Unions (COSATU), the South African Confederation of Trade Unions (SACOTU), the South African Labour Bulletin and selected rural advice offices.

Collective bargaining:

Manages the implementation of the Labour Relations Act (1995) and uses funds to manage registration of labour organisations; publishes and extends collective agreements; supports participation in collective bargaining structures; participates in the governance structures of the Commission for Conciliation, Mediation and Arbitration; and participates in relevant NEDLAC activities.

Employment equity:

Promotes equity in the labour market by improving the enforcement of the Employment Equity Act (1998).

Employment standards:

Protects vulnerable workers in the labour market by administering the Basic Conditions of Employment Act (1997).

Source: Department of Employment and Labour (2021)

3.3.3 Education and Training of Workers

South Africa spends a larger share of its GPD on education (primary, secondary, and tertiary) than most OECD and partner countries (OECD, 2019b). However, this spending has mixed outcomes. Overall, South Africa ranked 67th out of 100 countries on human capital in WEF and A.T. Kearney's (2018) readiness assessment. South Africa was 90th out of 141 countries in the category of "skills" in the Global Competitiveness Index's ranking (WEF, 2019). Specific elements of this rating involved mean years of schooling – 60th, extent of staff training – 40th, quality of vocational training – 119th, skillset of graduates – 102nd, digital skills among active population – 126th, ease of finding skilled employees – 98th, school life expectancy – 73rd, critical thinking in teaching – 95th, and pupil-to-teacher ratio in primary education – 109th.

Globally, South Africa has high levels of secondary school enrolment rates (World Bank, 2021). In 2018, only 18% of young adults did not have upper secondary education, a drop from 27% in 2008 (OECD, 2019b). However, South Africa has the lowest proportion of tertiary education achievement across OECD countries, with only 7% having achieved this level (OECD, 2019b). While slow and steady progress has occurred, learning outcomes remain low by global and regional standards (World Bank, 2018a).

as "a labour market that is specific to digital platforms and to working arrangements that are focused on short-term contracts and task-based work".

Problematically, South Africa was found to have a declining quality in an assessment of the adequacy of the skillsets of all graduates from 2016 to 2020 for both secondary school and university graduates (Schwab and Zahidi, 2020). Based on a measure of business views on employees' skills (skillset mismatch, digital skills, critical thinking in teaching) and an assessment of firms' training (percentage of firms offering formal training, extent of staff training), Schwab and Zahidi (2020) ranked South Africa 32nd out of 37 economies[11] related to being prepared to "Update education curricula and expand investment in the skills needed for jobs and 'markets of tomorrow'". Furthermore, insufficient skills have been identified as the key constraint to reducing poverty and inequality in South Africa (World Bank, 2018a). Building skills can provide many benefits, including raising the productivity of workers and entrepreneurs, helping firms expand production at competitive prices, promoting additional hiring, boosting aggregate demand, and contributing to economic growth. In contrast, the existing low skill levels contribute to high unemployment and low growth, productivity, and competitiveness.

3.3.4 Employment Needs

There is a need to create new jobs in South Africa for the large unemployed population. These needs are particularly strong for the youth, those with lower levels of educational attainment, and the black population. 4IR systems have the potential to help address this challenge as economic growth due the adoption of 4IR systems could create jobs. However, growth of 4IR can also exacerbate this challenge through creating a reduction in the need for human labour. Tensions between these dynamics are addressed throughout the working paper series.

3.4 Innovation and 4IR in South Africa

The way that 4IR spreads across South Africa will shape the future of the development issues outlined above. This sub-section focuses on identifying key dynamics related to innovation and 4IR in South Africa. The first part provides an overview of key features of the national innovation system. While the discussion here provides a brief introduction to the nature of South Africa's national innovation system, a more detailed exploration is provided in Alexander (2022a), the second working paper in this series. The second part of this sub-section provides a snapshot of the current spread of 4IR in South Africa. Again, while this provides a big-picture overview, Alexander (2022b), the third paper in the working paper series, provides a more detailed exploration.[12]

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[11] Selected on the basis of data availability, the 37 countries are: Argentina, Australia, Austria, Belgium, Brazil, Canada, Chile, China, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Indonesia, Ireland, Israel, Italy, Japan, Korea, Rep., Mexico, Netherlands, New Zealand, Poland, Portugal, Russian Federation, Slovak Republic, South Africa, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

[12] Specifically, Alexander (2022b) focuses on how 4IR is being adopted in two key sectors, connectivity services (including infrastructure) and manufacturing.

3.4.1 Overview of the National Innovation System

South Africa's innovation system has been ranked globally by several assessments. The country ranked 49th out of 131 countries related to innovation inputs, which were defined as elements of the national economy that enable innovative activities. This ranking is composed of scores for "institutions", "human capital and research", "infrastructure", "market sophistication", and "business sophistication" (Cornell University et al., 2020). As South Africa's inputs rank is comparatively better than its outputs (68th), South Africa seems to be less efficient at converting inputs into innovative outputs than other countries, and this efficiency rate has been declining (National Advisory Council on Innovation [NACI], 2020). This situation means that there is scope for South Africa to use its existing inputs more effectively. WEF and A.T. Kearney (2018) identify South Africa's ability to innovate as a strength and describe a strong innovation culture.

South Africa's Ministerial Review Panel on Science, Technology and Innovation Institutional Landscape (MRP-STIIL, 2017) states that problems that have been identified in the national innovation system include a weak innovation climate, with low participation in innovation by businesses, limited ability of government to encourage broader participation in innovation, and slow responses to changing societal demands. These challenges are maintained through deficiencies in policies and programmes that stimulate collaboration and knowledge exchange between research and industrial organisations. Weaknesses in South Africa's innovation system are manifested in low performance in industries based on technology, and in particular 4IR-related technologies, as will be discussed below.

Overall, South Africa ranked poorly in an assessment of countries' abilities to revive and transform markets and the innovation system after the Covid crisis (Schwab and Zahidi, 2020). South Africa tied with Chile for 32nd place out of 37 countries related to ability to "incentivize and expand patient investments in research, innovation and invention that can create new 'markets of tomorrow'". Furthermore, it ranked 35th in its ability to "increase incentives to direct financial resources towards long-term investments, strengthen stability and expand inclusion" and "facilitate the creation of 'markets of tomorrow', especially in areas that require public-private collaboration".

An important issue to include when considering the expansion of 4IR is the opportunities that exist for start-ups. South Africa has also been ranked on a number of factors related to starting a business (see Figure 17). Notably, South Africa is in the first decile for cost of starting a new business, and the ratio of new businesses compared to working age population. While the time to start a business has ranked poorly compared to other countries, the average time it takes has been declining, reducing from 56 days in 2000 to 40 days in 2018 (World Bank, 2021). However, in the World Bank's (2019) assessment, South Africa ranked 134th out of 190 in starting a business, based on criteria related to number of procedures, time and cost. Furthermore, in the National Entrepreneurship Context Index, which combines experts' measurements of the state of national Entrepreneurship Framework Conditions,[13] South Africa ranked in the 10th decile (Bosma et al., 2020).

While many of the framework conditions for entrepreneurship remain poor in global comparisons, entrepreneurship levels almost doubled between 2001 and 2019 (Bosma et al., 2020). A major constraint on developing start-ups has been identified as a shortage of skills (Cunningham, 2018b). In addition, black graduates with skills suited to founding start-ups are much more likely to take jobs at established companies compared to starting a new business (Cunningham, 2018b). While many industries have high barriers to entry, digital tools may be able to reduce these barriers, as companies can more easily get access to international technological capabilities (Bell et al., 2018). In line with the high unemployment rate, the World Bank (2018c) notes that, for many entrepreneurs, creating jobs, rather than growth, is the main motivation.

South Africa has explicitly used a national innovation system approach in its science, technology, and innovation policy since the mid-1990s (MRP-STIIL, 2017). During this time, the national innovation system has changed and become larger and more complex. While a lack of a unified governance structure for the national innovation system has been noted (MRP-STIIL, 2017), there are a number of policies involved in shaping the national innovation system, including some that are targeted at shaping the entire innovation system and others that target specific elements of the system. Some of the major national policies, programmes and organisations that support the overall national innovation system, with specific consideration of the promotion of 4IR, are outlined below. Initiatives focused on specific elements of the innovation system are discussed in more depth in Alexander (2022a), the second paper in this working paper series.

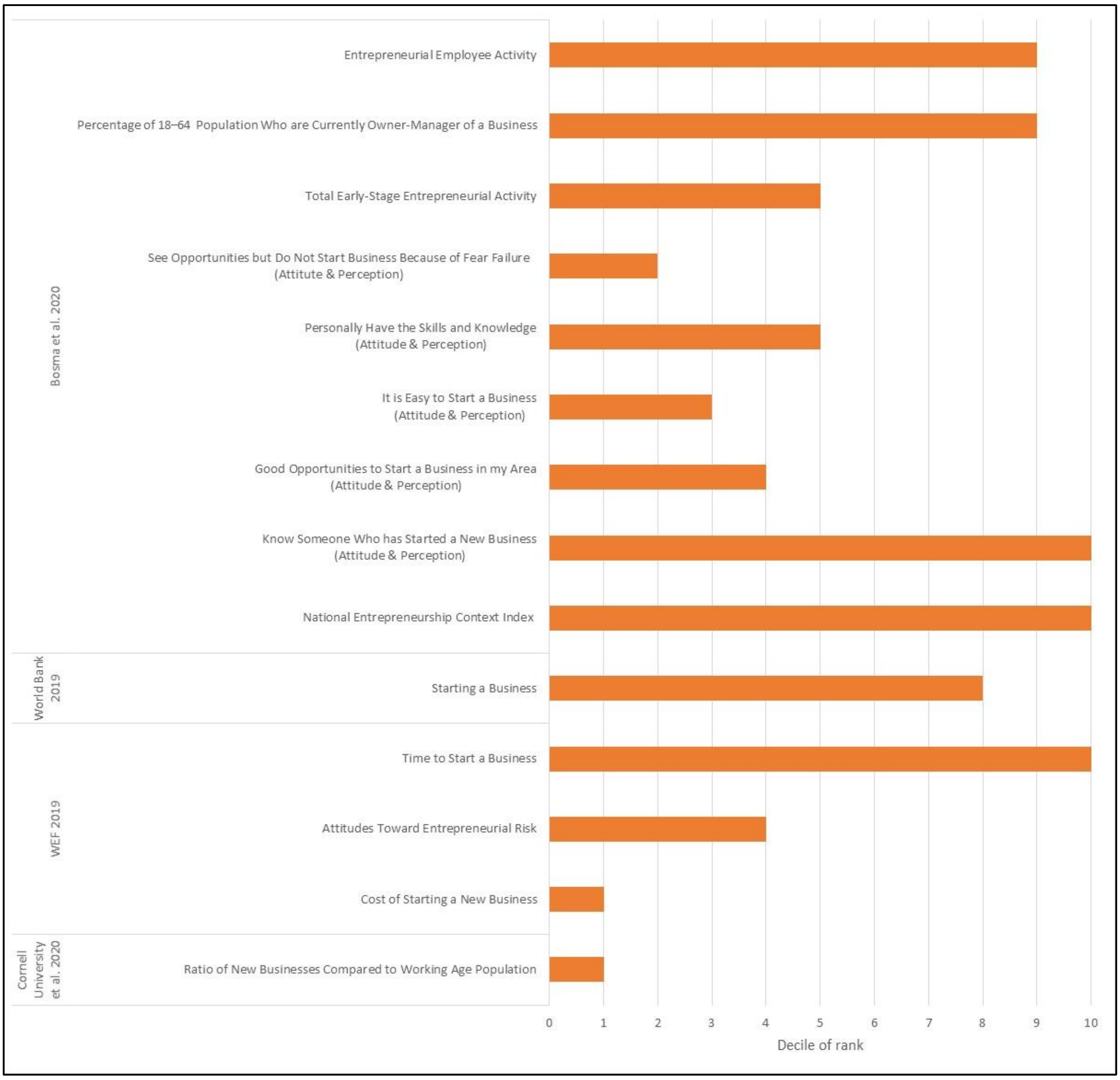
PC4IR was established in 2019. The commission, chaired by the president, is tasked with identifying relevant policies, strategies and action plans to help South Africa become a major player in 4IR. In addition, NACI advises the Minister for Science and Innovation on the role and contribution of science, mathematics, innovation and technology in promoting national objectives. Also notable is the National Science and Technology Forum, a multi-stakeholder organisation representing more than 100 organisations, councils and institutions, which focuses on science, engineering, technology, and innovation and provides guidance for public policy.

Multiple agencies are involved in South Africa's diverse innovation-related policies and programmes. Key agencies include the Department of Science and Innovation (DSI) (formerly the Department for Science and Technology [DST]); the Department for Trade, Industry and Competition (DTIC); the Department of Communications and Digital

[13] The Entrepreneurial Framework Conditions are entrepreneurial finance, government policies – support and relevance, government policies –- taxes and bureaucracy, government entrepreneurship programmes, entrepreneurial education at school stage, entrepreneurial education at post-school stage, R&D transfer, commercial and legal infrastructure, internal market dynamics, internal market burdens or entry regulation, physical infrastructure, and cultural and social norms.

Technology; the Department of Planning, Monitoring and Evaluation; and the Technology Innovation Agency (TIA). In addition, a number of other ministries are involved in broader elements of related policy development and implementation. These government entities cooperate with various actors, such as research councils, universities, and industry associations in developing national policies and programmes.

Figure 17: Global Rankings Related to Starting a New Business in South Africa



Sources: Bosma et al. (2020); Cornell University et al. (2020); WEF (2019); World Bank (2019)

South Africa has an overarching national plan, the National Development Plan (NDP) 2030, which provides a strategic framework related to eliminating poverty and reducing inequality by 2030. This national plan is intended to guide national progress. The NDP has identified science, technology and innovation as drivers for growth (PC4IR, 2020). However, while the plan places a high level of importance on entrepreneurship in the digital economy, it has been criticised for not providing adequate consideration of sectoral needs and for having a lack of clear implementation and coordination plans or plans for monitoring and evaluation (OECD, 2020).

Another important plan related to the national innovation system was the DST's Ten-Year Innovation Plan that ran from 2008 to 2018. Following the end of this policy, DST produced the White Paper on Science, Technology and Innovation in 2019. This publication has set the stage for a new ten-year plan that is currently being developed (DSI, 2020).

As discussed above, industrial policy is an important factor shaping the innovation system. Post-apartheid industrial policy in South Africa focused on financial incentives intended to support capital investment, R&D, and human resource development, which were spread thinly and resulted in limited impact (with the exception of targeted policies for the automotive and clothing and textile sectors) (Andreoni and Tregenna, 2020). At the same time, trade was liberalised and domestic companies struggled to compete with global competitors (Andreoni and Tregenna, 2020). Industrial policy shifted with the introduction of the National Industrial Policy Framework (NIPF) in 2007, which continued to focus on financial incentives, but with increased funding, along with the prioritisation of manufacturing and increasing R&D expenditure (Andreoni and Tregenna, 2020). The NIPF involved a series of IPAPs over a ten-year period.

IPAP support measures have included sectoral programmes and transversal policies. However, the 2018 IPAP (DTI, 2018) describes a lack of intergovernmental coordination as a problem with reaching goals. In addition, Bell et al. (2018) assert that poor commitment across government agencies following the introduction of the NIPF has undermined and limited the impact of policy interventions. Furthermore, the New Growth Path Framework sought to aim at enhancing growth, employment creation and equity, with the principal target of creating five million jobs from 2010 to 2020.

The government also has a number of sector-specific plans. Specific plans related to connectivity services and different types of manufacturing are discussed in Alexander (2022b), the third paper in this working paper series. In addition, the Public-Private Growth Initiative (PPGI) is a sector-based collaboration between government and business, which involves representatives from 24 sectors and focuses on enabling, facilitating, and driving actions to implement sector-developed growth plans.

Finally, another overarching plan is the Economic Reconstruction and Recovery Plan that has been announced for the promotion of development after the COVID-19 crisis (The Presidency of the Republic of South Africa, 2020). Key elements of this plan that are related to innovation systems and 4IR are a focus on infrastructure and green economy interventions. It also seeks to promote employment-orientated strategic localisation, reindustrialisation, and export promotion. Industrialisation through localisation will involve seeking to reduce the proportion of imported intermediate and finished goods, improving the efficiency of local producers, and developing more competitive exports. In addition, the plan includes:

- Modernising and reforming network industries and associated state-owned enterprises
- Re-orienting trade policies and pursuing greater regional integration to boost exports, employment, and innovation
- Lowering barriers to entry to make it easier for businesses to start, grow, and compete
- Creating greater levels of economic inclusion, including through addressing high levels of economic concentration
- Addressing the weak job-creating capacity of the economy
- Boosting education and skills development
- Addressing racial, gender and geographical inequalities that hamper deeper economic growth and development

Cross-national comparisons provide a general overview of the government's role in South African industry. The government had a mid-level rating in WEF and A.T. Kearney's (2018) Readiness for the Future of Production report, with a ranking of 49th out of 100. However, in the same ranking, the country ranked lower in the element of regulatory efficiency (66th/100). The NRI (Portulans Institute, 2020) ranked the ease of doing business as around average, at 79th out of 134. Government regulations, according to the NRI (Portulans Institute, 2020), are world leading in relation to e-commerce legislation (tied with multiple countries at a rank of 1st/134), and above average related to regulatory quality (60th/134), legal frameworks' adaptability to emerging technologies (41st/134), and privacy protection by law content (46th/134). In contrast, they are below average in terms of the ICT regulatory environment (99th/134) (Portulans Institute, 2020).

As stated above, South Africa has numerous diverse and potentially complementary policies that can support innovation and industrial development. However, in the past there have been problems with intergovernmental coordination and coherence in applying these policies (Andreoni and Tregenna, 2020; Bell et al., 2018; DST, 2019; DTI, 2018; MRP-STIIL, 2017). In addition, a lack of adequate monitoring and evaluation has been noted (DST, 2019). Genesis Analytics (2019) found that gaps in government internal capabilities reduce the effectiveness of programmes, such as procurement, local government engagement with business, and taxation.

Genesis Analytics describes government policies as ambitious, but identified challenges with efficient and effective implementation, and a lack of compliance with internally developed processes that affect the ability to engage with businesses. In this assessment, government approaches to digital firms have not been calibrated appropriately, and these firms often rely on the logic of pre-existing regulations that are not appropriate for digital firms. Furthermore, Genesis Analytics (2019) found a large and persistent gap related to local governance and sector-specific regulation.

Cutting across diverse ongoing challenges that have been found in the structure of the innovation system, MRP-STIIL (2017) outlines two key challenges limiting the national innovation system's responsiveness to recommendations. One is that the system is not driven by a centralised governance structure with executive powers or implementation authority.

The second is that the system does not have an entity responsible for system mapping, analysis, building, steering, evaluation, learning and foresight, which could provide evidence-based strategic advice or action plans within a centralised governance structure. Consequently, the system is found to have poor responsiveness to market and social demands.

A similar issue is highlighted by Bell et al. (2018: 60). They mention that strategy documents have been created, including the industrial policy framework and action plans. However, the proposed objectives and policy levers “have been undermined by the fragmentation of the state and the failure of government departments to follow-through”.

This sub-section has provided an introduction to key features of South Africa’s innovation system. MRP-STIIL (2017: 11) proposes that the national innovation system needs “a backbone of hardware (high-end infrastructure and equipment), human resources (scientists, entrepreneurs, or communities, including historical knowledge holders), funding, and support for the various phases of the innovation realisation or commercialisation”. To build a better understanding of the characteristics of South Africa’s innovation system, and this system’s ability to support the spread of 4IR, Alexander (2022a), the second paper in this series, explores components of the system in more depth.

3.4.2 4IR in South Africa

South Africa has been ranked relatively well in several categories within global assessments on topics related to innovation (see Figure 18). In most categories, South Africa was in the top half of countries evaluated. Categories ranked particularly well include global brand value, ratio of new businesses compared to working age population, citable documents H-Index, companies embracing disruptive ideas, secure internet servers, robot density, investment in emerging technologies, and adoption of emerging technologies. For most categories, South Africa was in the fourth or fifth decile. Categories where South Africa ranked in the bottom half are cultural and creative service exports, trademark applications, trademarks by origin, patents by origin, high-tech exports, internet shopping, ICT services exports, and mobile app creation.

Considering types of innovation that could be seen as more specific to 4IR,[14] South Africa averages in the 5th decile. Overall, the NRI (Portulans Institute, 2020),which measures network readiness based on technology (access, content, future technologies), people

[14] These are high-tech exports, medium- and high-tech industry, internet shopping, online access to financial account, cybersecurity, secure internet servers, government publication and use of open data, government online services, robot density, computer software spending, ICT “Patent Cooperation Treaty” patent application, investment in emerging technologies, adoption of emerging technologies, mobile app development, mobile app creation, ICT services and exports, knowledge-intensive employment, country code top-level website domains, generic top-level website domains, ICTs and organisational model creation, company investment in emerging technology, and companies embracing disruptive ideas.

(individuals, businesses, governments), governance (trust, regulation, inclusion), and impact (economy, quality of life, SDG contribution), ranked South Africa 76th out of 134 countries. The Digital Evolution Index (Chakravorti and Chaturvedi, 2017) classifies South Africa as a country with low levels of digitalisation and low levels of momentum. Fagerberg and Srholec (2017) classify South Africa as a country that is catching up, which is distinguished from being a laggard by having better education and governance systems and rapid growth in technological capability. WEF and A.T. Kearney (2018) classified South Africa in the nascent category, which is described as the group least ready for the future of production. Furthermore, PC4IR (2020) notes that South Africa is underperforming related to the use of artificial intelligence, blockchain, virtual/augmented reality simulation environments, automatic data-processing machines, electrical and electronic goods, biotechnologies, storage/transmission, advanced materials, advanced sensor platforms, and medicinal products and pharmaceuticals. However, it should be noted that the Global Innovation Index classifies South Africa's innovation performance as above average for the country's level of development, and places it as the second highest performer in Sub-Saharan Africa, after Mauritius (Dutta et al., 2020).

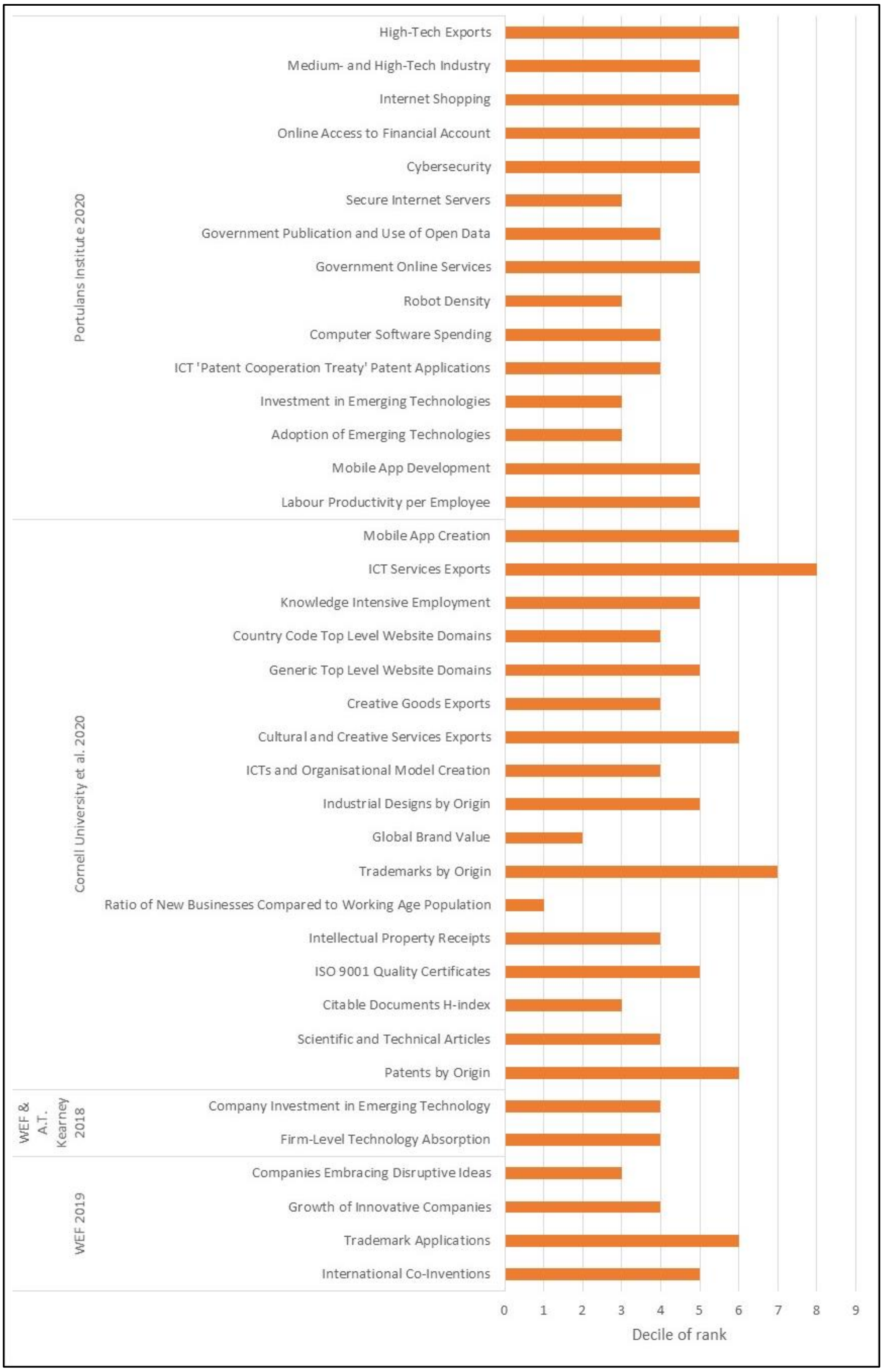
Exploring national dynamics, the Centre for Science, Technology and Innovation Indicators (CeSTII, 2020) conducted a survey of innovation covering 41 535 South African businesses which collectively employed over five million employees from 2014 to 2016. Most businesses (70%) were innovation-active (took some scientific, technological, organisational, financial, or commercial steps towards implementing an innovation) and 86% of employees worked for these businesses. The contribution to total business turnover by businesses that were innovation active was 81%.

Overall, businesses in CeSTII's survey reported similar levels of engaging in the four types of innovation that were measured: product innovation (48,2%), organisational innovation (42,0%), marketing innovation (41,7%), and process innovation (34,6%). However, there were sectoral differences. The highest levels of innovation were found in engineering and technology, manufacturing, and trade. The most commonly reported innovation activities were training (59,3%), acquisition of computer software (58,3%), and acquisition of computer hardware (57,2%). The highest levels of spending were for buying machinery and equipment. Innovative businesses were more likely to sell to global markets than non-innovative businesses. Innovative businesses were not very likely to use intellectual property rights protections, such as trade secrets or confidentiality agreements (17%), trademark registration (12%), South African patents (6%), and international patents (0,6%).

Furthermore, GEM's survey (Bosma et al., 2020), which focuses on entrepreneurs, reveals a number of characteristics about entrepreneurship in South Africa. Most (63%) South African respondents agreed that it was easy to start a business. As with other emerging economies, South African entrepreneurs were more likely to offer consumer services than business services, with less than 10% of entrepreneurs involved in business services. Sectoral distribution of entrepreneurial activity is displayed in Figure 19. Notably, only about 2% of

South African entrepreneurs described their business as offering a product or service that is new to their area or their country, and less than 1% described the product or service as new to the world.

Figure 18: Global Rankings Related to Innovation in South Africa

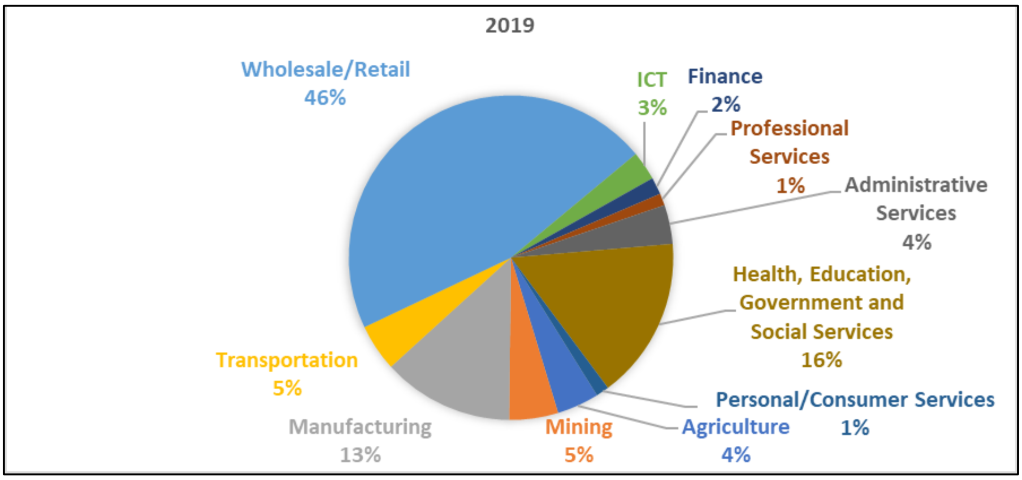


Sources: Cornell University et al. (2020); Portulans Institute (2020); WEF (2019); WEF and A.T. Kearney (2018)

Interviews reviewed for this working paper showed that there is a wide range of behaviours across South African businesses. Some comments from interviews illustrate the situation. One of the respondents described South Africa's adoption of 4IR as lagging, but that it also differs by sector.

> The paradigm change literally has to be from the third to the fourth industrial revolution, second to the fourth revolution. Now many companies are still stuck in the first and a half industrial revolution in South Africa. That's the problem … and so, I mean, they have to make a two and a half leap jump to the fourth.
>
> … [with] enough data, you can do machine learning and AI [artificial intelligence] et cetera, but we're not there yet.
>
> Certain sectors are. Banking, probably retail. Some of those more disruptive sectors and they are used to data, but a typical manufacturing company they'd look at you and say, well what is an analyst? Because that need is not there. (F18-I34)

Figure 19: Sector Distribution of New Entrepreneurial Activity in South Africa



Source: Bosma et al. (2020)

Another respondent described a general lack of progress and some elements of decline.

> South Africa and Africa in general has not seen any real industrial revolutions that have shaped their economies. We've seen like bits and drabs of it. During Apartheid we were kind of locked off from the rest of the world because of sanctions, and then when the borders opened up there was actually a lot of run on the market and strategically companies moved their investments out of the country. We lost a lot of innovation that we had.
>
> We've had a huge decline over the last twenty years in terms of the brain drain and the amount of seasoned individuals that have left, and China has filled a void. In the last thirty years China has pretty much taken over as the manufacturing arm of the whole world. (F16-I31)

A respondent from a consulting company that has clients in multiple countries described that many South African manufacturing clients were lagging in relation to the adoption of 4IR.

> What we're also seeing is in a lot of these factories is … They don't measure enough data matrix … They know what's going to some of the customers. They know what's going on the factory floor, because they've got people that know what's going on the factory floor with experience. That guy walks in, in the floor, and he sort of listens. There's a machine, something sounds funny, he goes and he does something. But they also do, and I mean that's all over the world, it's, 'you do preventative maintenance'. So, every Friday, you shut down the plant and you lose everything … So, the one thing that that we've seen is, a lot of our customers, what can benefit them is, just [to] measure. And eventually, you can take all the data and you can … see how the thing operates, you'll see that maybe I don't have to shut down the plant every Friday … okay, predictive maintenance. (F13-I22)

4. Conclusion

This working paper provides a basis for considering South Africa's prospects related to 4IR. It has presented a series of key concepts related to how 4IR emerges and spreads and how related changes can impact national economies. In addition, it has also shared a snapshot of South Africa's economic development indicators, along with an overview of the national innovation system and the country's progression towards adopting 4IR systems. This depiction shows South Africa has strengths and weaknesses related to the progression of 4IR, and that it is a country which can benefit from further expansion of 4IR.

Overall, this four-part working paper series identifies opportunities and challenges South Africa faces related to 4IR's emergence and spread. 4IR can involve changes which range from minor adjustments to products' features to the creation of new sectors and technologies that transform how the economy operates and how people's daily lives are structured. 4IR is spreading around the world at different paces. For many industries, changes need to be made for countries to stay or become globally competitive. However, it has been argued that some countries can compete in the future using traditional business models for some sectors (WEF and A.T. Kearney, 2018).

PC4IR (2020) has outlined a vision for South Africa's development as involving prosperity and wealth creation; inclusiveness; and being connected, digitally advanced and smart. Furthermore, developing 4IR systems can help to reach a number of the goals in South Africa's National Development Plan 2020 (National Planning Commission, 2012), specifically those related to:

- Economy and Employment (Unemployment, GDP, Redistribution)
- Economic Infrastructure (Utilities: electricity, water, public transit, port, broadband)
- Improving Education, Training and Innovation
- Environmental Sustainability and Resilience
- South Africa in the Region and the World
- Transforming Human Settlements

PC4IR (2020) identifies that South Africa's national innovation systems needs research and ideas for how it can be more effective. This working paper series contributes to this process by providing an up-to-date compilation of findings from multiple studies that have assessed elements of South Africa's national innovation system. By drawing from interview data, it also provides first-hand accounts from businesses and other stakeholders about their experiences working in South Africa. The findings are intended to support decision making processes for multiple stakeholders and to provide guidance for future research.

In order to identify interventions for improving national innovation systems, it is necessary to explore existing innovation systems. Edquist (2011) calls the process of identifying systemic problems and their causes "diagnostic analysis" and sees this as a crucial step to developing innovation policies. He says that problems that are identified can be addressed by the public or private sectors and the nature of this balance can be determined by innovation policy.

The second paper in this series, Alexander (2022a), examines different elements of South Africa's national innovation system by characterising three categories of elements. First, contextual factors in the national innovation system are explored. Key factors considered include the regulatory system and competitive environment, infrastructure, availability of inputs, and demand. Second, the key actors are identified and divided into firms and a variety of organisations providing business support services. Third, the domestic and global networks that actors participate in are explored.

Connectivity services and manufacturing are two key sectors involved in the growth of 4IR, which are considered in this series. Deloitte's (2016) study on South Africa's preparedness for 4IR identified the largest challenge as connectivity and accessibility. This working paper series explores how this issue has progressed. Connectivity services are seen as involving infrastructure and other services. These services are considered from two dimensions. One is whether the businesses are providing services that allow manufacturers, and other businesses, to employ 4IR business models. The other is whether connectivity service businesses themselves are adopting 4IR models. When looking at the manufacturing industry, internal and external factors can also be considered. Manufacturers can use 4IR systems within their own internal operations and they can also use 4IR systems in their engagement with customers, both in terms of the buyer-seller relationships and in terms of the features of the products they produce.

The third paper, Alexander (2022b), focuses on these two sectors. The discussion of connectivity services incorporates case studies of transportation and communication services, while the discussion of manufacturing incorporates case studies of automotive and mining equipment production. This paper explores general sector characteristics, individual firms' experiences, key actors and the industry support environments, and the dynamics of industry-specific production networks.

Finally, the fourth paper, Alexander (2022c), considers how 4IR adoption may influence trajectories of South Africa's economy, with a particular assessment of environmental and labour-related factors. It draws out key issues identified across the first three papers and shares individual businesses and stakeholders' expectations and hopes related to the future of 4IR in South Africa. In addition, it compiles relevant recommendations from a variety of recent reports that have explored aspects of 4IR and innovation systems in South Africa.

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Annexure A: Overview of Interviews

A key source of data for this paper is a set of 51 interviews conducted with businesses and key stakeholders involved in connectivity services and manufacturing in 2019 and 2021. An overview of companies that were interviewed is provided in Table 1, and an overview of the stakeholders that were interviewed is provided in Table 2. The interviews typically had one or two representatives from the organisation. Interviews were recorded and transcribed.[15] Transcripts and notes were reviewed and coded using qualitative data analysis software to systematically draw out key findings.

Table 1: Companies Interviewed

Firm identifier	Interviews	Type	Firm size[16]
F01	I01	Lighting manufacturer	Small
F02	I02	Parts manufacturer 1 (machine and spare parts manufacturer)	Medium
F03	I03	Robot manufacturer 1 (collaborative robots)	Micro
F04	I04	Logistics 1 (packaging and logistics provider)	Large
F05	I05	Parts manufacturer 2 (automotive and locomotive parts)	Large
F06	I06	Engineering software producer	Small
F07	I07, I08, I09	Consulting for 4IR 1 (digitisation and design)	Large
F08	I10	Automotive original equipment manufacturer (OEM) 1	Large
F09	I11, I12	Logistics 2	Large
F10	I13	Traffic management 1	Medium
F11	I14, I15, I16	Automotive OEM 2	Large
F12	I17, I18, I19	Part Manufacturer 3 (car parts)	Large
F13	I20, I21, I22, I23, I24, I25	Consulting for 4IR 2 (mechanical engineering design and prototype services, also transportation management projects)	Medium
F14	I26, I27, I28, I29	Parts manufacturer 4 (car parts)	Large
F15	I30	Mining equipment manufacturer 1	Large
F16	I31, I32	Consulting for 4IR 3 (VR)	Small
F17	I33	Consulting for 4IR 4 (automation)	Small

[15] Except for one respondent who did not want to be recorded and one interview where the recording failed. In both cases, detailed notes were taken.

[16] Size is measured by number of employees. Micro is fewer than 10, small is 10 to 49, medium is 50 to 249, and large is 250 or more.

Firm identifier	**Interviews**	**Type**	**Firm size**[16]
F18	I34	Consulting for 4IR 5	Missing
F19	I35	Mining equipment manufacturer 2	Medium
F20	I41	Robot manufacturer 2	Small
F21	I37, I38	Traffic management 2	Large
F22	I39	Automotive OEM 3	Large
F23	I43	Consulting for 4IR 6 (mining)	Medium
F24	I44	Consulting for 4IR 7 (logistics)	Small
F25	I46	VR training	Micro

Table 2: Stakeholders Interviewed

Stakeholder identifier	Interviews	Description
S01	I36	4IR-focused industry association
S02	I42	Government agency
S03	I45	Mining industry association
S04	I47	Government agency
S05	I48	Government agency
S06	I49	Government agency
S07	I50	Logistics industry association
S08	I51	4IR-focused industry association 2
S09	I40	Automotive industry association

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