Assessing the Ability of the National Innovation System of South Africa to Facilitate the Fourth Industrial Revolution

Rachel Alexander

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DSI/NRF SOUTH AFRICAN RESEARCH CHAIR IN INDUSTRIAL DEVELOPMENT

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Abstract

This working paper examines different elements of South Africa's national innovation system related to their ability to support the expansion of the Fourth Industrial Revolution. The national innovation system is assessed 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 including firms and a variety of organisations providing business support services are profiled. Third, the domestic and global networks that actors participate in are considered. This working paper is the second in a series of four.

Keywords: National innovation system, Industrial development, South Africa

JEL codes: O31, O33, O55, L22

About the Author

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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 dataset 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 fourth industrial revolution (4IR) is driving changes to economic and social systems around the world. 4IR can be seen as "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" (Presidential Commission on the Fourth Industrial Revolution [PC4IR], 2020: 25). The paces at which countries are experiencing these changes differ, and countries' abilities to adopt new technologies and systems will shape national developments over the coming years. The ability of businesses to adopt and develop 4IR technology and systems can be regarded as being shaped by the characteristics of national innovation systems.[1] To better understand the circumstances shaping the emergence of 4IR in South Africa, this paper asks how the national innovation system can support or hinder 4IR-related innovation.

Overall, this paper presents an assessment of key elements of South Africa's national innovation system. The national innovation system is considered to involve three components, namely contextual factors, actors, and networks. The process of innovation is seen as involving businesses developing new products or processes. These can be new to the world, the region or just to the individual firm. The components of the innovation system are seen as being crucial for shaping firms' abilities to innovate and to shape opportunities that may stimulate innovation. The discussion draws from available published material and 51 interviews with key South African stakeholders conducted between 2019 and 2021 (see Annexure A).

The following section identifies key contextual factors shaping South Africa's innovation system. The third section discusses key actors in the innovation system, which include businesses, financial service providers, research institutions, and other organisations that provide support services to businesses. The fourth section discusses the characteristics of networks that facilitate activities within South Africa's national innovation system. Finally, the fifth section provides a conclusion.

2. Key Contextual Factors Shaping South Africa's Innovation System

South Africa's innovation system is shaped by a number of contextual factors that determine businesses' experiences. Key contextual factors are covered in this section. First, the sets of rules and structures shaping firms' options are explored. Second, the availability of inputs for businesses is considered. Third, the types of demand that exist in the national market are assessed. Fourth, the available infrastructure is examined. Fifth, a variety of other contextual factors are briefly discussed.

[1] This topic is discussed in more detail in Alexander (2022a), the first paper in this working paper series.

2.1 Regulation and Competitive Environment

Firms in South Africa work in an environment that involves a set of local regulations and the existence of competitors that shape their options. Studies have shown that poor institutional environments (e.g., rule of law, regulatory quality, property and patent right protection, history of instability, lack of trust, corruption) are barriers to innovation (Zanello et al., 2016). This sub-section provides an overview of key regulations and dynamics that shape the environment in which South African businesses operate.

A wide variety of government agencies are responsible for creating regulations that shape the national innovation system. Key elements of South Africa's regulatory framework for science, technology and innovation (STI) organisations can be divided into three categories: sector-specific legislation under various ministries, the Public Finance Management Act (PFMA) of 2015, and company law (Ministerial Review Panel on Science, Technology and Innovation Institutional Landscape [MRP-STIIL], 2017). The nature of the organisations creating regulations can differ. Some regulators sit within organisations that have both regulatory and profit-making mandates, such as the South Africa Bureau of Standards (SABS) and the Council for Scientific and Industrial Research (CSIR), which can create tension (MRP-STIIL, 2017).

Another factor to consider is that some regulations operate at the provincial or local level. Also notable is that some firms work in special economic zones (SEZs) that can have regulations that differ from those of other areas. SEZs are areas designated for targeted economic activities. They are intended to promote national economic growth and encourage exports by providing measures to attract foreign and domestic investments and technology. These include laws and systems that are different from national norms, such as various reductions in taxes. The Department of Trade, Industry and Competition (DTIC) designates four types of SEZs in South Africa, namely free ports, free trade zones, industrial development zones, and sector development zones.

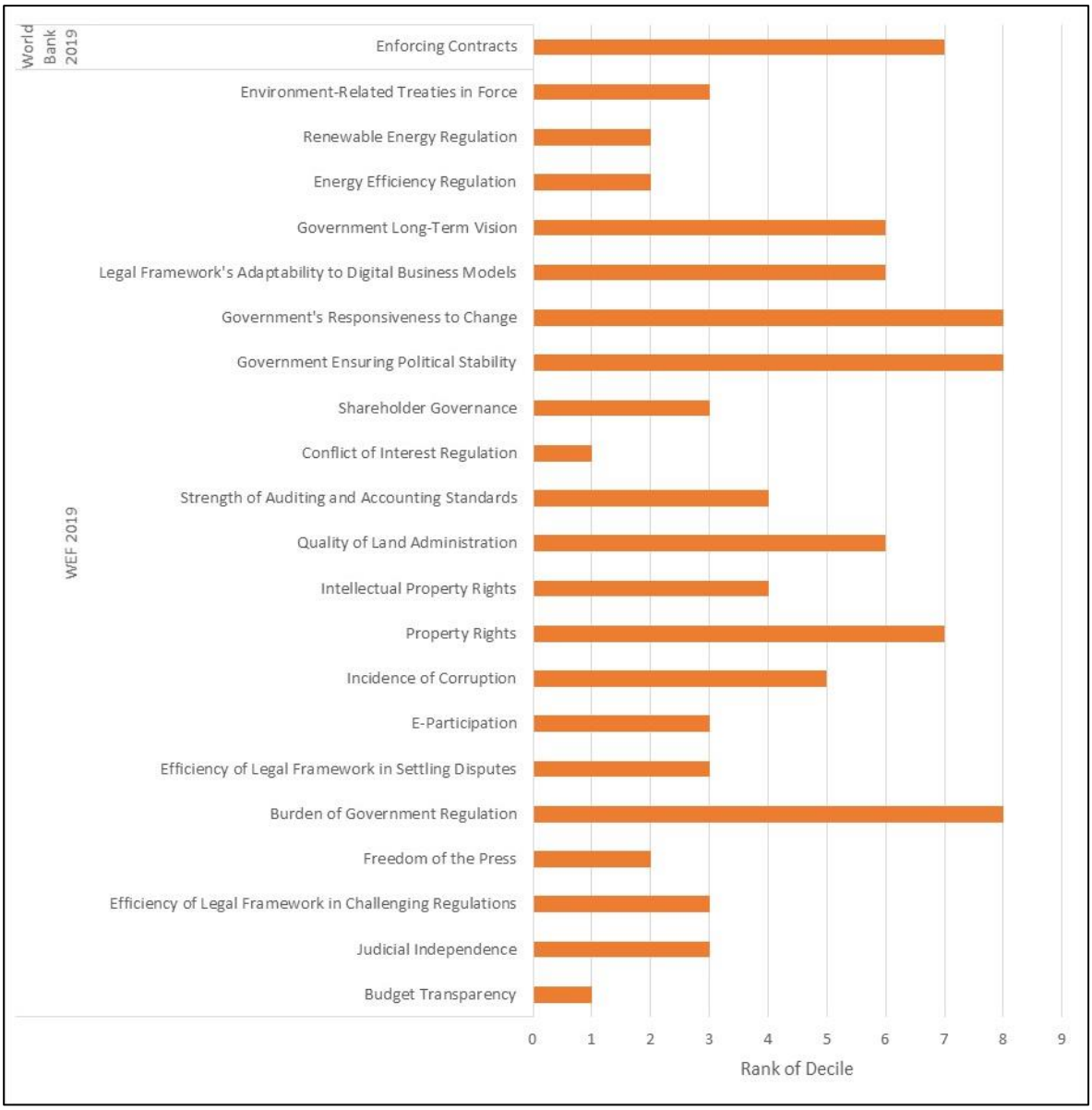
2.1.1 Regulations Shaping Firm Behaviour

In global comparisons, South Africa's regulatory institutions have ranged from being world leading to lagging (see Figure 1[2]). Categories with notably high rankings are environment-related treaties in force, renewable energy regulation, energy efficiency regulation, shareholder governance, conflict of interest regulation, efficiency of legal framework in settling disputes, efficiency of legal framework in challenging regulations, judicial independence, and budget transparency. However, South Africa was among the bottom half of nations in the categories of enforcing contracts (based on the time, cost and quality of judicial process), government long-term vision, legal framework's adaptability to digital business models, government's responsiveness to change, government ensuring political

[2] This figure shows deciles which categorise how South Africa ranks compared to other countries. For example, a position in the first decile indicates that South Africa is in the top 10% of countries.

stability, quality of land administration, property rights, and burden of government regulation.

Figure 1: Global Rankings of South Africa's Regulatory System



Sources: World Bank (2019); World Economic Forum (WEF) (2019)

Overall, companies have experienced difficulties with facing regulations that are perceived to be overly bureaucratic. Notably, South Africa's burden of government regulation is globally ranked in the 8th decile. Entrepreneurs and small businesses in particular can be inhibited by bureaucratic requirements (MRP-STIIL, 2017; Bosma et al., 2020). However, regulation can impede the development of innovative companies of all types. For example, biotech companies in South Africa are limited through various regulations (the Biodiversity Act of 2004, the Intellectual Property Rights from Publicly Financed Research and Development Act of 2008, the National Health Act of 2003, the Consumer Protection Act of 2008, and the Licensing of Businesses Bill of 2013) (MRP-STIIL, 2017). Also, research institutions report that

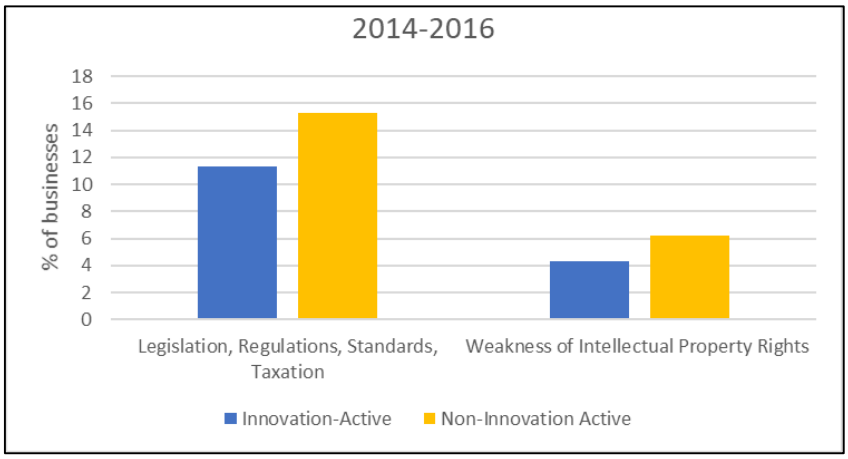
the PFMA hampers research because of its effects on procurement, dealing with value-added tax (VAT), and the long process of registering start-ups (MRP-STIIL, 2017). Another challenge is that municipalities have inconsistent interpretations of environmental legislation, which affects businesses' abilities to function (Department for Trade and Industry [DTI], 2018).

In a large survey that covered 41 535 South African businesses, some South African firms reported existing regulations as a barrier to innovating (see Figure 2). However, most businesses did not find regulations to be a barrier. Noticeably, regulation-related factors are more commonly reported as a barrier for non-innovation-active businesses compared to innovation-active businesses. As described above, the impact of regulatory barriers differs based on firms' characteristics. Firm size and industry are key factors to consider.

Respondents in the interviews used to develop this paper also shared challenges related to regulations that were perceived to impede business activity. One respondent complained that there was "red tape" everywhere, preventing people from investing.

> It's red tape everywhere and they make it more difficult and then that's why certain people start sitting back and say let me rather keep my money … Open this. All of a sudden you will have investment flying in. (F19-I35)

Figure 2: Regulation-Related Barriers to Innovation



Source: Centre for Science, Technology and Innovation Indicators (CeSTII) (2020)

One specific factor pertinent to innovation that should be considered is the quality of intellectual property rights (IPRs). South Africa's IPRs are globally ranked in the 4th decile (see Figure 1). A negative impact of weak IPRs on innovation has been found in multiple studies (Zanello et al., 2016). However, some large multinational firms strategically place elements of innovation activities in countries with weak IPRs as they have the capacity to manage the risk internally (Zhao, 2006). An important factor to consider is that when innovation involves absorbing and adapting new knowledge the process does not typically involve patents, and this process can actually benefit from weak IPRs. In South Africa, the World Bank (2018a) identified that existing intellectual property (IP) legislation creates risks and delays. Nevertheless, as noted in Figure 2, only a small number of businesses say that the weakness of IPRs impedes their ability to innovate.

As with IPRs, labour legislation can have different effects. Strong labour laws can help employees have decent work. However, labour laws can also create barriers for businesses' ability to be able to adapt to changing situations. The World Bank (2018a) asserts that South Africa's labour legislation does not have the flexibility needed to help high-risk and potentially high-growth start-ups. In addition, small businesses have reported difficulties with labour market regulation (Bosma et al., 2020).

Exchange controls are another type of regulation that businesses have experienced as burdensome. For example, exchange controls have been found to push businesses to register intellectual property (IP) and businesses offshore (World Bank, 2018a). In addition, academic institutions have reported that regulations from the National Treasury on exchange controls create delays in implementing agreements with international funders, and restrictions related to hiring foreign skilled staff negatively affect their institutions (MRP-STIIL, 2017).

Standards are also a type of regulation that can be helpful for businesses, but can likewise be experienced as a burden. For newly developed systems to be compatible, standards need to be in place. Standards can be set at different levels (e.g., national or international, and can be set by public or private organisations. Firms can learn from seeking to meet international standards for global buyers (Pietrobelli and Rabellotti, 2011; De Marchi et al., 2018), and national systems can benefit from promoting and developing international standards. Employing international standards can be more efficient than developing potentially incompatible national standards. Notably, international regulations at the sector level can create more opportunities for global-scale business (WEF and A.T. Kearney, 2018). Nationally, standards can be promoted by public policy or through industry bodies. The use of standards can vary across industries and can be applied to products, processes, and people.

Within an industry, a lack of standards can be a problem. As new developments emerge, technology may not compatible. A respondent described the challenge of trying to deal with having multiple traffic-detection systems being used simultaneously.

> These three systems at the moment don't talk to each other … Unfortunately, we don't flick a switch and it's there. It takes years to … get people to talk to each other to sort out the legal issues. To further the technology is normally the easy part. You know, to get a few engineers around this table, we can sort out the technology but so that this boss, so that boss … talk to each other, that's the challenge. (F10-I13)

However, as new technologies emerge, it may be difficult for regulators to identify which system may be best from the outset. This is an ongoing challenge.

Another issue is that changing performance standards can drive change in how technology operates. One respondent described new environmental standards as driving the adoption of 4IR.

> But definitely, I think it's changing quickly, no. The vehicles are changing quickly, because there's a lot more pressure coming from a regulatory point of view into the market. So, hybrid vehicles, electric vehicles. (F22-I39)

On the other hand, standards can restrict innovation. One respondent described that trying to be innovative in the face of many regulations can be difficult.

> We are … designing around the policy so that we know what is coming up, and then they won't be able to kick us out with arbitrary qualifications like your IP rating is wrong, or the fitting is the wrong colour, it's not food safe, or they are always thinking up some kind of stupid reason for putting another standard in place so that someone can't make money. The problem with being a manufacturer in that type of environment is that, you are limited so much in terms of your design. It limits you in terms of the boundaries around the technical parameters. (F01-I01)

Companies that work across countries can also offer different products and services that are tailored to the regulatory environment of where they are selling. One South African logistics company commented on different opportunities across African markets.

> So, what works in Nigeria might not work somewhere else, because there's also regulatory stuff that we've been dealing with that sometimes holds us back. In Mozambique, we sell [products] in the informal environment. Great opportunity. And taking that business model, which is based on technology, containing your van and its stock … But taking that somewhere else, the context doesn't always allow for that. It's a great model, but one must make sure it is applicable in the next country [where] you take it to. (F09-I11)

Finally, various forms of regulation can be seen as specifically creating difficulties in relation to the expansion of 4IR. Notably, Figure 1 shows low rankings related to regulation connected to business activities that can be considered as part of 4IR. For example, the legal framework's adaptability to digital business models ranks in the 6th decile. The government's responsiveness to change is in the 8th. Information communications technology (ICT) and communications policies have also been found to be overly burdensome and a disincentive to invest in ICT infrastructure (World Bank, 2018a).

One policy area of growing importance to 4IR is how data is regulated. How South Africa develops regulations in this area will be important for shaping future possibilities for 4IR (Azmeh and Foster, 2018). Particular issues arise related to data ownership. One respondent described some challenges related to data regulation for multinational companies.

> These countries that say, 'You can measure your data, but you may not take it outside the borders'. If you have a multinational company that means you have to set up servers there, or not have access to the data. So, there's all sorts of things in terms of data, who owns the data. (F13-I22)

Regulations can also affect opportunities for specific types of 4IR technologies. Another respondent described regulation as a key issue impeding the development of drones.

> There [are] some strong opinions going around that South African Civil Aviation Authority [SACAA] is really stifling the potential business that could be provided in this industry sector. I mean through regulation. So, it's almost impossible for a small business to get the correct licensing and legally operate your UAVs [unmanned aerial vehicles/drones].

> So, in that sense, there's very little demand for a company to actually build and develop UAVs unless they're exporting it internationally. Yeah, the SACAA are just basically killing the industry locally, it takes over a year for a small company and a lot of money just to get the licensing.
>
> … [The] technical knowledge base and the experience of South African engineers, pilots, et cetera, in the UAV industry is on par with the rest of the world. It's just regulation is very stifling.
>
> … There [are] already a few businesses, local businesses that mostly export products overseas. And they're making the world-class UAV systems, but they can't sell it or operate it locally … so there's like 28 registered businesses, and there's a backlog of about 200 businesses, and they process like a handful per year. And it takes us very long time and money ….
>
> There's been some studies on the potential for commercialisation. And if the regulations were less strict in the UAV industry, and it's quite immense, the amount of jobs that [would be] created. (F13-I25)

2.1.2 Regulation Shaping the Competitive Environment

Policies that shape competition are another important factor that shape firms' experiences. In a global comparison, rankings of elements of South Africa's competitive environment vary, but generally place in the middle range (see Figure 3). South Africa was found to be in the 4th decile related to competition in the service market. However, related to the dominance of a small group of large firms in the national economy, South Africa was ranked in the 6th decile. Furthermore, South Africa was also found to rank in the 6th decile in relation to the distortive effects of taxes and subsidies on competition.

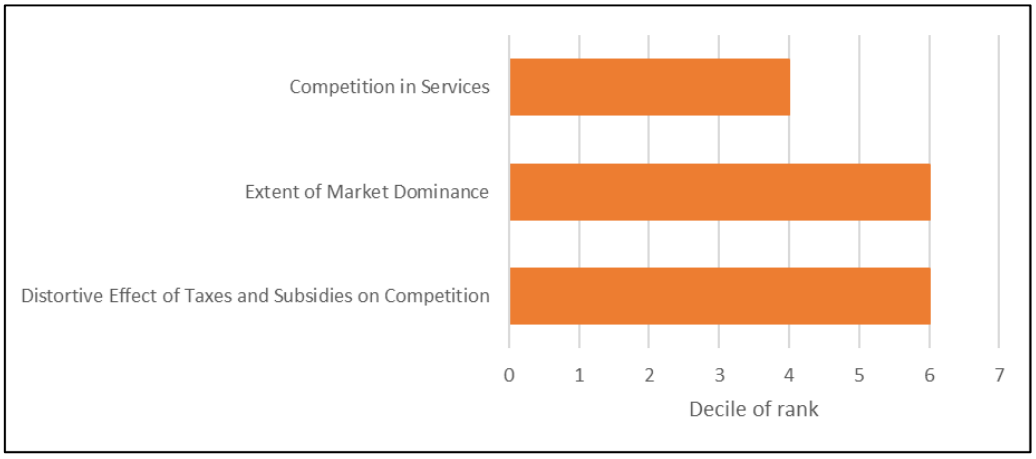
Competition policy is important for preventing anti-competitive behaviour and predatory pricing. A small and decreasing gap was found in relation to having adequate competition policy in South Africa (Genesis Analytics, 2019). This is an issue that can be particularly important for the development of 4IR. Notably, South Africa ranked 28th out of 37 countries[3] in a recent assessment measuring its ability to "rethink competition and anti-trust frameworks needed in the Fourth Industrial Revolution, ensuring market access, both locally and internationally" (Schwab and Zahidi, 2020).

While regulation is needed to ensure fair competition, too much policy and regulation can stifle competition. A system of closed markets was prevalent in South Africa's pre-democratic systems. The economic system involved regulated oligopolies, monopolies and high levels of state control. Some contemporary agricultural and manufacturing markets still have

[3] 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.

structures that limit competition, based on remnants of these pre-democracy systems (World Bank, 2018b). Notably, state intervention undermining the creation of competitive price markets in South Africa is found to have a stronger effect than in peer countries (World Bank, 2018b). This includes elements such as state-owned enterprise (SOE) involvement in markets, direct government control of enterprises, price controls, command and control regulations, and barriers to entrepreneurship.

Figure 3: Global Rankings of South Africa's Competitive Environment



Source: WEF (2019)

Competition dynamics can be related to industry type. Notably, network industries have specific properties that can differ from those of other industries. These industries include telecommunications, computer software and hardware, some forms of transportation (e.g., airlines, railroads, roads, shipping), financial services (e.g., financial exchanges, clearing houses, credit and debit networks, and automated transactions banking networks), and industries relying on virtual networks that involve compatible goods that share a common technical platform (e.g., video-playing systems). A common feature of network industries is what has been called "network effects", which involve a network becoming more valuable as it grows (Economides, 2006). Firms can make money from selling access to their network directly, or having users of a freely provided network purchase additional products or services. In addition, networks that include proprietary technical standards can result in "winner-take-most" markets in which one player dominates. In some cases (i.e., industries), having one unified network can create the most benefit, while in other cases competition between networks can be a better solution.

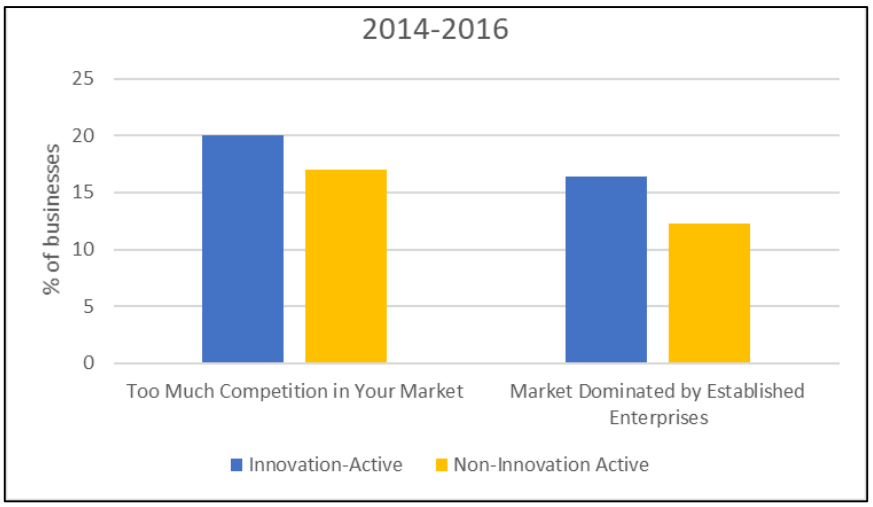
Some network industries require regulations related to service provision because networks may not cover all potential users if shaped purely by market forces (e.g., rural road access). In South Africa, several network industries are wholly or substantially controlled by the state, including air transport, energy, telecommunications, and the postal service (World Bank, 2018b). The role the state plays in network industries needs to balance the need for control to ensure equitable service delivery, while also allowing for innovation that can lead to improvements in the quality of services being provided. The World Bank (2018c) has assessed

that South African regulations related to competition for energy, transport, and communications are relatively restrictive and that these regulations are creating inefficiencies in these sectors, which increase costs for businesses.

As discussed in the first paper in this working paper series (Alexander, 2022a), 4IR creates opportunities for entrepreneurs to develop radically new businesses. However, market restrictions can limit these opportunities. Notably, incumbent firms can have an incentive to ensure that regulations prevent opportunities for potential new entrants. In South Africa, incumbents in finance, telecommunications, energy, transport, and media have successfully blocked regulations that would have opened markets (Bell et al., 2018).

The types of firms operating in the competitive environment in which firms work is an important factor shaping their actions. A key feature of competition in South Africa is that SOEs and large firms dominate many sectors and play a role in determining logistics and costs for other sectors.[4] In addition, South African firms also have to compete with global competitors, both within South Africa and in export markets. A number of firms have said that the structure of the competitive environment is a barrier to innovation (see Figure 4).

Figure 4: Competition-related Barriers to Innovation



Source: CeSTII (2020)

Overall, competition can be a driver of innovation. One of the respondents spoke about competition driving his company's actions.

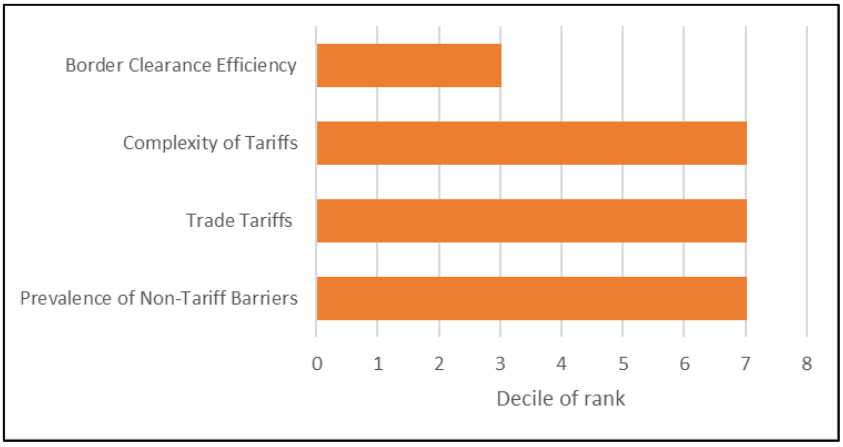
> So, probably the biggest competitor in this sort of space [is Company A]. They're a massive manufacturer and supplier … So, this is sort of an answer to their offering into different spaces. And we, if you want to be in that market at all, you have to, simply because the price of which they sell their equipment is very competitive. So there really has been an exercise in building the cheapest, most effective system that we could. And it's turned out really well, I think. (F21-I37)

[4] More detail on the types of domestic firms found in South Africa is provided in Sub-Section 3.1.

In an era of globalisation, global competition is a particularly important factor to consider. As discussed in Alexander (2022a), market liberalisation in South Africa has created a major change in how the economy functions. Many firms are now subject to global competition. Consequently, many businesses have struggled to compete with low-cost imports (Andreoni and Tregenna, 2020). Having a strong innovation system can be important for creating a base for companies to be prepared to face global competitors.

While South African markets have been liberalised, they still have higher trade barriers than many other countries. Notably, South Africa was found in a global comparison to have high levels of complexity of tariffs and trade tariffs, and a prevalence of non-tariff barriers (see Figure 5). Difficulties with trade openness can shape companies' access to inputs for their supply chains (see Sub-Section 2.3.1) and change the nature of the types of competitors that firms face when selling to the South African market.

Figure 5: Global Rankings Related to South Africa's Trade Openness



Source: WEF (2019)

The interviews reviewed for this paper showed a variety of perspectives related to South African firms facing global competitors. A key issue is that leading global competitors are already benefiting from using 4IR technologies and systems. One respondent described comparing his facilities to global competitors and seeing that his competitors use much higher levels of automation.

> I was looking at some of the companies in Japan and in Thailand, they do the similar operations that we do. And there's much more automation there, where the guys don't physically handle the blades. It's all robotics to bring the blades in. It's nicely done, basically. So that is why they can keep the plants clean. If you walk through my plant … It's really a hard-working plant. If you picture this in your mind, the old blacksmith whacking things. That's exactly what it is done. Yeah. Red blades, hot blades, presses, machines, setups. (F14-I28)

A representative of a consulting firm described how some of their South African clients were struggling to compete with global competitors who had adopted 4IR technologies and processes.

> Some of our customers, they've got very old machines, 30 years plus the factories been running. They had a captive market. And now, all of a sudden, they don't. So now there's more people doing what they do. It's been the borders have been thrown open. People are coming in from outside … They could basically ask what they wanted … And now they've got competition … They are in the fear of having to close the factories. Now they run it and go industry 4 and think that's the solution, then you tell them about [what] industry 4 is going to cost them. (F13-I22)

While, in some cases, global competition can make it very difficult for domestic companies to survive, in other cases global competition can be a driver that promotes innovation. One respondent from an automotive parts supplier said that, overall, his business compared well to those in other countries.

> We actually compare [to other countries in connection to 4IR] quite well, to be honest, we've had some people coming from overseas, the one place where we can, you know, improve I would say, because I've also been to Japan before, the other place is the automation side, where a lot of overseas places … there's a massive amount of automation. So, we've got certain pockets of excellence regarding automation … to be honest, we don't have to stand back in some on some production lines, we're actually outperforming them. (F14-I27)

Different levels of 4IR adoption at the firm level can be seen as leading to different outcomes in a globally competitive market.

> They've been caught out because we are buying the steel back from China cheaper than what we send it for. Because I automated. People like [company name], they didn't automate [so they are] more expensive. So now they're losing sales because people are buying from China because they didn't automate. (F20-I41)

Within a system of increasingly liberalised global trade, national policies are important for shaping the competitiveness of domestic firms. One respondent, whose firm is a subsidiary of an automotive multinational, described how supportive government policy helps his business to deal with pressure to compete with other production locations.

> We need to compete with our sister plant in [country A]. And we get tracked down to the last cent whether the vehicle here is cheaper or more expensive than in [country A]. And our big advantage right now still is that we are still cheaper because of the APDP [Automotive Production and Development Programme][5] that allows us to have a favourable cost position … we believe that we need to be proactive now here and get us in a better position than the rest of the group. (F11-I15)

2.2 Infrastructure

Infrastructure includes transportation, energy, water, ICT systems, and research infrastructure. This sub-section focuses on infrastructure as a component of the national innovation system.

[5] The APDP is described and discussed in Alexander (2022b), the third paper in this working paper series.

In this role, infrastructure can support all actors' innovation processes. Alexander (2022b), the third paper in this working paper series, explores how innovation occurs for businesses involved in providing connectivity infrastructure (specifically considering communication and transportation).

Infrastructure and infrastructure services play a key role in creating strong national innovation systems. The United Nations Conference on Trade and Development (UNCTAD, 2018: xi) describes infrastructure as "a long-term investment in an uncertain future". Infrastructure can be seen as involving scale economies, large sunk costs, strong complementarities, and long timelines, while being prone to monopoly structures and often benefiting from network effects (UNCTAD, 2018). Furthermore, a lack of physical infrastructure has been found to discourage foreign direct investment (FDI) (Kinda, 2010).

Infrastructure has long been seen as a pivotal factor enabling for development processes. 4IR technologies may have an even greater reliance on infrastructure, particularly connectivity infrastructure. Fagerberg and Srholec (2017) say that, in order to be able to use knowledge, access to ICTs and means of transport is crucial. ICT infrastructure services can facilitate the operation and management of ICT systems, such as cloud computing, data-hosting services, information technology [IT] management, security, and storage (MarketLine, 2020a). A major consideration in 4IR systems is the need for systems to be able to process large amounts of digital data. High computing power is needed for blockchain systems, which require powerful computers and a good supply of electricity. In addition, speed in production and distribution processes (e.g., just-in-time delivery and small runs with frequent deliveries) forms a large part of the 4IR and is dependent on adequate transportation and communication infrastructure. Innovation and upgrading related to connectivity services create diverse new opportunities for businesses. Developing countries can benefit in particular from the development of ICT infrastructure. Benefits include reducing information isolation by allowing firms to access data and to communicate, and facilitating greater integration among national institutions, such as firms and research institutes (Zanello et al., 2016).

Research infrastructure is also important for supporting national innovation systems. It includes equipment that needs to be managed by technically competent staff, as well as simpler equipment that is easier to use. It can involve physical and digital components. This infrastructure can support both exploratory research and product development. Access to public research infrastructure can enable companies to innovate.

Infrastructure provision has also been associated with a number of challenges. An overarching challenge related to infrastructure is environmental sustainability. Problems can range from environmental destruction during building processes to long-term pollution related to use. Notably, freight transport systems have been responsible for high levels of carbon emissions. These systems may be transformed dramatically in the coming years based on 4IR developments related to sustainable power sources and autonomous technologies. Equitable access to infrastructure and infrastructure services is another important challenge. Different

groups of people and companies, even within the same country, can have highly diverging access to infrastructure.

2.2.1 Status of South Africa's Economic Infrastructure

In global comparisons, as with regulations, some of South Africa's infrastructure has been found to be advanced, while other elements are lagging (see Figure 6). South Africa ranks very well on international internet bandwidth, 4G mobile network coverage, efficiency of air transport services, and road connectivity. Key problem areas include electricity output, ICT access, reliability of water supply, electricity access, alternative and nuclear energy use, and electricity infrastructure.

Existing infrastructure faces a number of ongoing challenges. One key challenge facing South African infrastructure is how the systems have been designed. The rail and port systems cater mostly to mining and are insufficiently equipped for other export industries, both in the design of routes and in the tariff structures (World Bank, 2018b). Consequently, non-mining industries often rely on road freight, but they still have to deal with poorly designed port services that have fees 88% higher than the global average (World Bank, 2018b). A second challenge has been management practices. Much of the infrastructure is managed by SOEs. Mismanagement in these organisations has led to manufacturers paying higher electricity and port charges, as well as to rail and port inefficiencies and logistical bottlenecks (DTI, 2018). A third challenge is the poor quality of existing systems. While South Africa's infrastructure is of a relatively high quality for a middle-income country, its quality has been deteriorating (World Bank, 2018b). Reasons for this decline in quality include insufficient public investment, declining capacity (including in SOE management), and slow responsiveness to changes (World Bank, 2018b).

South Africa's research infrastructure has also been found to be lagging. National research infrastructure includes mainly medium to large national facilities run by government agencies, which can be used by universities, science councils, industry, and government (MRP-STIIL, 2017). This research infrastructure lacks the required funding, including funding needed for data centres necessary for data storage and big data analytics (MRP-STIIL, 2017).

Problems with economic infrastructure can affect businesses' ability to innovate and incorporate 4IR systems and technologies. A small number of South African firms (8%) reported a lack of infrastructure as a barrier to innovation (CeSTII, 2020). One respondent in the interviews reviewed for this working paper described how infrastructure issues underlie the ability of companies to develop 4IR systems.

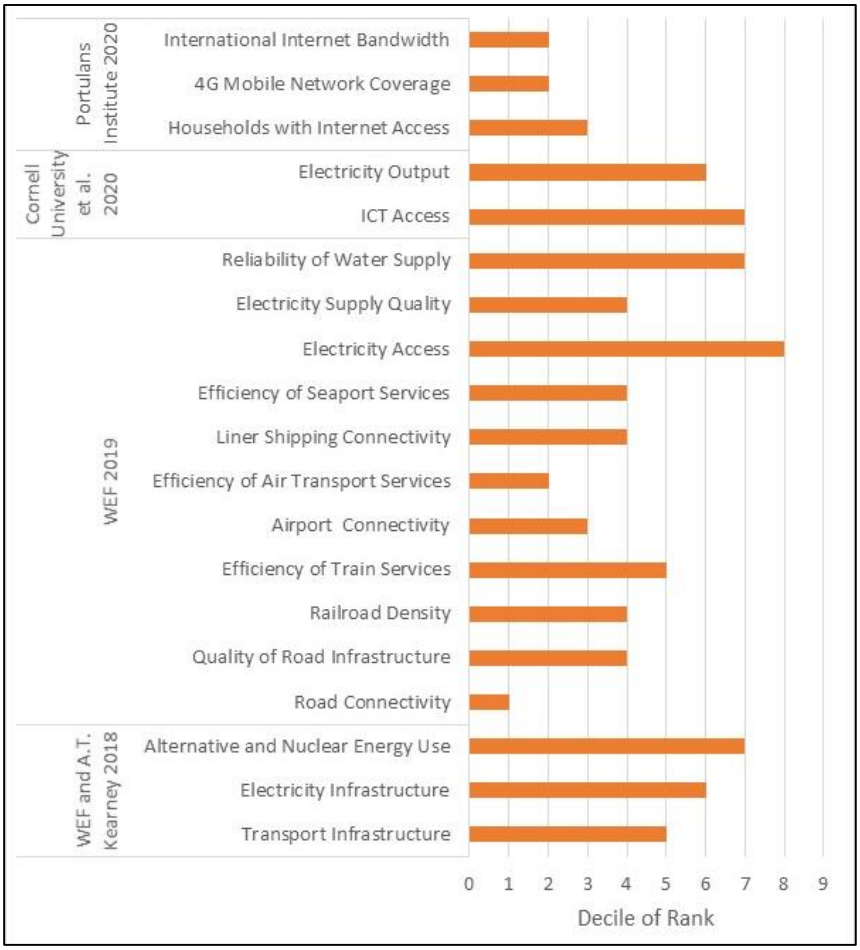
> It's very easy to have problems, which are related to simple things, poorly connected terminal cables, earthing not done properly. Simple things that are really fundamental … In my view, you want 4IR to work, make sure the foundation is solid … You can't ignore the cracks in the foundation while you're putting on an extra storey. You've got to sort that out. And that, I think, is the risk of focusing on 4IR … if you really want that to work,

> you've got to have this in place. Infrastructure … the whole thing of freeing up bandwidth. If we want 4IR to work that bandwidth is really essential. (F21-I38)

Another respondent from the same company highlighted the importance of connectivity services and power needs.

> If you look at building stuff for different markets or different applications or different customers, I think the most important things that you need to take into consideration is power budget. So essentially, 'do you have power?', 'is it battery operated?' – that kind of thing. Connectivity budget. Are you able to send any information? If you are, how much? And those two – well, then, obviously third of all, and very important as well, pricing. Those three together will largely determine the kinds of technology that you implement on what you're building. (F21-I37)

Figure 6: Global Rankings of Elements of South Africa's Economic Infrastructure



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

Electricity supply is a key challenge in South Africa. Notably, security, predictability, and price hikes are major concerns (DTI, 2018). One of the interviewees summed this up succinctly.

> Existing electricity provision is not adequate. (F23-I43)

A representative of another company provided an example of internet speed being an impediment.

> Something we've also played around a bit with is trying to implement 5G internet speed solutions, which is pretty much standard in most advanced laboratories around the world, which we don't really have in Africa at the moment, which does cause a few problems. But yeah, trying to work around that I guess. But it would be nice if we could implement. Yeah, I'm thinking specifically 5G. … Yeah, the internet, the transfer of data, I think, is one of the most crucial problems we have in Africa at the moment. Even just with regards of even education, or if you are to use the robots, again, logging in, just to transfer knowledge. It's too slow. And were looking at IoT, internet of things, which we've done a few projects on as well. And the sensors are quite quick, in the sample rates quite high, fetching a lot of data. The data isn't processed fast enough. (F13-I21)

However, the ICT situation is improving, as indicated by a further comment by the same respondent.

> I'm focusing on connectivity, because there's actually directly, in with the work I do, it's a very big issue … I have seen some changes in the recent years. I do believe it's still going to take some time, though. (F13-I21)

Another issue is that internet coverage is not uniform across the country. Access to fixed-line data is concentrated in urban centres (Genesis Analytics, 2019). Rural areas in particular can be hampered by poor access to ICT infrastructure.

> So, if we take for example, the stuff I'm doing in agriculture, connectivity is a very big problem. Forget about 3G or 4G or anything else, you would, in most cases have access to a GPRS connection. So that's probably early, late 90s, maybe where that technology comes from and that, that brings you down to single kilobits per second, which is very little data. So, forget about media streaming, or any such thing. (F21-I37)

This can affect the operations of a variety of businesses. For example, ICT services are increasingly becoming important to the provision of modern transportation services. When considering the expansion of connected vehicles, infrastructure is being developed in urban areas but is currently insufficient in rural areas.

> So, for example, you would have a very good connected vehicle experience in Joburg or Durban or Cape Town or wherever, but go to the rural areas or less populated areas, maybe you don't need as much then. But that starts to fall apart. For us, in terms of our business, and what we do as part traffic law enforcement … it definitely will have an impact on what we do and how we do it. (F21-I37)

Notably, South African road transport infrastructure also varies by region, as can be seen from one firm's description of their work.

> We do really rural stuff. We do a lot of road safety. And I think that's the area where we need a serious intervention in our little country. (F10-I13)

Furthermore, South African firms are creating products that are designed to match the existing infrastructure.

> We are seeing places where people are coming up with [IoT] products and implementing that, like a traffic counter, if I plant a pole next to a road with a little radar device, it's a small amount of data I can have it sent to me once an hour, in little packets of data. That's a perfect application for it … because it's small packets of information. You don't need a fibre optic cable and running all the way there. So … where do you apply technology? In what situation? (F10-I13)

In addition, South African firms are using technology that is suited to different clients' contexts. For example, one company representative spoke about having to adapt global designs based on the connectivity infrastructure available where a product will be used.

> When we're developing on this side, we try to keep that environment [of our client's country], their infrastructure in mind as well. They, for example, do have much faster internet speeds using 5G. So, for them, latency isn't that big issue. So, we might decide, okay, here we have that issue, but we might not spend as much time trying to solve it, because it's not a problem over there. (F13-I21)

However, poor infrastructure can also cause companies not to invest in South Africa at all. Some companies choose to locate parts of their businesses in different locations when the infrastructure is insufficient.

> [Company name] set up their engineering centre in India. They set up offshore. And so too has [another company] ... Two separate companies. So, you need to see what these big companies are doing. They are not setting up in South Africa. People said infrastructure is not there. (F22-I39)

2.2.2 Planning and Investing in Infrastructure in South Africa

A number of public agencies are involved in managing South Africa's infrastructure. The National Department of Transport (NDoT) develops policies and legislation to govern roads, railways, ports, airports, pipelines, as well as intermodal operations of freight and public transport. The NDoT also oversees a set of SOEs that run various elements of the transport system. The South African National Road Agency (SANRAL), an SOE, manages national roads, while provincial transport departments are responsible for approximately 49 000 km of the paved road network. The Department of Public Enterprises manages Transnet, an important SOE related to managing transportation infrastructure. Furthermore, the National Ports Act gives the Transnet Ports Authority (TNPA) power to manage ports.

Challenges with infrastructure have been described as "a political football between the 'market failure' and 'government failure' camps" (UNCTAD, 2018: xi). With the notable exception of China, public investment in infrastructure has generally been declining since the 1980s. Countries often use a combination of public and private funding, with higher levels of public funding in low-income countries. A public sector role in infrastructure is often needed due to the specific characteristics of some infrastructure projects. These include long

timelines for returns, capital intensity, returns involving private and social elements, complexity of planning and execution, feedback loops between growth and economic development, features specific to the countries executing the projects, non-linear effects of infrastructure investments, as well as other location-specific risks and uncertainties (UNCTAD, 2018).

While, in many cases, policy makers have sought to increase private sector investment in infrastructure projects, multiple challenges exist (UNCTAD, 2018). One challenge is that the short-term priorities of private sector investors can lead to a lack of investment in projects with long-term outcomes. Another challenge is that projects can produce benefits that cannot be captured by investors. Notably, capital-intensive infrastructure projects, such as highways, airports, harbours, utility distribution systems, railways, water and sewer systems, and telecommunication systems, can have scale and network effects. When infrastructure has strong scale and network effects, corporate interests could focus on profits rather than on activities that would lead to broader social outcomes (UNCTAD, 2018).

Prominent contemporary infrastructure approaches are based on two global developments (UNCTAD, 2018). One is the focus on having a market-friendly economy and reduced government spending, which led to the widespread privatisation of infrastructure in the 1980s. The second is the global growth of financialisation in the 1990s, which led to infrastructure being a popular type of traded asset.

Many countries, including South Africa, currently face a lack of sufficient infrastructure. One perspective on this challenge is identifying a financing gap. This perspective is based on four key points (UNCTAD, 2018). The first is an estimation that different countries' financing gaps are of similar orders of magnitude. Second is that most public sector budgets are considered to be constrained, with difficulty faced from increasing debt. Third is that private sector funding can be harnessed to fill a gap in public budgets related to infrastructure funding. Fourth, this process requires a pipeline of bankable projects that can attract investors.[6]

A problem is that the needed and potentially beneficial infrastructure projects are often not bankable. To address this problem, actors promoting the benefits for private financing have identified ways to make infrastructure more profitable (see Box 1). These are diverse and include modifying institutional and regulatory conditions.

South Africa has faced a challenge related to a decrease in public infrastructure funding in recent years. In the period after apartheid, while the government focused on supply-side policy interventions, little attention was paid to investing in infrastructure. With infrastructure funding levels rising only slightly from a low in the early 1990s, they remain below the norm for well-performing middle-income countries (Andreoni and Tregenna, 2020). From the start of the 2000s until 2009, public infrastructure investment generally grew

[6] Bankability involves an assurance that loans can be repaid and that investors will get adequate returns.

as a percentage of gross domestic product (GDP); however, since then it has been on a slow decline (Organisation for Economic Co-operation and Development [OECD], 2020).

Box 1: Measures to Make Infrastructure More Profitable

- Adopt user chargers
- Involve public sector support
- Clearly identify potential returns and risks
- Create systems to ensure stakeholder approval, such as compensation schemes
- Provide de-risking instruments, such as credit guarantees
- Provide government-created mapping of long-term investment paths to reduce investors' uncertainty about the future
- Provide more liquid security exchanges, such as governments issuing equity and debt on their own infrastructure projects
- Adopt more favourable international investment frameworks, including limits on expropriation and clear dispute-resolution mechanisms
- Standardise contractual terms, which can attract funds for smaller projects, project pooling to reduce transaction costs for smaller projects and attract larger investors, and ease restrictions on pension investments
- Create well-developed capital markets and develop an investor-friendly regulatory framework
- Conduct sufficient planning to identify bankable projects, including ensuring enough resources are devoted to project preparation
- Allow multilateral banks to join investment platforms, where they can provide technical expertise, capacity-building and financing instruments

Source: UNCTAD (2018)

Nominal levels of public sector[7] spending on infrastructure decreased in the final years of the 2010s (Statistics South Africa [Stats SA], 2020). Overall, less was spent on plant, machinery and equipment, and new construction works, while more was spent on transport equipment, land and existing buildings, leased assets and investment property, and "other" fixed assets. Eskom (a public electricity utility) was the major contributor to the overall decline in 2019, due to budget cuts and finalising a number of its larger projects. Despite this decline, Eskom remains the biggest public sector infrastructure spender. Transnet (a state-owned rail, port, and pipeline company) had the second biggest decrease because of a reduction in spending on plant, machinery, and equipment. However, it did increase spending on new construction works related to rail and ports. SANRAL had the third largest decrease due to reduced spending on road construction. Provincial government departments decreased spending due to delays and interruptions, mostly related to building schools and maintaining road infrastructure.

However, some actors have increased their spending (Stats SA, 2020). Notably, local governments increased their infrastructure spending. Higher education institutions (HEIs) also spent more, with Stellenbosch University notably funding the construction of the

[7] The public sector includes 747 institutions, covering the national government and provincial government departments, municipalities, public corporations, higher education institutions and extra-budgetary accounts and funds.

Biomedical Research Institute (BMRI). The national government and the National Department of Defence also increased their spending.

When seeking to increase infrastructure investment, strategic planning is needed to ensure that infrastructure investment is targeted in ways that create productivity growth (UNCTAD, 2018). A key challenge in this area is the time scale involved in infrastructure projects. Societal changes and the adoption of 4IR systems can modify needs as time goes by. For example, following the COVID-19 experience of high levels of teleworking, many jobs may continue to be remote after the crisis. Network effects and synergies along with the perspectives of diverse stakeholders also need to be taken into account when planning (UNCTAD, 2018).

Infrastructure planning should be part of broader development strategies that involve positive feedback between infrastructure, productivity, and growth (UNCTAD, 2018). Infrastructure development needs a long-term vision. One challenge with allowing only "bankable" projects to go ahead is that these are not necessarily the most needed for a country. In addition, the piecemeal process that would ensue may not be able to realise the synergies that are needed between different types of infrastructure.

Some opportunities for increased private sector investment have been emerging in South Africa. Certain elements of South Africa's infrastructure have already received private investment. For example, the Renewable Energy Independent Power Producer Procurement Programme (REIPPP) attracted a large amount of private investment (The Infrastructure Consortium for Africa [ICA], 2018). Considering a selected range of funding institutes'[8] allocation of funds to African infrastructure, South Africa was the country that received the largest share (28%, which involved over 25 billion USD from 2009 to 2014) (Warren, 2015). China has also been a major investor in South African infrastructure (Warren, 2015).

While some elements of infrastructure emerge from private-sector initiatives, as discussed above, governments play a big role in ensuring that adequate national infrastructure is developed. UNCTAD (2018) highlights the benefits of countries increasingly creating development plans in the 21st century. However, they note that infrastructure is often not given a central enough role, and clear frameworks to move from ambition to implementation are lacking. Infrastructure policies need to be entwined with broader development strategies and take into account the perspectives of diverse stakeholders. Governments need to develop strong capacities for planning, project preparation and execution that are tied to clear monitoring and evaluation, and connected to penalties that can ensure that costs are kept down. UNCTAD (2018) also says that infrastructure policy requires the government to take a more active planning role than industrial policy. Leaving infrastructure decisions to finance ministries will not result in the necessary infrastructure being developed. Infrastructure

[8] The development financial institutions include ADB, AFD, Afreximbank, DBSA, DEG, EIB, FMO, IDB, IFC, JBIC, KfW, US Ex-Im, UKEF, and The World Bank.

planning needs to consider synergies between systems that are crucial for enabling development processes.

South Africa has a number of plans related to infrastructure development, as well as a number of sector- and issue-focused plans and strategies. One is the National Transport Master Plan (NATMAP) 2050, which focuses on developing an integrated and sustainable framework for a multi-modal transport system. In addition, the National Infrastructure Plan, launched in 2012, proposes a 20-year timeline for infrastructure project development. In the same year, the Southern African Development Community (SADC) launched the Regional Infrastructure Development Master Plan, which guides infrastructure development such as road, rail, and ports, and creates a framework for planning and cooperation with development partners and the private sector.

In terms of supporting the development of research infrastructure, the Department of Science and Technology (DST) drove the creation of the South Africa Research Infrastructure Road Map, which was launched in 2016 (MRP-STIIL, 2017). This plan includes developing cyberinfrastructure in consultation with government, academia, research entities, and the private sector.

While infrastructure spending has been decreasing in recent years (Stats SA, 2020), a renewed priority has been expressed through several initiatives announced in 2020 (Arnoldi, 2020). At the Sustainable Infrastructure Development Symposium South Africa in 2020, 276 infrastructure projects were identified. The country has an Infrastructure Investment Plan that will be implemented by a new entity called Infrastructure South Africa (ISA). Working in collaboration with the Department of Public Works and Infrastructure (DPWI), the ISA will be responsible for project preparation, packaging, funding pathways and strategic oversight. The ISA is also developing a new 25-year National Infrastructure Plan, and will pursue various types of funding, including project bonds, green infrastructure bonds, transformation bonds and green climate funds. The DPWI has also developed a new methodology for project planning called the Sustainable Infrastructure Development System, which was launched in 2020.

Furthermore, the DPWI created an Infrastructure Investment Fund that will provide seed capital for project planning (Arnoldi, 2020). The Development Bank of Southern Africa will establish and manage the fund, which intends to crowd-in the private sector through de-risking projects (Henderson, 2020). The OECD (2020) posits that the success of the infrastructure fund will be dependent on being able to bring in private-sector financing

Finally, the 2020 Economic Reconstruction and Recovery Plan, which was put in place to deal with the effects of COVID-19, places emphasis on infrastructure (The Presidency of the Republic of South Africa, 2020). The Public Financial Management Act and the Municipal Financial Management Act will be reviewed in order to encourage private-sector investment. This plan seeks to modernise freight transport, refurbish rail lines, improve efficiency at ports,

and protect rail infrastructure from vandalism. Emphasis is also being placed on supporting the development of a local supplier base.

2.3 Availability of Inputs

This sub-section focuses on the innovation system's ability to provide inputs for businesses. Inputs can be materials and equipment, or they can be people. The availability of these inputs shapes opportunities for innovation. Both can help to bring new knowledge and innovation into a firm.

2.3.1 Material Inputs

In terms of material inputs, companies need to have access to the equipment they need and materials that are required to offer products or services. These can be available locally, or can be sourced from abroad. There are pros and cons to local versus foreign sourcing. Local materials can be accessed more easily and local sourcing can support local economic development. However, higher levels of imports in manufactured products have been found to be associated with higher productivity and product sophistication, and importing a wider variety of intermediate inputs is also associated with higher productivity (Banga, 2017; Edwards et al., 2020). This is seen to support a learning process through importing. The benefits were found to be similar for imports from advanced economies versus imports from emerging economies, which was contrary to the authors' expectation that superior technology embedded in imports from advanced economies would have a stronger positive effect on firms' productivity (Edwards et al., 2020). The authors identified that the learning process may result from new varieties that complement existing inputs, or foreign inputs that have a higher quality than domestic products. Access to foreign inputs is shaped by trade openness, as discussed in Sub-Section 2.1.2.

A challenge that some industries faces is that some inputs are made only by a small number of producers, which leaves businesses with limited options for suppliers. For example, marine freight is dependent on a small group of ship suppliers that are capable of making products that meet international standards (MarketLine, 2020b). However, this industry is changing, as many companies are exploring the development of more sustainable ship production (MarketLine, 2020b).

South African firms are generally found to have adequate access to technology, with a small and decreasing gap found in Genesis Analytics' (2019) assessment of firms' access. In some sectors, foreign inputs are very common. For example, in South Africa's automotive exports, local content levels were between 30% and 35% (UNCTAD, 2019). Across all sectors, however, local content predominates, comprising 77,5% of exports in 2016 (OECD, 2018). For manufactured exports, local content was about 70%, and for service exports, local content was above 85%. Of South Africa's imported intermediate goods, 34,4% were used for products that were exported, which is below the OECD average of 45,5% (OECD, 2018). The industries with the highest shares of intermediate imports used for exports were basic metals

(49,6%), machinery and equipment NEC (not elsewhere classified) (45,5%), and other transport equipment (40,7%) (OECD, 2018). Overall, South Africa uses relatively high-technology imported inputs as part of their exported products (World Bank, 2016).

For some South African firms, the high costs of intermediate inputs create a challenge for carrying out competitive manufacturing in the country. Particularly, this is an issue for products requiring steel, chemicals and products in plastic value chains (DTI, 2018). In addition, one of the interviewees noted that high-tech supplies are often cheaper to import than to make domestically (F05-I05). Another firm described the need to use foreign contractors as a part of a project to keep the costs down (F10-I13).

Many innovative South African businesses report using new technologies to innovate, whereas very few non-innovative businesses reported using new technologies (CeSTII, 2020). Advanced technologies reported to be used by innovation-active businesses include computerised design and engineering (44% of businesses), business intelligence technologies (26%), green technologies (23%), advanced information-control technologies (21%), advanced processing and fabrication technologies (18%), geomatics or geospatial technologies (11%), biotechnologies/bio products (4%), nanotechnology (3%), and other types of advanced technology (0,4%).

New technological development can allow businesses to change and improve their offerings. As 4IR systems evolve, the increasing use of technology, such as digitally integrated production systems, the cost of and the availability of technology can be factors shaping developments. The access to such inputs is changing in South Africa. One respondent described trying to adopt new technologies as they became available.

> We will talk about 4.0. You read articles every now and then … You read it to say okay, this is coming down the pipeline, [to see] what is happening … We didn't do it because of industry 4.0. We've done it because that is just [the] technology available. So, we started off with barcodes and a human readable number, then RFID [radio frequency identification] came out … now it could be [a] Bluetooth speaker … we try to think of what we can do with it. And, when we think about our clients and how we can use it. And then, we started packing it and you say, 'But how will I sell it?' That's the big question. How do I create value with it? Why would a person buy it? Why will they use it? … So how am I going to get money from it? (F04-I04)

Another key issue related to 4IR is that, as technology advances, it is becoming cheaper and easier to use. One respondent described how this is changing production processes in South Africa.

> So, to give you a good example of the impact that the AI [artificial intelligence] technologies that we have access to at the moment, is making on the products that we build, we, historically, five, six years ago, developed a license plate recognition camera, which the cost to build, never mind, the R&D [research and development] would be in the region of about R50 000. We're currently finalising a replacement, that will do the exact same job with some additional features, where the cost to build is R3 500. So, it's a

> massive reduction in price simply because we can offload a lot of the processing onto an artificial intelligence system that's dedicated to doing that. It becomes a lot easier for us to do. Essentially, through machine learning, train it to do whatever it is we want to do. So, for example, we want to detect pedestrians, vehicles, motorcycles, bicycles, whatever, it becomes an easy task to do, we don't need an expert necessarily to train the machine to do that. (F21-I37)

These changes can also be seen as helpful for dealing with global competition (as was discussed in Sub-Section 2.1.2). The respondent further described how adopting 4IR technological enhancements is becoming a key part of being able to compete.

> Essentially that I think the biggest driving force behind it is the need to come up with a way to reduce the cost of products. The market is becoming ever more competitive, I think, not only in our industry, anywhere, and whatever you can do to get an edge is what you do to get your edge. So, the systems are becoming very accessible. I mean, it's becoming probably close to where high school kids can start playing with AI systems and with machine learning and build cool stuff that they want to build. So, it would be very detrimental not to explore these avenues … I think that the growth in the market is directly proportional to the difficulty of implementing these kinds of products decreasing. So, it's becoming cheaper. It's becoming easier to build. More people are offering these products. So, for us, great that the market is expanding, but at the same time competition is coming in as well. (F21-I37)

Furthermore, it is important to note that domestic production of high-tech equipment is emerging. One South African firm described how they are starting to develop robots for industrial use (F13-I21).

However, for some technologies, high costs continue to be a barrier to further levels of adoption of 4IR systems. Cost is a barrier to adopting advanced robotics and 3D printing for many South African manufacturers (Deonarain, 2019). Another challenge is the high cost of data. High data costs are a challenge that can particularly affect businesses trying to grow in the digital economy, which could have high potential for growth and job creation (World Bank, 2018a). One respondent described the situation as follows:

> I would say the cost of data is still prohibitively expensive for individuals and certainly for companies. I think there was acceleration and adoption because of COVID. People remote working. Companies had to make big investments to have that capability available. (F23-I43)

Finally, as 4IR expands, the types of inputs that are needed by businesses are changing. It is notable that 4IR products are increasingly using minerals as part of new product and material designs. An opportunity that exists in South Africa is that the country produces a lot of minerals. Currently, these are often exported and processed in other countries. However, potential exists for increasing domestic processing and using these materials as inputs for domestic manufacturing. This topic is discussed further in the final paper in this working paper series (Alexander, 2022c).

2.3.2 Workforce and Knowledge Pools

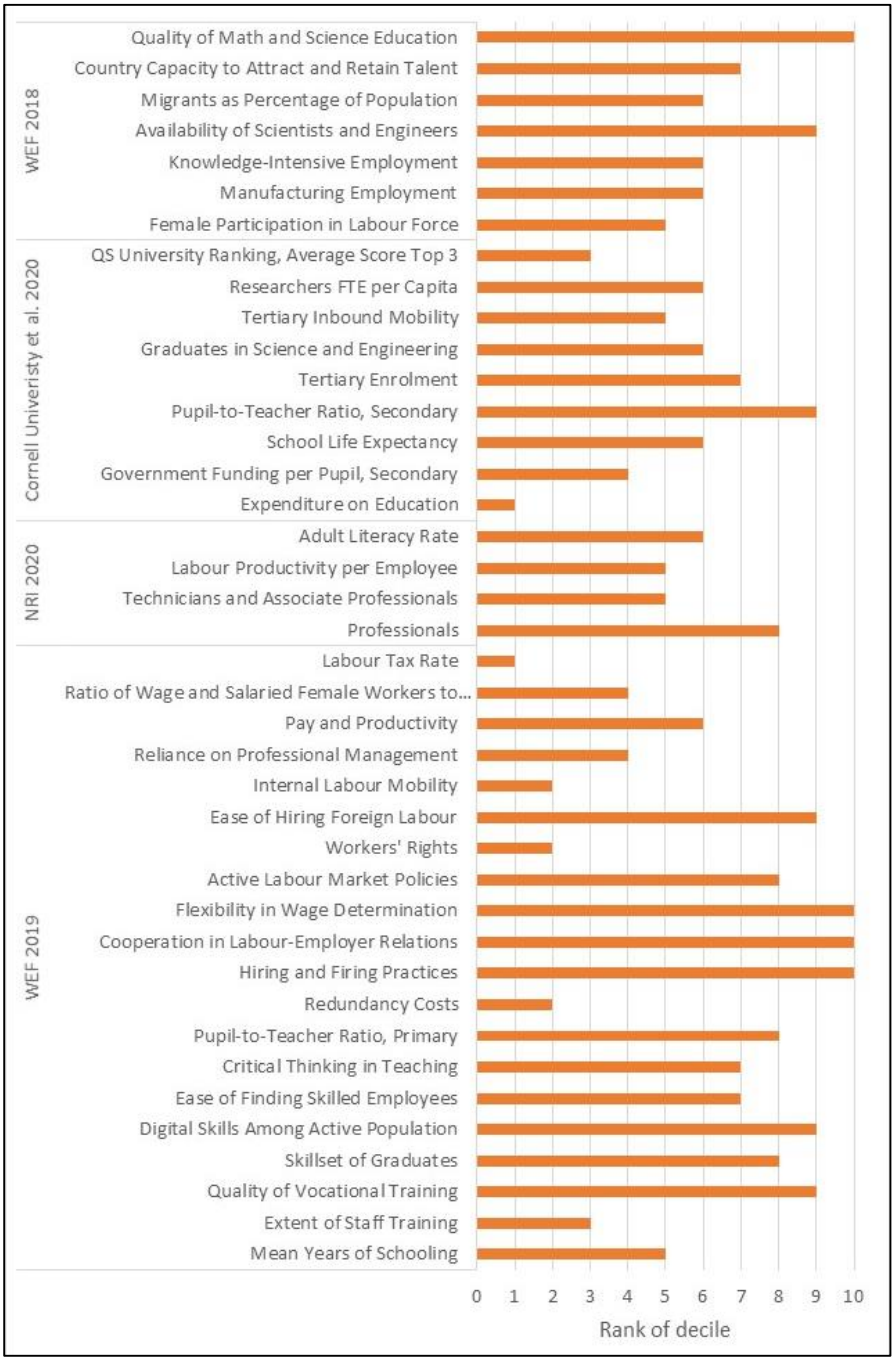
In global comparisons, South Africa ranks poorly in relation to a number of characteristics of the available workforce (see Figure 7). Notably, the country is in the bottom half globally in the categories of quality of maths and science education, capacity to attract and retain talent, migrants as a percentage of population, availability of scientists and engineers, knowledge-intensive employment, manufacturing employment, full-time equivalent (FTE) researchers per capita, graduates in science and engineering, tertiary enrolment, pupil-to-teacher ratio for secondary school, school life expectancy, adult literacy rate, professionals, pay and productivity, ease of hiring foreign labour, active labour market policies, flexibility in wage determination, cooperation in labour-employment relations, hiring and firing practices, quality of vocational training, skillset of graduates, possession of sufficient digital skills among active population, ease of finding skilled employees, critical thinking in teaching, and pupil-to-teacher ratio in primary school. Categories in which South Africa ranked well include university ranking, expenditure on education, labour tax rate, internal labour mobility, workers' rights, redundancy costs, and extent of staff training. Despite poor outcomes, South Africa allocates a larger share of GDP to fund primary, secondary and post-school education and training than many comparable countries (National Advisory Council on Innovation [NACI], 2020).

The characteristics of the workforce are shaped largely by education and training opportunities. Key factors are whether workers with the appropriate skills are available to meet the needs of existing businesses. Another issue is whether jobs are available for the existing workforce. Innovation policies typically consider education and training as key requirements (de Otero, 2020). Key factors include supporting the development of a suitable workforce and the ability to help workers to upgrade their skills over time. Notably, innovations are reliant on available skills and create a demand for new skills. These intertwined dynamics require policy makers to coordinate between diverse actors (de Otero, 2020).

While national dynamics are important, as with material inputs, workers can also be sought from abroad. However, access to global workers has been found to be a challenge, as can be seen by the category of "ease of hiring foreign labour" in Figure 7 ranking in the 9th decile. Easing access to foreign workers can be one way address challenges related to South Africa's workforce. In addition, upgrading the capabilities of the domestic workforce can strengthen the national innovation system.

The rest of this sub-section focuses on the domestic workforce with the discussion split into three parts. First, it discusses processes of national skills formation. Second, it considers the South African government's efforts to create jobs for a workforce facing high levels of unemployment. Third, it identifies gaps in skills needed versus skills available and considers how businesses perceive the qualities of the existing workforce and their ability to access the types of workers they need.

Figure 7: Global Rankings of South Africa's Workforce



Sources: WEF (2019); Cornell University et al. (2020); Portulans Institute (2020)

Producing Skills and Knowledge Pools

Formal education and public research play a large role in shaping the national innovation system. Outside of some countries with high levels of natural resources, countries with the highest incomes have developed diversified knowledge pools that cannot be emulated easily (Hausmann et al., 2014). Education and training can happen in multiple contexts. These include secondary school, technical and vocational education and training (TVET) systems, universities, and work-based training. Some training institutes are involved in research activities, while public research also takes place at dedicated institutions. Box 2 lists a variety

of functions that can be offered by a national education and training system. Objectives related to the priorities of multiple policies can influence education policies, such as innovation policies shaping TVET governance (de Otero, 2020), and ICT policies shaping national education systems (Echávarri, 2013). In developing countries, a key barrier to innovation across different settings and geographical areas is weak education systems – from basic education to training institutions and universities (Zanello et al., 2016).

Box 2: Functions of National Education and Training Systems

- Primary and secondary education
- Exposing youth to emerging technologies, scientific thinking, abstraction and logic
- Vocational skills
- Higher education
- Ongoing education, workforce development, and retraining
- Developing pools of specialised knowledge
- Providing interns, researchers, and instruments to industry
- Academic research
- Attracting funding to enable research

Source: Cunningham (2018a)

South Africa's school system includes 12 grades and leads to the matriculation exam. A large and steady gap has been found between basic and secondary schooling (Genesis Analytics, 2019). Fewer than two-thirds of students pass their matric exams and, of those who pass, 10% receive a score that allows them to attend a university (Department of Planning Monitoring and Evaluation [DPME] Development Indicators, 2019, as cited in PC4IR, 2020). A range of quality is found within the school system, but, overall, the outcomes are low on average, with higher performance outcomes found in public fee-paying schools (located in more affluent areas) than in non-fee-paying schools (World Bank, 2018b). While South Africa has one of the highest education budgets for a developing country, the education system underperforms, with key trends including high dropout rates (over half of students do not complete high school), and poor-quality mathematics education (Bosma et al., 2020). Furthermore, inadequate numbers of students are ready for studies in science, engineering and technology (MRP-STIIL, 2017).

In 2009, the Department of Higher Education and Training (DHET) was established to oversee the university and college sector, adult learning centres, private institutions, the sector education and training authorities (SETAs), the National Skills Fund (NSF), and the regulatory bodies responsible for qualifications and quality assurance, which form an integrated "post-school" system (Field et al., 2014). The Post-School Education and Training (PSET) system consists of TVET colleges, community education and training centres (CETCs), universities, SETAs, the National Skills Authority (NSA), and the NSF (PC4IR, 2020). Micro-credentialing institutions, offering short training programmes on specific topics, provide another option for post-secondary education.

A large, but declining, gap has been identified in access to educational pathways in South Africa (Genesis Analytics, 2019). Costs are a key challenge (Genesis Analytics, 2019). For

instance, tertiary education costs have risen faster than the consumer price index. The barriers are more difficult for black youth, with 53% of black African youth citing a lack of finances as the reason for not attending post-school training. This is above the national average and the 28% average of white youth. Lack of finances was estimated to cause 48% of dropouts in 2010. Recent protests have called for free higher education in South Africa (World Bank, 2018b).

South Africa's universities range significantly in quality (World Bank, 2018b).[9] A number of challenges have been identified in the country's university system (MRP-STIIL, 2017; Cunningham, 2018a). One is that there are not enough academics, qualified technical support staff, infrastructure and equipment to increase postgraduate numbers and research output. More qualified supervisors are needed to expand the output of doctoral graduates. Universities also struggle with funding, which limits their ability to hire additional staff that are needed to increase research productivity and teaching outputs. Further challenges are created by having insufficient management with overly bureaucratised structures. These challenges have, at times, been exacerbated by mergers creating larger institutions that are even more difficult to manage. In addition, there is insufficient collaboration between universities, with a lack of trust or willingness preventing the sharing of equipment and human resources. Challenges reported by academic institutions that affect their ability to function are outlined in Box 3.

Box 3: Self-reported Challenges Facing Academic Institutions

- Weakness in their relationships with DHET and other government departments
- DHET was thought to have a slow response to the changing social environment (instability following fees protests) and changing scientific environment (expectations related to publications)
- A lack of alignment between government departments was also found to be a problem, particularly with reporting requirements
- Inadequate funding, with unrealistic expectations by DST related to research
- Turnover of senior staff at National Research Foundation (NRF) creating delays
- Lack of long-term financial stability and insufficient funding for students, infrastructure and research
- Failure to retain and attract qualified and diverse staff
- Lack of capacity to supervise PhD students to meet NDP targets
- Deteriorating infrastructure

Source: MRP-STILL (2017)

Academic institutions have been making active efforts to address these challenges (MRP-STIIL, 2017). They are seeking to address the lack of diversity in race and gender of staff and students. Some academic institutions are developing and expanding programmes related to the development of the rural economy. Overall, academic institutions have been found to undertake a number of actions to support national priorities (see Box 4).

[9] This sub-section focuses on education and training provided by universities. Sub-Section 3.3 provides a more detailed exploration of the broader roles that are played by universities.

Box 4: Academic Institutions' Actions to Support National Priorities

- Prioritising socially disadvantaged groups in admissions policies
- Revising language and policies to be more inclusive
- Running foundation year and extended programmes
- Offering online admission processes
- Providing financial support to disadvantaged students
- Offering opportunities for students to discuss key challenges facing South Africa
- Building active citizens for the future
- Adding African studies to curricula
- Running academic outreach and cultural enrichment programmes
- Identifying and responding to the needs of marginalised identities within the institutions
- Running programmes on research skills development, academic and professional skills development for postgraduate students and postdoctoral fellows, and teaching and research development for staff, in order to support job creation and skills development

Source: MRP-STILL (2017)

South Africa has a system of public and private TVET colleges. Financial barriers lead many students into TVETs, which have lower costs (as government subsidies cover 80% of the costs of official college programmes) (Genesis Analytics, 2019). While 72% of public HEI students are black, 92% of TVET students are black.

Countries can differ in how well TVET is integrated into innovation systems, and this can affect the governance of skills formation and diffusion. For TVET systems to have the most benefit, coordination should occur between TVET supply, general education, labour markets and various government actors (de Otero, 2020). A large and steady gap has been identified in South Africa's TVET system with problems including education not matching industry needs and lack of practical experience for students (Genesis Analytics, 2019). DHET has sought to address problems with weak management at some of these colleges (Field et al., 2014).

Nine community colleges are also in operation that cater to post-school youth and adults who do not qualify for admission to TVET colleges or universities but who wish to improve their skills for employability or move on to further education in TVET colleges or universities. Another option is attending a micro-crediting institutions or e-learning (Genesis Analytics, 2019). However, digital access can be a barrier for these options. Furthermore, frameworks for tertiary education have been found to be rigid and lack the flexibility needed to support micro-credentialing institutions.

The SETA system exists to provide training for employees in all major economic sectors and is funded by a levy from industry. SETAs focus on learnerships, internships, unit-based skills programmes, and apprenticeships. Several studies have found deficiencies in the efficacy of this system (MRP-STIIL, 2017). Employers have been found to lack interest in the programme because of a high administrative burden and perceiving the skills levy simply as an additional tax (World Bank, 2018b). Overall, the disbursement of SETA funding has been less than what has been budgeted, which has led DHET to attempt to incentivise SETAs to allocate more funds to HEIs and TVETs (Genesis Analytics, 2019).

Overall, companies play a large role in national skill development. One aspect of industry involvement is supporting student training programmes. There are multiple programmes for students to gain work experience. One is the DSI-NRF (Department of Science and Innovation-National Research Foundation) Internship Programme for undergraduate and postgraduate students. A respondent in one of the interviews reviewed for this paper described how his company supports students at multiple levels of education.

> We do a lot of work with [University A]. They actually bring the mechatronics guys around our facility there to do some training … then [University B] trains the guys up as well … We get quite a lot of guys coming in. Even get guys from local high schools. You know, they're interested in mechatronics. And they got to do that career week or whatever. [If] there's a little bit of a lull, and we're working normal hours, then we'll bring the youngsters in and give them a bash. (F05-I05)

Firm involvement in educational institutions can also be a process that helps to bring international technologies to South African students. For example, a multinational company spoke about donating equipment to South African educational institutions.

> We do engage with [Training Institute A] … and we have donated [equipment] to the Institute … the big affiliation is with the [Training Institute A] and [a German institute] and they are now developing that in collaboration with our training officer to try and put something together that makes sense for a South African context. (F20-I41)

Another respondent spoke about having discussions with government officials to help develop training programmes.

> [Our] group has got different legs all over the world. One is obviously in South Africa. We're based here … We've been in discussion with DST and sort of DTI. One of it was for training. If you take one or two of these industry 4 type technologies and you say, well, let's make it real. And let's train young people in that. In an engineering point of view, there was discussions [about] how can we get involved in the South African landscape. (F13-I22)

Another aspect of industry involvement in training is supporting skills development for employees. For example, nearly 30% of respondents in a survey of mining industry firms reported actively investing in skills upgrading to help with digital transformation (PricewaterhouseCoopers [PwC], 2021). Bell et al. (2018) say that a lack of coordination between skills development policies and industrial policies has resulted in companies having to provide their own training programmes, which disadvantages smaller firms. Cunningham (2018a) describes private organisations filling a training void as meeting a short-term need, but not addressing systemic deficiencies. Respondents in firm interviews reviewed for this paper spoke about various forms of training that they provide to their employees.

> They come with the basic knowledge that is needed for them to enter the job market. They can code. They can do this, but then we have to build on top that knowledge and how they have to work. So, if somebody comes straight from university [with a BSc] in

> computer sciences, there's a lot of work that we have to do before that person can begin really to add value to the company … I think between six to nine months. (F07-I08)

Sometimes this can involve sending employees for training abroad.

> The technical guys, they get special training that you can't find in the institutions in South Africa. So, we send them overseas to Germany, or wherever machine comes from. If it is Japan, they go to Japan. (F12-I18)

In addition to formal education and training, other forms of knowledge flows also help to build the workforce. One key way for knowledge to spread is when people move between companies. Firms can benefit from employees moving between firms, as they bring new knowledge. One respondent described the development of local knowledge clusters.

> [We recruit] locally, I'll tell you something. Our business is deliberately located where we are. I'm sure you're familiar with cluster theory … We are established here by design. Pretoria is the defence and aerospace establishment of the country. You want engineers, electronic engineers? Be in Pretoria. Not Johannesburg. Not Cape Town. You want gaming? Go to Cape Town. If you want to do gaming, locate yourself in Cape Town. They cornered that market. You want apps and things like that? Johannesburg. You want serious engineering? Pretoria. [Here it's all] related companies … We build aircrafts in this city. Build helicopters in the city. We build serious tech. And it's been like this since the 70s. So, by being located here, finding engineers is not a problem. (F07-I08)

A related challenge is that some firms struggle to retain people with critical skills (Genesis Analytics, 2019). This can be a problem when firms are investing in training their employees. Respondents in the interviews reviewed for this paper described other companies poaching their staff because it is hard to find qualified people. Also, people are trained by an employer and then choose to leave because there are a lot of opportunities for qualified people. One respondent described how this problem related to finding suppliers.

> But to find people in industry is very hard. And unfortunately, the pool is so small that it's really just people stealing our suppliers and vice versa, which is not pleasant. But that's kind of the nature of the game. (F20-I41)

Informal skills development is also happening through more diffuse methods. Individuals can access learning materials through online resources. Furthermore, one respondent described that the general public is developing familiarity with technology by using smart phones.

> What's interesting on African spaces, people's maturity around these things, mobile devices, and some of them have got two or three just because the networks are so poor. So, what we're seeing is that because of this becoming a mature tool in people's hands, it can bring in technologies in their workplace, so that definitely helps. (F09-I11)

Producing Jobs

As discussed in Alexander (2022a), the first paper in this working paper series, South Africa has high levels of unemployment. To address the national need for more jobs, a number of

programmes have been developed to help create jobs (South African Government, 2021). The implementation of these policies is a factor that shapes dynamics in the national innovation system.

A major initiative is the Presidential Jobs Summit Framework agreement. The agreement seeks to create 275 000 jobs annually. Commitments include boosting the economy; procurement interventions and industrial financing; assisting small businesses through township supplier development programmes and supporting youth entrepreneurship; increasing access to community colleges and technical and vocational training colleges; implementation of a national minimum wage; ensuring employment tax incentives work correctly; and establishing a national anti-corruption strategy.

Another programme is the Youth Employment Service (YES), a business-led collaboration with government and labour. This programme seeks to create one million work opportunities for youth. One respondent described positive experiences working with the YES programme.

> There's a lot of people, you know, the unemployed youth. So, what we do is we give them a 12-month programme. And depending on my volume and my workload … we move them around machineries and they get experience. However, at the end of 12 months, if we haven't got permanent positions for these people, we let them go. But so far, everybody that's coming to the YES programme … became a permanent position. (F14-I28)

Many other cross-sectoral programmes are being run. The Employment Tax Incentive seeks to encourage employers to hire young work seekers. The Amavulandlela Funding Scheme has been designed by the Small Enterprise Finance Agency (SEFA) to support entrepreneurs with disabilities. Also, the Expanded Public Works Programme (EPWP) employs workers with government, contractors, or other non-governmental organisations under the Ministerial Conditions of Employment for the EPWP or learnership employment conditions.

Some programmes are also sector specific. For example, sector-focused programmes have been developed for the clothing and textile sector and the poultry sector. In addition, the Public-Private Growth Initiative involves private sector commitment to invest R840 billion in 43 projects across 19 sectors and create 155 000 jobs by 2024. Furthermore, the government has an overall objective to support sectors that are expected to have higher job-absorption capacity in the short and medium term (Andreoni and Tregenna, 2020).

A number of respondents in the interviews reviewed for this paper described feeling pressure to maintain their workforces and to hire new workers. One respondent referred to the government's focus on job creation as follows.

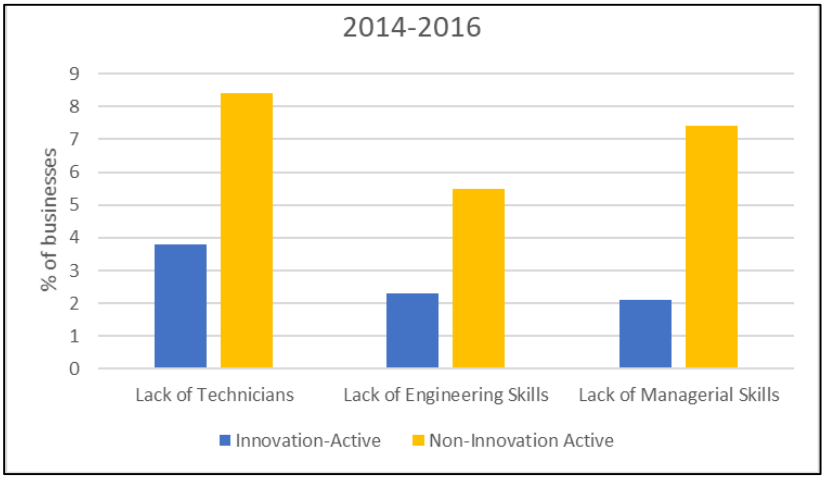
> For us being a company in South Africa, we need to have the labour. Each company needs a certain amount of labour, like you spoke about affirmative action and those things. So, you still need to give a certain number of people work. In order to not pay extra taxes or whatever the case may be. There will [be] some sort of penalty if you go and automate everything. (F12-I17)

Gaps in the Production of Needed Skills and Suitable Workers

Overall, South Africa's education system is not producing the needed skills. While the science, technology, engineering, and mathematics (STEM) fields account for 30% of university graduates (DPME Development Indicators 2019, as cited in PC4IR 2020), South Africa has inadequate high-level science, engineering and technology, and technical skills for the economy (DST, 2019). One challenge is that South Africa has a shortage of qualified teachers in science, mathematics, and other disciplines (MRP-STIIL, 2017). South African businesses have expressed some challenges related to lacking the needed skills in their businesses. Specifically, some businesses have identified a lack of technicians, engineering skills, and managerial skills as barriers to innovation (see Figure 8).

Another challenge is that the information being taught is not necessarily what the job market needs. The responsiveness of the education system to technological change is an important factor. HEIs are of a high quality, but have a shortage of demand-driven curriculum design (Genesis Analytics, 2019). University and TVET curricula have been found to be outdated and inflexible, which prevents them from meeting the evolving skill demands of the labour market (Cunningham, 2018a; Genesis Analytics, 2019). Specifically relevant for the spread of 4IR, South African education is not providing the necessary skills for the digital economy (Bosma et al., 2020). Digital talent has been found to be rare at all skill levels (but especially in terms of higher-end/global skills) and is becoming a critical bottleneck for the growth of digital start-ups (World Bank, 2018a).

Figure 8: Skill-related Barriers to Innovation



Source: CeSTII (2020)

Some respondents also highlighted challenges related to communication between industry and HEIs. One respondent spoke about universities' lack of alignment with evolving needs related to 4IR, particularly the need for technically trained people to be creative.

> In my mind, the universities are not … on the cutting edge of this with students that are coming out to come into work in our work place. … So, if we go to the electrical engineering department [at University A]. You'd say what are you guys teaching your

> students? How to creatively work with these technologies? Okay, hold on, what are all these technologies? So, if I'm now a civil engineer, how can I use AI? I am being taught how to throw, how to dig a foundation and the mechanics of building a building, and all that traditional stuff.
>
> But now, I have to overlay all these new technologies onto that, because when I get out into the workspace, they're going to expect me to know this. I have to be creative in the deployment of this. If I'm not taught how to be creative, if I've got no art skills, I am a box standard civil engineering [graduate], I've got no creative bone in my body. How do I change that? So, there has to be different types of engagement. We have to break the traditional modes of lecturing, teaching, et cetera. Get people to be more creative. So, in the university itself, it has to be like [a] think tank. It has … to be on the [cutting edge] the whole time … What's going on? What's changing? Where do we see danger areas? (F06-I06)

A further challenge is that new types of skills are needed as 4IR systems and technologies develop. One respondent mentioned that the skills that are needed are still undefined.

> The skills don't exist because the frameworks don't exist. Along the way there's researchers who are working at universities trying to understand human behaviour frameworks. Like, how do we make these simulations work better? How does the research substantiate these mediums, these techniques? … We learn from that. I personally read the papers that get written. I read a lot of literature and books on AR [augmented reality] and VR [virtual reality] design and also where the industry is going, and a lot of fourth industrial revolution content.
>
> There isn't a skill set, there isn't a job that you train for per se. There isn't a school that's teaching how to become an AR or VR developer. It's a game developer with thirty or forty percent more skills. We do that thirty or forty percent here in the company, but that sixty percent that you need, you get it from a school or an institution of some sort.
>
> We also actually have guys who are completely self-taught, who just watched YouTube tutorials and who've done online courses and who are more than competent compared to some of the kids who come out of school. It's always about aptitude and it's always about the work ethic. If you work hard, you will be good at your job. We don't measure anyone on their skills and qualification. If we do an assessment of you and we give you an interview and you're good and we like your attitude and we like the energy and presence that you have, we give you an internship. Even if your skills aren't that great, if your improvement is that much better, if your improvement level is that much faster every day, we know it's inevitable you're going to be good at your job. (F16-I31)

While there are still uncertainties, a number of new skills are already known. A challenge with South Africa's education system is that is has been slow to develop new academic qualifications and programmes based on industry needs, rather taking an approach of waiting until a collective demand emerges as opposed to meeting the needs of front-runners (Cunningham, 2018a). One respondent felt that companies share some of the responsibility for this problem. He felt that, to enable the expansion of 4IR, companies should be more proactive in telling universities about the types of skills they need.

> I think companies like ourself, need to guard institutions as to what skills we'll require the next decade and beyond. And therefore, the curriculums have to be customised to specifically meet those requirements going forward … Ourselves and all the other players in the marketplace, if we want to really play very effective and efficiently in the fourth industrial revolution, we need to define what skill sets we need to prepare the business wise before going forward … I think the industry has to drive that aggressively.
>
> No disrespect to academia, but I don't think academia should define that … at this point in time … [our company is] not doing a very good job at this stage. In my view, I don't believe we are engaging with tertiary education at this point in time to define what skillsets we require at this stage … So, we shouldn't be complaining as a sector, if we don't get the right skills, if we're not asking for it to be developed over four, five-year term.
>
> … If [our company] wants to get into the fourth industrial evolution, we have to take a view where the industry makes it. And we need to say, 'These are the skill sets required, data scientists, data engineers, application, insurance, et cetera.' And that's typically what has to be done at this point in time. So, we can't be pushing out current engineers and they're becoming petrol station jockeys or they're selling newspapers on the street, because you can mismatch the need of what the economy requires versus what academia is actually pushing out. (F07-I09)

Some businesses reported that workers with higher level skills training meet their needs better than workers with training for lower skilled jobs (Lorenz et al., 2019). While some high-level skills are in short supply (e.g., data engineers and programmers), businesses perceived the skills of electrical and mechanical engineers to be good. Speaking of higher-level skills, one respondent described that the challenges faced in South Africa are similar to challenges faced by businesses around the world.

> I hear a lot of commentators in South Africa saying if we don't jump on the bus, now we're going to miss it. I think that's utterly nonsense. When we attend conferences in Western Europe, the challenges that we face in South Africa, we're not that far behind Germany and Netherlands and Belgium. When we speak to companies there, they also just look in awe at what people are doing and say we're not there yet. And these are also SMEs [small medium enterprises]. Companies like us.
>
> The one example I like to use is a conference [we] attended … So, it was specifically looking at maintenance, utilising industry 4 technology, so using utilising a lot of data analysis and AI and machine learning and deep learning. And one of the presentations was done by Intel, Intel is one of the most recognised companies in the world. And their presentation focused on how they struggled to cope with big data. They cannot cope with big data. Now, if Intel cannot cope with big data, how are we supposed to do that? So, everybody has their own challenges.
>
> … [However,] I think the gap between high-tech and low-tech in South Africa is maybe bigger than [in] Europe. (F13-I20)

Students from TVET institutions are often not perceived to have the necessary skills when entering jobs (Lorenz et al., 2019). Accordingly, there is less of a demand for vocational

training than for universities in South Africa because the skills being taught do not match well with job opportunities (World Bank, 2018b). One respondent described an example of the problems he has experienced with the system.

> I was in an interview [with] one of the students entering into the maintenance department. She had a certificate with her saying that she's a welder. So, I asked her to bring a spirit level and come. And she asked me 'what's that?' But you put a certificate that says you're a welder. So, I've got a question about where she got the certificate. What was taught? (F14-I28)

Deficits also exist among people applying for jobs that do not require specific training. For low-skill jobs, employees have been found to have weak numeracy, communication, and teamwork skills (Lorenz et al., 2019).

As 4IR technologies expand, the nature of factory work is changing and requires new digital skills. People who are currently in the workforce are lacking the skills needed for the future of work. The focus of the South African education systems on youth and new graduates has led to a lack of funding for further education, retraining, and adult education (Cunningham, 2018a). One respondent described how these changes are playing out in his business.

> A lot of people in my plant are very old. They've been doing the same thing for 15, 20 years. And they come from the local surrounding areas, rural areas. However, in the last year or so we've been getting more students, younger ones … You find the contrast in the plant with the younger ones want to go more technical and … the old guys are more manual. And that's the two scenarios I have in my plant at the moment. (F14-I28)

Another issue is that 4IR can create the need to bring together people with very different skill sets. This is particularly a factor as more infrastructure and common products become digitally connected.

> A lot of what you have to do to make things that are smart work is dirty work … Going out doing field tests, digging holes and ground land cables. People don't want to get involved in that too much. And the level of skills that are involved in doing that level of work is very low. And when you're working in a very high-tech environment, it's very easy to have problems, which are related to simple things. Poorly connected terminal cables, earthing not done properly, simple things that are really fundamental … physical connectivity issues. (F21-I38)

One respondent described a lack of skill within their company, leading to limited use of 4IR technologies.

> In the context of what we do, a lot of the new technologies are still not applied. Or applicable, I should say, applicable because of the lack of skills. (F17-I33)

However, another emerging issue is that 4IR developments do not necessarily need sophisticated technical skills. One development that is happening is that high-tech systems are increasing available in ready-made products that a company can buy and have operated by staff with lower levels of training. One respondent described how being able to buy

systems with AI has decreased the need for internal staff with high-level programming skills as the technology has simpler user interfaces.

> It sort of levels the field in terms of developing products, because your, the algorithm that you create now, for example, to detect or to classify a vehicle that's no longer determined by how good a team of software engineers you have. That's now determined by how good a team of people you have who can draw little square boxes around cars. Quite as simple as that … It will be a big impact. (F21-I37)

Firms also discussed challenges related to workers that were not related to skills. One challenge described by South African managers was high wage costs.

> Look, our labour cost in South Africa … it is quite expensive. You've got all these unions, all these parties, all these extra costs. (F12-I17)

A key attribute of the workforce in South Africa is the strong role of labour unions. These unions can support the development of decent work within South Africa. However, they can face challenges when companies are not committed to staying in a particular country. A representative from a company described how this situation creates challenges for businesses and that, when companies are competing globally, labour issues can make them move production to other countries.

> The labour situation in South Africa is a concern. In terms of strikes and stuff like that. Because to be honest, we can't really afford the strikes … So, if we've got an issue, you know, we're going to stop them. [Customers depend on us but] can get [product] from Argentina and from Thailand … So, I've worked at a company … where the MD got fed up with all the politics in the strikes and he said, 'I'm going to close this business'. And he did. And we were 1 000 million Rand company … that was going back to 1998 … That's it you're part of the International, you know, competing on the international scene, not in South Africa anymore part of the global stage. (F14-I27)

Challenges with labour costs are a crucial concern for businesses competing in a global marketplace. Both government policy and union action can help to address these issues to support the creation of fairly paid jobs in South Africa.

Respondents also expressed several challenges with behaviour in the workforce. One challenge mentioned was absenteeism.

> So, which is difficult for us in the cultural environment that we're operating in, absenteeism is always an issue. (F11-I15)

Substance abuse was also an issue mentioned by respondents.

> The alcohol and drug abuse, that's the biggest challenge we're facing now, but based on the improvement that we have now in the industry, it's going down. It's improving day by day, because we're training [in] house, that we're training them that just we empower them to know their importance on the company. … So right now, they are wide open, that in future, they will end up like myself as a team leader, because we're busy training

> them how to operate the robots, how to operate the machines, automatically, stuff like that. So right now, they are on time now. (F12-I18)

These are challenges that can have complex root causes but need to be addressed to help businesses function efficiently and engage in innovation.

2.4 Demand

National demand is a key factor that can drive innovation. Demand can come from the private and public sectors. This sub-section considers levels of demand that South African firms experience and the types of market pressures that firms experience.

2.4.1 Market Size

In a situation with relatively open trade, South African producers can sell their products abroad but also face competition from global competitors when it comes to selling to local buyers. When businesses have more sales, they can learn more and obtain increased resources which can support innovation processes. South Africa has a number of policies and initiatives designed to increase demand for local businesses.

Public sector procurement is one way for public actors to increase demand for local production. The government has required minimum levels of local content in tenders for 23 designated sectors and products (DTI, 2018). The National Industrial Participation Programme promotes local content in goods and services provided to the government and parastatals. New public procurement regulations in 2017 were intended to support small businesses, rural and township enterprises and designated groups, and to promote local industrial development. They included a stipulation that 30% of certain categories of state procurement should go to small, medium and micro-scale enterprises (SMMEs), cooperatives, and township-based or rural enterprises (World Bank, 2018b). State bodies can also include prequalification criteria in tenders to help to encourage that diverse businesses have more opportunities. Factors addressed have been based on broad-based black economic empowerment (BBBEE) status[10] and business types (World Bank, 2018b).

Some initiatives have focused on specific supply chains, such as a programme focused on rail supply chains (DTI, 2018). Based on this type of approach, freight rolling stock has been designated under South Africa's Preferential Procurement Policy Framework Act (PPPFA) to use domestic procurement to boost the industry. In total, over 60 companies (original equipment manufacturers [OEMS] and first-tier suppliers) were benefitting from Transnet Freight Rail and Passenger Rail Agency of South Africa (PRASA) contracts in 2018.

However, local procurement policies have faced challenges. DTI (2018) identified a problem with persistent non-compliance in SOEs' implementation of localisation policies. They

[10] See Sub-Section 2.5.5.

attribute this problem to both poor coordination as well as corruption, collusion and rent-seeking.

Notably, government procurement of advanced technology products in South Africa ranked 44th out of 100 (WEF and A.T. Kearney, 2018). There is room for improvement in this area. In the Business and Innovation Survey (CeSTII, 2020), about 22% of businesses reported having contracts to provide goods or services to the public sector (almost all in South Africa). Of these businesses, about half of those in industry (52%) reported that innovation was required as part of the contract, and only about a quarter in services (24%) reported such a requirement. In a national assessment, a large and persistent gap was found in the government's ICT procurement (Genesis Analytics, 2019). Genesis Analytics (2019) says there is an opportunity for government procurement to prioritise digitisation in services and to focus on using domestic suppliers.

The government has also tried to promote local procurement in private companies' supply chains. Actions have included providing financial incentives for local sourcing. One of the interviewees mentioned trying to fulfil obligations related to local content.

> We're putting more people in to get our local content targets done. (F11-I15)

In addition, the government has sought to promote demand for South African products from the general public. The Proudly South African Campaign, with funding from the DTI, promotes the purchasing of South Africa-made products.

Government initiatives have also sought to develop companies' capabilities to play roles in meeting demands from domestic value chains (DTI, 2018). For example, a number of programmes involve supplier development for the rail industry. The National Tooling Initiative (NTI) and National Foundry Technology Network (NFTN) focus on skills development, job creation, technology development and adoption, enterprise development and export promotion. The Scaw Metals Supplier Development Programme seeks to help local foundries to supply coupler components to Transnet. NFTN has helped suppliers to sell to the rail industry. Three centres of excellence (Western Cape, Pretoria, and KwaZulu-Natal) and two trade test centres (Pretoria and Western Cape) have been set up, with state-of-the-art equipment. The Enterprise Development Programme has supported over 100 tool, die and, mould companies.

2.4.2 Market Characteristics

The consumer market in South Africa is very diverse. The country has a population of around 59 million people, and GDP per capita in 2019 was $6 000 (World Bank, 2021). About 19% of the population was living on less than $1,90[11] a day in 2014 (World Bank, 2021). At this time, the top 10% of the population held 51% of the income and GDP per capita was $6 400. This

[11] At 2011 international prices.

situation represents high levels of inequality and creates a market where different consumers have dramatically different levels of purchasing power.

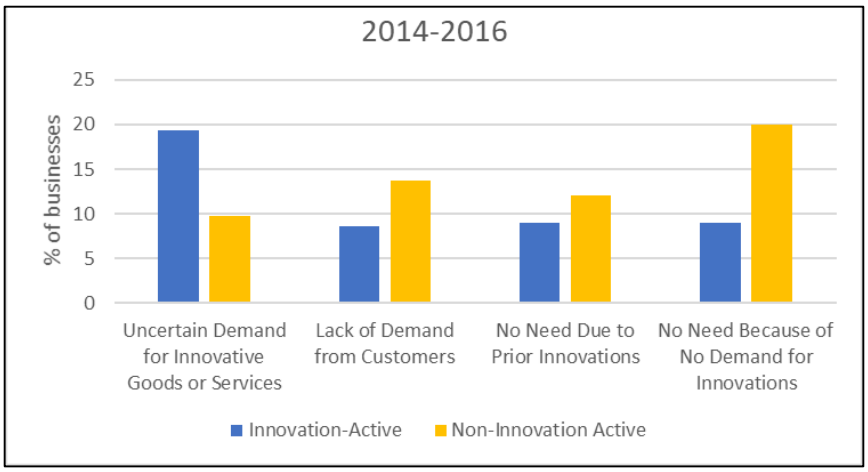
As with the diversity between individuals in South Africa, the characteristics of businesses buying products and services differ greatly. Differences between buyers (individuals or businesses) can be based on price as well as types of products or services desired. South African firms have identified a number of demand-related barriers to innovation (see Figure 9).

Diverse types of demand can be seen as driving firms to adopt 4IR technology and systems. One issue is that some companies experience demands which encourage them to engage in process upgrading. Such demands can drive companies to adopt digital and automated processes to help improve factors such as speed, consistency, and traceability of their production processes.

> From the get go quality requirements. The automotive standard has gone up in the last three models that we've built to an extent where everything needs to be monitored and traced. And it's not like how it was five years ago. Even five years ago, you had systems in place, yes, and traceability started, but we could never trace a part that's on a finished car that was produced two years ago and trace it back to the exact date that it was built. (F12-I17 – Respondent 2)

> That's the reason why we automate. It's because if you keep the volume and then quality, for also consistency … with manual operation you can't keep up. (F12-I17 – Respondent 1)

Figure 9: Demand-related Barriers to Innovation



Source: CeSTII (2020)

A second issue is that customers can demand enhanced, higher tech, or digital features in their products and services. These demands can lead to companies producing products and services with 4IR features.

> We're speaking to another company … one of their needs is inspection … they want to know exactly in all the warehouses, what is what, where and how much of the product I can put on a truck to optimally fill it without having to weigh … they wanted it visually.

> So, you drive in with the truck and all information is there in the internal systems, then know what to put on that truck where the truck needs to go offload or whatever.
>
> … best case for them would be [to] just put cameras there. So, you drive in, and in as soon as you drive in the truck's identified, the driver's identified, the load's identified the amount of, so immediately, the guy could say, well, you need to drive to there, offload there. And once you're done, you will pick up this much [at] another spot. (F13-I22)

A consulting company promoting 4IR systems described the demand for their services being based on productivity and safety concerns.

> There is an increased demand of automation and that what we are keeping needs to be more automated for primarily two reasons. And it depends on the industry. Product productivity and safety, mining industry, for instance. Because of the many accidents we had the last couple of years. (F17-I33)

For the second type of change, which involves modifying the features of goods or services, the capabilities of users can shape design processes. Firms described purposefully designing products to match the capabilities of their target users. This can include the user interface and, especially for business customers, also maintenance requirements.

> If we design something, we think, 'who is going to maintain this? Who is going to look after this?' So, we try not to build stuff that goes to the moon, if we don't have people looking after it. (F19-I35)

Additionally, customers have varying levels of appetite for making some of the changes that are part of 4IR systems. A logistics service provider representative said,

> What you tend to find now it's all clients want to go to Industrial Revolution 4.0, but … I'm not exactly sure how much of the data they're willing to give, and how much they want to receive, and how much decision making they say they are willing to allow to be happening automatically. (F04-I04)

One issue is that individual buyers' previous experiences with technology can shape their willingness to adopt new technology in the future.

> So, a guy would go to the mine with a battery system, and then they will realise the battery is trouble. If you go afterwards, even if you have a product that works perfectly, [he] will be sceptical to use batteries. [He] will say no, no, no, I dealt with this in the past. (F19-I35)

Alternately, some companies are leaders and more willing to experiment with new technology. The respondent from the mining equipment company went on to describe another type of more progressive customer.

> So, you also get the leaders and the followers in the mining industry as well. You get a few companies that watch other companies what they do first, when they [figure] all the R&D out, 'Oh, that's working. Okay, let's jump on.' (F19-I35)

Another key issue is that different sectors have different levels of demand for 4IR products. A respondent from a South African company focused on VR described a lack of national demand for AR/VR entertainment options.

> So, if you have to think about entertaining somebody for a minute and you want to do it on Hollywood Blockbuster, how much does it cost you? If you want to do it in VR and AR what does it cost you? What does it cost to do it in games? What does it cost to do it in board games? And all this kind of translates to you know, opportunities in media and entertainment. Like when you realistically understand how much it takes, or how much it costs to entertain someone for a minute and you look back to the complexities of all these different mediums, what is the ultimate strategy that you should be employing to create content that is engaging? … There are companies out there that are doing entertainment focused AR-VR … Across the world there are other opportunities that other people capitalised on that don't necessarily suit us here. Like, in the States there is huge market for entertainment. So, the companies are selling their headsets to let people play games and for companies to open arcades and to build the entertainment industry because that market is conducive to that … In South Africa and across Africa and in emerging markets, gaming is not an opportunity. You need to be able to build economies so that you can have people who have disposable income that can spend on entertainment. Right now, you can't appropriate money to entertainment when you need to appropriate it to food and rent. (F16-I31)

However, this company did have a demand for other types of AR/VR products in South Africa. A key client base was companies using such technologies in their internal operations.

In the globalised economy, with South African firms producing products for customers in multiple locations, changes in global demand can also affect South Africa. One of the respondents described how global demand for electric vehicles may shape the car market in the country.

> So, we're still kind of driving older technology and these kinds of things, but I think because of the basic design of the vehicle is changing so dramatically and so quickly, we're automatically going to get affected in the future. And because we're exporting vehicles into Europe and to other markets with automatic, [it's] gonna get impacted on our production line. (F22-I39)

In addition to customer demands, businesses face a number of societal demands. As discussed in the first paper in this working paper series (Alexander, 2022a), three key needs in South Africa are attaining economic development, reducing environment impacts and generating increased employment. Seeking to achieve national progress in these areas can shape firms' behaviours. It can also prompt sustainable entrepreneurship (Schaltegger and Wagner, 2011).

One challenge in South Africa is that some companies would like to upgrade and innovate in relation to 4IR, but they do not have ready customers looking for these changes. However, in some cases, companies in South Africa have been able to move beyond the issue of low demand. Many businesses spoke about educating their potential customers about the

benefits of new technologies. This dynamic is discussed further in Alexander (2022b), the third paper in this working paper series.

2.5 Additional Contextual Factors

There are many contextual factors that shape the environment of South Africa's businesses. All cannot be covered in this paper. This final part of this section provides a brief overview of some additional factors that have not been covered above.

2.5.1 Norms

South African businesses operate in an environment that is shaped by a number of norms. One aspect of norms that can shape the adoption and spread of 4IR is the willingness of people to establish new businesses. South Africans' appetite for entrepreneurial risk is above the global average, ranking in the 4th decile in an international comparison (WEF, 2019). Respondents in the interviews reviewed for this paper described South Africans as being entrepreneurial people who look for solutions.

> We're a country that's sort of like, knows how to make a plan … the engineering guys from the different OEMs enjoy that about us, that when we do come up against a brick wall, even if it's one of their mistakes … 'we tend to always come up with a solution that's more cost effective and simpler to implement. (F05-I05)

> There's a culture of competitiveness. There's a culture of 'I can't buy it from anybody'. So, if they ask you, [you] have to create it. (F04-I04)

Another factor to consider that shapes the potential for 4IR is how people perceive the potential changes that could be involved. One respondent highlighted the importance of individuals' mindsets related to the adoption of 4IR.

> Depending on which sector you look at, clearly there are differences in terms of their preparedness … and ultimately, it's about the enablement of the individuals to be able to deal with this stuff.

> But there is clearly, there is a psychological component of understanding, comprehending, and understanding the implications thereof before … you can impart skills about how do you use a 3D printing machine or how do you use this … if you are not ready for this, then you have problem. (F18-I34)

Another respondent highlighted how norms can affect people's aspirations.

> So, you know, South Africa hasn't really seen what an industrial revolution looks like. They haven't seen like massive expansion that has happened in other parts of the world. So, there's no context. People don't understand what the world should look like and what to aspire towards. Even the media … doesn't show how the rest of the world is moving forward. It just shows the poverty and it kind of doesn't necessarily motivate anyone forward. (F16-I31)

People's previous experience with 4IR and digital technology can shape their openness to using such systems in the future. This use of digital services can help to change national

norms. The e-participation ranking, which assesses the use of online services to facilitate the provision of information by governments to citizens, places South Africa in the 3rd decile in a global comparison (WEF, 2019). Furthermore, the Network Readiness Index (NRI) (Portulans Institute, 2020) ranked South Africa highly in a set of 134 countries in terms of the socioeconomic gap in the use of digital payments (52nd), and rural gap in the use of the digital payments (35th).

While the importance of regulation and standards was discussed in Sub-Section 2.1, norms can shape the effect these institutions have. In some cases, norms can involve violating local laws. One respondent described how UAVs are being developed and used despite regulations designed to limit their use.

> So, the people that do operate [UAVs] are either [a] very small group, or they're doing it illegally … For the people doing it illegally, it's usually the smaller jobs. (F13-I25)

A challenge with some 4IR technologies and systems is that they involve changes to norms that have been involved in earlier production models. Sometimes actors feel friction when trying to change these norms. In general, many South African businesses are reluctant to try new technology. One respondent, whose company sells robotic technology, described some companies' resistance to introducing processes of automation.

> South Africa has lower adoption of robots than other regions because of the mentality of not wanting to change, even for executives, decision makers with good qualifications. (F20-I41)

Another area in which norms can be seen as impeding the spread of 4IR is in terms of increased data sharing. This is often a key part of 4IR systems, but can violate norms related to privacy. One respondent described this problem.

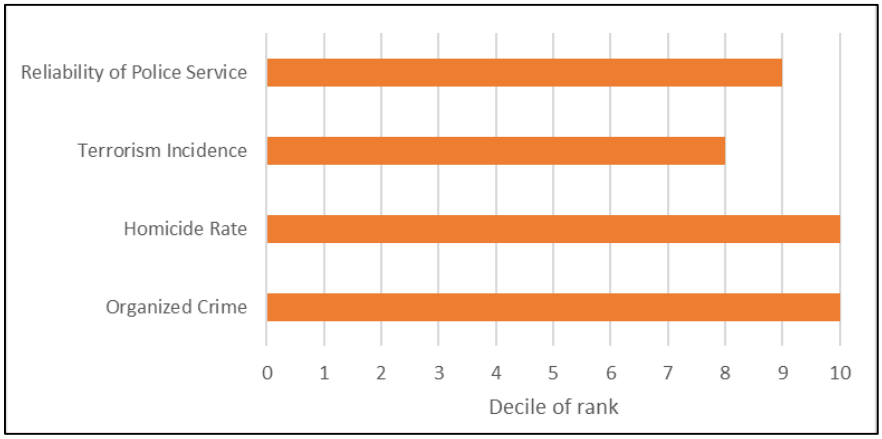
> Everybody's talking about the … Amazons and their business models and how they utilise technology to leverage their business models. But your run of the mill companies, not so much, because there is still a lack of trust. And new business models require the sharing of data. There is still a lack of trust … in South Africa, people do not want to share data. (F13-I20)

2.5.2 Security and Corruption

Another contextual factor that shapes businesses' innovation systems is security and corruption. Crime and fear of crime can shape businesses' experiences. In comparison to other countries, South Africa ranks poorly on many categories related to security (see Figure 10).

One challenge related to crime is that items can be imported illegally. For example, a problem this creates is that illegally imported road vehicles can displace new car sales. This is a serious problem, as about 300 000 of the 12,7 million road vehicles on South Africa's roads are estimated to be illegally imported (Vermeulen, 2020).

Figure 10: Global Rankings Related to Security in South Africa



Source: WEF (2019)

Another key issue is theft of and damage to public infrastructure. South Africa is facing an ongoing problem of theft of valuable parts of infrastructure.

> So, on any good weekend in Tshwane, we lose about 10 traffic signal poles because people drive them over. Jo'burg is the same. So, that has to be fixed. People steal electrical cables that is probably 15% of the other problems you have to fix that. (F10-I13)

The rail system has been seriously affected by this problem.

> I think in the past five months, there's been 3 or 4 serious accidents with fatalities in them. The reason those accidents … happen, believe it or not, it's because the Germans are very good at making technology. But they have Germany in their mind when they're making the technology. They don't have Africa. So, the whole signalling system, that PRASA spent about between 7 to R10 billion to install, which is a very good signalling system, is copper based … They are stealing the copper. And when they steal the copper, there's no signalling system … That's why people have died. (F04-I04)

Another respondent described rail-related theft increasing during the COVID-19 period.

> [The] rail system has been seriously damaged due to theft during the COVID-19 lock-down. (F25-I46)

In other cases, economic unrest has created security challenges. One respondent described violent protests.

> Trucks get burned on the roads because of disputes between freight companies and because people resent foreign drivers getting jobs. (F24-I44)

Risk of crime can be a factor preventing the implementation of 4IR systems. For example, fear of cybercrime and privacy issues has created resistance to the adoption of cloud computing (Deloitte, 2016). While Genesis Analytics (2019) found government regulation of data protection and cyber-security to be deficient, they did find the gap to be declining.

On the other hand, some 4IR services have developed as a response to the risk of crime. For example, new policies and businesses are developing to mitigate problems with cybersecurity (MarketLine, 2020a).

Multiple 4IR-related services are being created to mitigate risks of theft. One respondent described the vehicle-tracking industry growing because of such risk.

> You know in South Africa, vehicle tracking is a big business because of the crime. (F10-I13)

Another firm described how they have innovated to deal with the issue of copper wire in train lines being stolen (F07-I08). Their innovation involves 4IR systems based on the use of new digital technologies.

A further risk firms have been seeking to minimise with 4IR systems is theft of products during shipment. One company described how technology can play a big role in ensuring the security of shipments.

> Every process is hamstrung by huge amounts of theft in South Africa. It's just the nature … and that's what's encouraging automation as well. Because it's quite difficult to steal something that a robot is handling. If you had to ask, the average operator guy who runs the facility will tell you it's probably the biggest problem … the best is not to have any humans touch it. If they have to touch it, they should scan, re-scan and re-scan. (F24-I44)

2.5.3 Legacy Systems

Legacy systems are another crucial factor affecting the development of 4IR. In some cases, existing systems can be a hindrance to future development. For example, one respondent said that mines' existing systems are not set up in ways that can easily be moved to 4IR systems.

> The fundamentals of a mine [are] that, in this case … chrome gets dumped somewhere and a truck has to lift it up … and drive it around. So, there's some very basic process challenges that you currently have. So, for example, whatever the person does he still has to write it on a piece of paper and the piece of paper is given to another person et cetera, et cetera.
>
> So, whereas you have this phenomenal autonomous mining technologies, which are somewhere in the future, the fundamentals are not there yet. Which is that the digitisation hasn't occurred … Ultimately, we'd want to have a paperless situation … The problem is that the data systems, the legacy systems we have today, they are built for technologies which didn't really network properly and that were islands. And now the problem is you need to have this collaborative value creation including IoT and it doesn't work. (F18-I34)

Another respondent described how reluctance to move to new systems can be a challenge.

> There's … a client, who has an existing system [it] likes. It doesn't want to get rid of it. Right. So would do whatever is legally in the power to keep what they have. And we've

> seen that recently, in a couple of tenders that we've done with, it's been quite difficult in getting the process to step ahead, even after tendering, and the tender has been awarded and that kind of thing. So that's, that's a bit of a drawback here. In the bigger scheme of things, it's nothing major, I think it's just an issue of timing. (F21-I37)

Another issue with legacy systems in the characteristics of existing jobs. Ongoing challenges can be drivers for innovation. One issue is when jobs pose risks to workers' health and safety. Such risky jobs can promote innovation and the adoption of 4IR processes that can improve safety.

> An area that we're currently looking at assisting in automation, we are looking at investing in shot peening … the technology will come in, in the added add-ons to that machine, where the human safety part of it comes [in] … It's fairly unsafe, the current practice that we have. Although we've put a lot of safety rules in place, the core action itself is an unsafe action. By the nature of the operation, anybody working with boiling oil is going to get burned sometime or the other. (F14-I28)

In addition, some jobs that are difficult can create a motivation to develop automated systems.

> Well, the automation levels in the body shops, obviously, that's a traditional discussion. So how far do you go down and robots and not. That has increased over the years, driven mainly by technology in a way that you can't do differently. Now most of our, like our laser welding equipment that we have in the in the body shop, you cannot weld with a spot weld gun, you need to have the laser, or we have certain jigs that cannot be operated other than robotic because they're too heavy. So that's, that's the main driver. (F11-I15)

In some contexts, South Africa lacks existing systems. At times, a lack of legacy systems can create more freedom for innovation to take place. One company described an advantage of being able to innovate without having to deal with legacy systems.

> If you look at being first to market with these kinds of things in countries [where they] haven't existed, there's actually quite a big advantage to that, because you now get to sort of experiment with what you do without risking breaking terms and conditions or that kind of stuff. So, it becomes almost like a playground within certain limits to do things that you wanted to. So, there are some advantages to that. Yeah. (F21-I37)

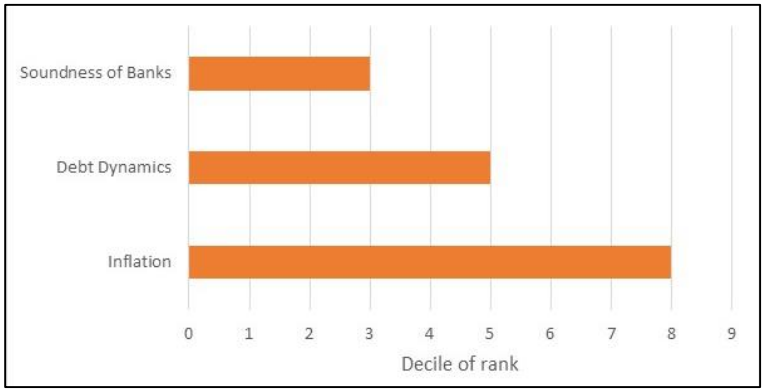
Some new technologies can be applied regardless of previous systems, giving countries the potential to leapfrog to more advanced technologies and systems without having adopted earlier developments. With growing technological developments, companies can, in some cases, leapfrog in their development processes by using digital technologies to solve problems that present severe challenges for physical infrastructure. One respondent described the potential benefits of being able to "leapfrog" over some technologies.

> In South Africa, we don't have the same level of advanced mobile technology. I think there's lots of opportunities for leapfrogging … Africa's big advantage must be the fact that they can leapfrog non-mobile technology, 5G and things like that. (F09-I11)

2.5.4 Macroeconomic Stability

Another issue shaping the national innovation system is the level of economic stability (see Figure 11). This can shape businesses' ability to plan and undertake longer term projects. South Africa ranked in the 8th decile in a global comparison of inflation. In another measure of macroeconomic stability in the same comparison, the country received a higher ranking, placing in the 5th decile in the category of debt dynamics. This category measures the change in public debt, weighted by a country's credit rating and debt level in relation to its GDP. In addition, South Africa ranked relatively well when comparing the soundness of banks.

Figure 11: Global Rankings Related to South Africa's Macroeconomic Stability



Source: WEF (2019)

2.5.5 History of Apartheid

A key contextual factor in South Africa is the country's history of Apartheid. Starting in 1948, this system involved legal segregation between racial groups and pervasive discrimination. After decades of national resistance and the introduction of global trade sanctions, the system officially ended in 1991.

A major long-lasting effect can be seen in the continued high levels of inequitable outcomes experienced by the black population. To address this issue, a key national priority in South Africa is black empowerment. The 1998 Employment Equity Act focuses on ensuring equitable representation of racial groups among employees in companies with over 50 people (World Bank, 2018b). The 2003 BBBEE Act sought to transform the corporate world. However, most of the benefits ended up going to a small group of politically connected black elites (World Bank, 2018b).

The BBBEE Act was amended in 2013. The current BBBEE system involves a points system for businesses that measures black representation in firm ownership, at senior management level, and at other employment levels; procurement from BBBEE-compliant suppliers; and supporting SMMEs, skills development, and socio-economic development. BBBEE scores determine which firms are eligible for government contracts (World Bank, 2018b).

The effects of BBBEE are still unclear (World Bank, 2018b). Respondents in the interviews reviewed for this paper referred to this system as shaping their decisions. For example, one business spoke about it shaping buyer-seller relationships.

> When I speak to companies here in South Africa, and I'm going to be honest, now they ask for four things. The first thing is 'are you BEE certified?' Other three things are cost, costs, and costs. (F13-I20)

A respondent from a multinational company spoke about the importance of the policy.

> And we've got other challenges in South Africa as well. We have to consider the BEE Act. (F12-I19)

Black empowerment policies are leading to increased staff training programmes. When asked about being able to recruit staff domestically, one respondent described that the BBBEE Act led to them hiring people without the requisite skills and then providing training.

> Something in South Africa that is called triple-B EE … if I'm not hiring those people locally, then I'm getting into trouble with that regulation … and hence the reason we are investing in training those people ourselves to get on the level where we need to have them. (F17-I33)

However, another respondent described problems with the training that is taking place as a result of this programme.

> We have a triple-B EE, broad-based black economic empowerment framework whereby organisations score, and they have to spend a certain amount for skills development … In other words, it tries to motivate the right thing in terms of people being trained, which is a good thing. There's a certain percentage, I think it's linked to payroll or whatever it might be. So, fundamentally it's okay.
>
> The question is what are the people trained on? So, [what] happens invariably is that the easiest is to send someone on an Excel course, right. So, I got a budget, and what do I send them on? Excel. Everybody needs Excel. The proper training of sending somebody to become an artisan is very expensive. (F18-I34)

Overall, black empowerment is a key priority of South Africa's industrial policy. The Black Industrialist Policy is another national policy that uses financial and non-financial interventions. The policy seeks to accelerate the quantitative and qualitative increase in black industrialists' participation in the economy, selected industrial sectors, and value chains. It also seeks to create multiple and diverse pathways and instruments for black industrialists to enter strategic industrial sectors and value chains.

2.5.6 Additional Social Factors

Other social factors also shape the national innovation system. For example, challenges related to widespread poverty can affect the environment in which businesses function. Another factor is the quality of national industrial relations and the quality of existing jobs.

Furthermore, freedom of the press can have an effect on how businesses behave. Notably, South Africa ranked 28th out of 141 countries on this issue (WEF, 2019).

2.5.7 Environmental Factors

Another important contextual factor is the natural environment. Some places have to deal with extreme weather or natural disasters, and related risks can shape how businesses behave. In some cases, such pressures can lead to innovative practices. For example, one company described designing their products to deal with heat in South Africa.

> Basically, we're customising for the South African market. We would typically not drive an LED at full potential because it's too hot here. An LED that's imported would not last here because it drives at full potential. So, if you compare specifications on paper, their specifications are so much better. They get more life out of a watt than we can, but our light lasts longer. (F01-I01)

Environmental factors can also shape how production happens. One respondent described how South African workers can be more productive than those in Thailand because of lower levels of heat and humidity.

> Thailand's labour cost is even lower than ours. But the difference is … if you look at my efficiency of my workforce is far better than what they will ever be. And they know it as well. Because of the heat and the humidity in Thailand there's no way you will ever load an operator up there to 90% that we aim for. So, I use a lot less labour. They use a lot more because of the heat and humidity and whatever. And, and that's the only reason why in the end, we can compete with them on a cost per unit basis. (F08-I10)

3. Key Actors in South Africa's Innovation System

By virtue of being in the same country, national businesses share common experiences that can result in the development of common features (Nelson, 1995; Henderson et al., 2002; Nelson and Winter, 2002; Hess, 2004). This section focuses on characterising key actors in South Africa's innovation system. The first part focuses on firms. The subsequent three parts consider specific types of actors that provide services to firms, including public and private entities. These are financial service providers, research institutes, and other support service providers. Each sub-section begins with a discussion of research on the roles of the particular actor being considered, and then provides an overview of the role they play in South Africa. While this section focuses on firms and support services, they are not the only key actors in the innovation system. Notably, additional key actors are government agencies that set innovation-related policies (as discussed in the first paper in this working paper series [Alexander, 2022a], with key actors including the PC4IR, NACI, the Minister of Science and Innovation, the National Science and Technology Forum, DSI, DTIC, the Department of Communications and Digital Technology, DPME, and the Technology Innovation Agency [TIA]) and educational institutions (as discussed in Sub-Section 2.3.2).

3.1 Firms

The first actor considered is firms. To understand innovation processes and the emergence of 4IR in South Africa, it is important to consider the types of firms that exist and the potential that exists for new businesses to emerge. The organisation of individual firms is a key factor in shaping the innovation process. Crucially, individual firm characteristics shape how a firm can incorporate 4IR systems. Firm behaviours can differ by industry, size, ownership model, and age. Furthermore, firms' ability to adopt technology depends on their internal capacities (OECD, 1998).

3.1.1 Firm Characteristics and Innovation

As described in the first paper in this working paper series (Alexander, 2022a), the way firms are organised can shape how they carry out innovation. Innovation can happen through everyday experiences of learning. It can also happen through active efforts of searching and exploring.

While early models of R&D often involved research taking place in labs, the organisation of research within many businesses shifted during the 1980s and 1990s. A key change has been closing or downsizing large labs and increasing reliance on open innovation (Teece, 2010). Open innovation involves innovation taking place through a process that is not confined in one organisation. It is defined as "the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" (Chesbrough, 2006).

Several changes have been involved in the spread of open innovation (Teece, 2010). First, R&D activity in large companies was decentralised in attempts to bring it closer to users. In some cases, firms had high levels of R&D expenses without R&D departments, such as carrying out developments directly within manufacturing facilities. Second, companies increasingly sought to partner with universities. Third, corporations embraced a variety of internal and external alliances to facilitate R&D, manufacturing and marketing. The changes have resulted in a global distribution of innovation activities in some sectors, which include, for example, US and European companies setting up increasing numbers of R&D facilities in emerging markets.

Despite the expansion of open innovation, individual firms' characteristics can shape their potential to benefit through innovation. Firms can face multiple internal challenges related to adopting new technologies. A key challenge firms can face, particularly in developing countries, relates to the education and skills of workers (Zanello et al., 2016). Multiple studies have shown a connection between the level of education of staff and innovation. Low levels of education in developing countries can thus be considered a barrier to innovation. A related challenge that firms can face is that some businesses may be reluctant to send their staff for training due to the risk that they may then leave the company (Cunningham, 2018a).

A number of firm-level capabilities have been identified as being related to firms' abilities to innovate. Capabilities have been found to be more important than firms' structural characteristics (e.g., size, sector) when it comes to adopting digital technology (Lee et al., 2020). For example, firms with higher digital capabilities have been found to produce more sophisticated products (Banga, 2022).

Capabilities have been conceptualised in multiple ways. Kim (1997: 86) outlined the concept of technological capabilities, which are defined as "the ability to make effective use of technological knowledge in efforts to assimilate, use, adapt and change existing technologies … to create new technologies and to develop new products and processes". These technological capabilities can be considered as having three layers. First, production capability is the most basic and is needed to operate a facility efficiently. Second, investment capability is needed to establish new ventures. Third, innovation capability is needed for developing new goods and services. Each of these is expected to become more of a challenge for individual firms as countries reach higher levels of development.

An important element of technological capabilities is absorption. Technology creation and diffusion are interdependent and the capacities for creating and adopting new technologies are similar (OECD, 1998). Firms require absorptive capacity to exploit new technologies (OECD, 2019a). To benefit from knowledge, firms need the capabilities to access, absorb and combine multiple types of knowledge, covering topics such as finance, logistics, products, markets and production (Fagerberg and Srholec, 2017). Absorbing and developing 4IR technologies increasingly depends on data processing capabilities and using software that modularises tasks.

Openness and networking capabilities are further important factors involved in innovation (Zanello et al., 2016). Innovation has been found to be driven by the social capabilities or competences of the managers within the firm. Trust can be beneficial for innovation, as it can facilitate information exchange and collective knowledge creation. In addition, pathways for communication are important for facilitating knowledge diffusion.

Notably, making complex changes, such as those that can be involved in adopting 4IR systems, can be seen as requiring dynamic capabilities (Teece, 2010). These capabilities involve the capacity to orchestrate activities and resources, which can involve carrying out internal changes to adjust to external changes or changing the external ecosystem to create new markets. Dynamic capabilities can involve change routines (e.g., product development along a known trajectory) and analysis (e.g., of investment choices). However, they more commonly involve creative managerial and entrepreneurial acts (e.g., pioneering new markets).

Teece (2007) proposes that a firm's dynamic capabilities involve an ongoing set of activities and adjustments made up of three clusters. First, sensing, which involves the identification and assessment of an opportunity. Second, seizing, which involves mobilising resources to address opportunities and capture value. Third, transforming, which involves continued renewal. These capability clusters are required for firms to sustain themselves as markets and

technologies change. Elements of each cluster can be split into two essential classes of activities creating value and capturing value.

Firms can also face challenges relating to innovating when they are operating in conditions of uncertainty. High levels of rapid global technological development can make it riskier for businesses to invest in new ideas, which can dissuade investment in new technology (Cunningham, 2018a). Dynamic capabilities are particularly relevant during times of change (Teece, 2010). The introduction of 4IR is creating such periods of change in productive systems around the world. Consequently, firms' levels of dynamic capabilities will be important as the impact of 4IR creates larger scale changes. Notably, start-ups may not face the same barriers as existing firms when it comes to incorporating new and changing technologies, as more advanced technologies can be incorporated from the beginning.

Adopting new technology can involve cost and risk related to activities such as keeping up with technological changes, searching, experimenting, absorbing new information and learning (Lall and Pietrobelli, 2005; Cunningham, 2018b). Another type of hurdle that firms face in relation to innovation, particularly in developing countries, is that firms' possession of financial capital and information can also shape their ability to innovate (Zanello et al., 2016). These resources can be in a firm's possession or access to them can thus be an important factor (e.g., access to financing and credit or to information about which technologies may be the best option). Firm size can also be an important factor, which is often correlated with its level of resources.

Companies can build capacities and, in some cases, they can bring them in by buying new equipment or hiring new people. Notably, firms can bring in new skills and knowledge by hiring graduates who may have learned about new technologies (Cunningham, 2018a). Also notable is that, in some cases, firms buy other companies to absorb their skills and knowledge. However, Teece (2010) notes that dynamic capabilities cannot be bought and must be built internally.

Overall, advanced capabilities can take a long time to build. Firms' capabilities are developed on the basis of their interaction with their environment (Lundvall, 2016a; Fagerberg and Srholec, 2017). Developing country firms that are in emerging domestic industries often work in an environment with low capabilities (Lall and Pietrobelli, 2005).

Capabilities are a major factor among the challenges firms can face with innovation. As more capable firms are more equipped to adopt digital processes, they will likely be best able to adapt to 4IR changes. This dynamic indicates that 4IR policies can have impact by supporting lagging firms and lagging sectors (Lee et al., 2020).

3.1.2 South Africa's Firms

Large firms play a pivotal role in South African industry. In most sectors, a small number of large firms dominate (DTI, 2018). Large firms make up over 65% of all employment and

turnover,[12] which is similar to the levels found in the United States, United Kingdom and Australia and among the largest among OECD countries (Tsebe et al., 2018). Also, large firms make up about 5% of firms in South Africa's business sector (comprising mining; manufacturing; electricity and gas; water supply and waste management; construction; wholesale and retail trade; transport and storage; accommodation and food services; information and telecommunication services; finance and insurance services; real estate and rental activities; professional, scientific and technical services and administrative and support services), which is also among the highest in OECD countries (Tsebe et al., 2018).

Changing conditions have been leading to higher levels of concentration. Notably, firms have been focused more on mergers and acquisitions than on expanding and upgrading their production capacity (Bell et al., 2018). Ownership patterns are also changing, with an increase in foreign and local institutional investors (Bell et al., 2018).

SOEs are also an important type of business in South Africa. SOEs present a risk to government in terms of debt, as they underperform due to mismanagement, corruption, overstaffing and high wage bills (OECD, 2020). Another issue is that there is a lack of transparency related to SOEs' subsidiaries (MRP-STIIL, 2017). Furthermore, gaps exist in regulating relationships between the state as shareholder, directors, and the executive management of SOEs, with duplication of infrastructure, functions, and expertise occurring across ministries (MRP-STIIL, 2017). SOEs find the PFMA and Treasury regulations to be impediments to efficient functioning and find the cost of compliance to be high, with PFMA reporting requirements seen as exposing sensitive information to private sector competitors (MRP-STIIL 2017).

A number of characteristics can be identified about South African businesses by looking at global comparisons (see Figure 12). In a global comparison, South African businesses' behaviour was ranked below average in two categories: firms with websites and the number of professionals as a share of the total workforce. However, they ranked above average in the categories of number of technicians and associate professionals as a share of the total workforce, business use of digital tools, R&D expenditure by business, joint venture (JV)/strategic alliance deals, and investment in innovation (Gross expenditure on R&D [GERD] financed [% of total GERD] and performed [% of GDP] by business). While South African firms on average do not rank very highly in these comparisons, many individual South African businesses are cutting edge and globally competitive (Genesis Analytics, 2019).

As mentioned above, South African firms are very diverse. One respondent highlighted the differences between some firms based on size and age.

> We do have a lot of high-tech companies in South Africa, and I'm talking about small, small companies that develop quite high tech. But then there's a big gap between them and the low-tech run of the mill companies … most start-ups and small [firms] are more

[12] This figure excludes firms with fewer than 10 employees.

> flexible … more agile to sort of investigate new technologies. Large companies struggle to investigate new technologies, even though they've got big budgets. They're just slow beasts. (F13-I20)

Figure 12: Global Rankings of South African Firm Characteristics

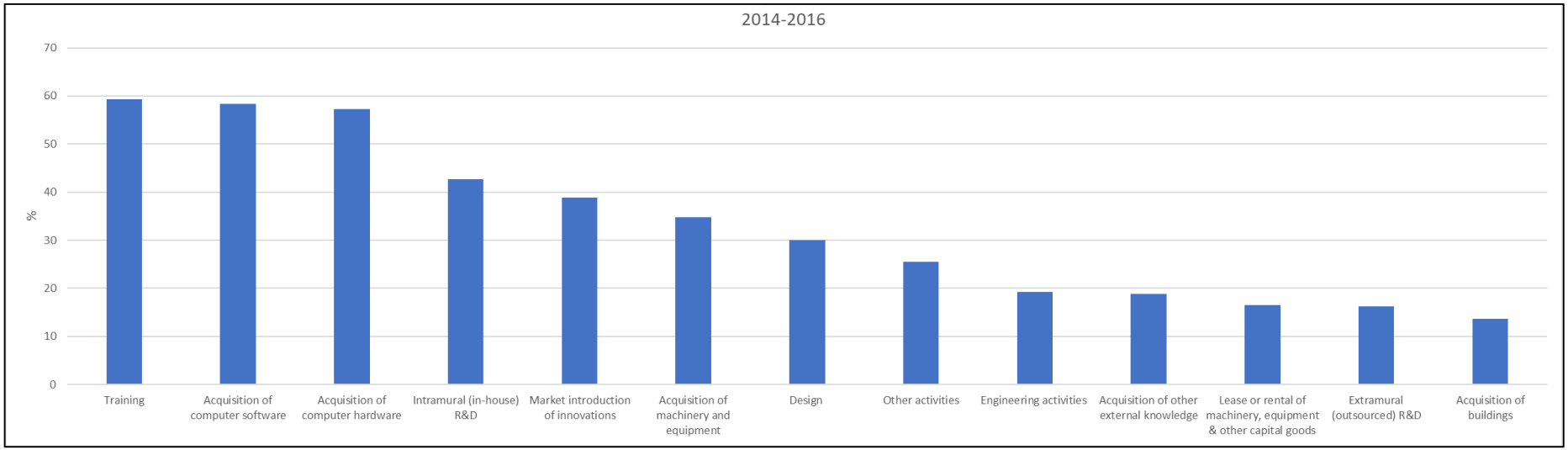
Sources: Cornell University et al. (2020); Portulans Institute (2020)

A survey of over 40 000 South African firms found that 70% of South African businesses had engaged in some form of innovation activity from 2014 to 2016 (CeSTII, 2020). This involved taking some sort of scientific, technological, organisational, financial, or commercial steps. Almost all of these firms (96%) introduced an innovation to their firms or markets during this period. In addition, innovation-active businesses employed 86% of the workforce. Innovation activities were diverse, with 48% engaging in product innovation, 42% in organisational innovation, 42% in marketing innovation, and 35% in process innovation. The engineering and technology, manufacturing, and trade sectors reported the greatest concentrations of innovation.

A number of common activities can be identified in businesses active in product and/or process innovation (see Figure 13). The most common activity was training, reported by 59% of businesses. The next most popular was acquisition of computer software and hardware. This was followed by in-house R&D. Most innovation expenditure was put towards the acquisition of machinery and equipment (see Figure 14).

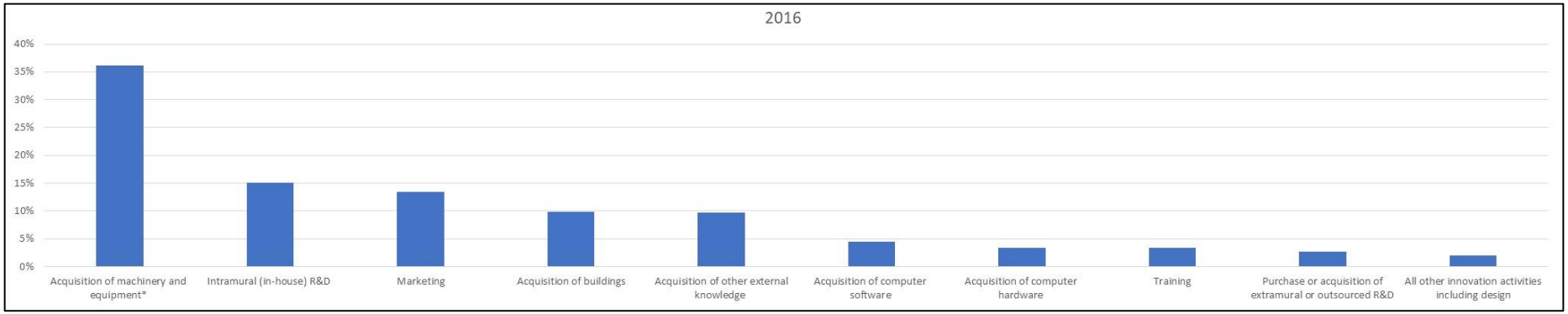
South African businesses also reported a variety of challenges related to innovation (CeSTII, 2020). Key challenges faced by innovation-active businesses include cost-related factors (lack of funds within your enterprise or group: 32%, lack of finance from sources outside your enterprise: 25%, lack of credit or private equity: 25%, innovation costs too high: 23%, difficulty in obtaining government grants or subsidies for innovation: 22%) and market factors (too much competition in your market: 20%, uncertain demand for innovation goods or services: 19%, and market dominated by established enterprises: 16%). Few firms reported facing challenges related to a lack of access to information (see Figure 15). However, a lack of information was a more commonly reported challenge for non-innovation-active firms.

Figure 13: Innovation Activities of Product and/or Process Innovation-active Businesses



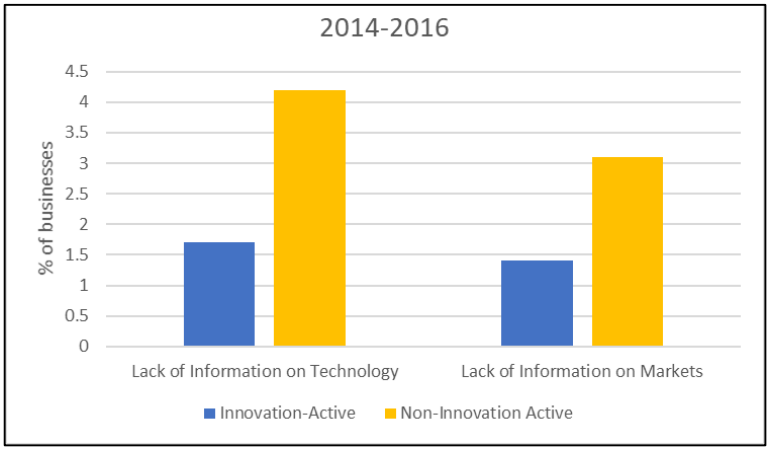
Source: CeSTII (2020)

Figure 14: Expenditure by Type of Innovation Activity



Source: CeSTII (2020); * Excludes acquisition of equipment for R&D

Figure 15: Information-related Barriers to Innovation



Source: CeSTII (2020)

3.2 Financial Service Providers

As discussed in the first paper in this working paper series (Alexander, 2022a), access to finance is an important factor shaping innovation. Consequently, the characteristics of the national financial ecosystems are an important factor to consider when looking at the innovation system. Key actors involved can be private firms and public organisations.

3.2.1 Financial Ecosystems

Availability of funding is an important condition shaping innovation processes. Funding can come through loans, investments or grants. The funding options available can shape the decisions that firms make. In developing countries, limited financial resources create a key barrier to innovation across different settings and geographical areas (Zanello et al., 2016).

Innovation is a lengthy and cumulative process, and the roles of different actors change across each stage (Mazzucato, 2018). Early stages often have high risk and low returns. Then, if innovation is successful, returns can increase substantially. Finally, returns flatten out. Considering breakthrough innovations, the early stages tend to have higher involvement of public R&D (institutes or universities), capital funds, government spending linked to public procurement, and innovation funds inside public banks. Venture funds have been found to have little interest in exploratory research, which leaves basic and applied research in some areas with limited funding options (Teece, 2010). After these high-risk patient funds have been invested, private funding plays more of a role, from, for example, venture capitalists.

Different types of firms are more or less likely to look for external sources of innovation funding (Christensen, 2010). Large firms often fund risky innovation processes internally, but this option is less available for small and medium firms. For technology-based firms, R&D costs can be high and products can have short life cycles, which necessitates looking for external funding. Private venture funds began to transform the US industry by the 1980s, particularly in the biotech and information technology sectors, with increasing funds and professionalism

of entrepreneurs (Teece, 2010). These firms often grew out of large R&D labs, with some new companies moving forward with technology that incumbents had rejected (Teece, 2010).

Differences also exist in the behaviour of firms in different countries. While companies do have access to international financial options, the nature of national financial systems continues to play a crucial role in national innovation systems (Christensen, 2010). Funding options can also differ across national systems. Particularly, developing countries have often been found to have a lack of available financial resources for businesses. In surveys, firms in lower income countries are more likely to report finance as a constraint than those in higher income countries (Bloom et al., 2010). Overall, in developing countries, higher levels of research funding comes from the public sector (Brundenius and Göransson, 2011; Primi and Toselli, 2020).

Policy makers shape the forms and levels of government funding that are available. They also shape the regulatory environment in which private funders operate. Policy makers can try to encourage longer term investment through measures such as creating a financial transaction tax and founding new financial institutions, such as mission-oriented state investment banks that provide long-term finance for high-risk investments needed for exploratory activities (Mazzucato, 2018). In addition, government policies can use various tax incentives to help businesses engage in innovation processes.

3.2.2 South Africa's Financial Ecosystem

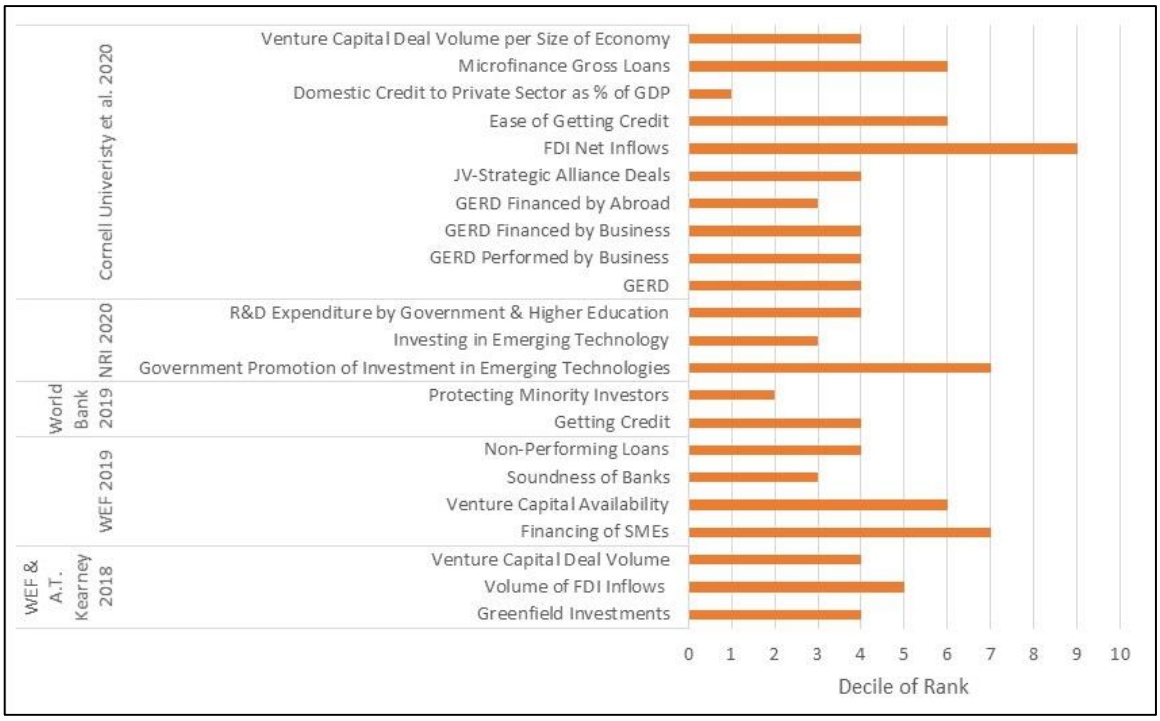
In South Africa, a number of private and public sector funding options are available for businesses. However, access to these funds has been found to be uneven. Overall, underfunding has been identified as a major constraining factor affecting the performance of the national innovation system (DST, 2019). While wide-ranging financial incentives are available, they are not systematically structured or based on evidence-led design (Genesis Analytics, 2019). Overall, gross domestic expenditure on R&D as a percentage of GDP was 0,83% in 2017/2018, which is below the 1,5% government target (NACI, 2020).

South Africa ranks well in global comparisons of many aspects of the funding ecosystem (see Figure 16). Notably well-ranked aspects include venture capital deal volume per size of economy, venture capital deal volume, domestic credit to private sector as percentage of GDP, GERD financed by abroad, GERD performed by business, overall GERD, investing in emerging technology, protecting minority investors, soundness of banks, and greenfield investments. Categories with particularly poor rankings are ease of getting credit, FDI net inflows, government promotion of investment in emerging technologies, and financing of SMEs.

The World Bank (2018a) found that availability of early and growth-stage financing was increasing, yet SMEs generally have difficulty accessing credit. This growth is mostly due to an increase in the number of venture capital companies, a sector that has been bolstered through tax incentives. However, these venture capital companies can only invest in firms

registered in South Africa and lack capacity, inclusiveness and critical size. They rarely invest in digitally enabled businesses. Digital start-ups continue to experience finance gaps throughout their development processes (World Bank, 2018a).

Figure 16: Global Rankings of Elements of South Africa's Funding Ecosystem



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

One area to consider is the funding that is available for public sector research. University funding from public expenditure increased from 0,7% of GDP in 2006 to 0,9% in 2016 (NACI, 2020). While this is a positive change, a number of problems exist related to the funding of public research. For example, tuition fees as a share of the total income received by HEIs increased to 37% in 2015 from 27% in 2006 (Genesis Analytics, 2019). Overall, a lack of available funding in recent years has limited investment in technological infrastructure at public education institutions (Cunningham, 2018b). Public education institutions are often incentivised to do commissioned research or sell services to companies that can afford to pay, which comes at the detriment of technological extension services, product testing and other services (Cunningham, 2018b).

MRP-STIIL (2017) provides a variety of information on the topic of public research funding. One concern is that industry's contribution to research and development at HEIs, which has historically surpassed that of governments, is declining. Another concern is that the success rate of research grants is decreasing and international donor funding is unpredictable and decreasing across Africa. Funding sources can shape the research agendas of public and private research institutions. SABS, the South African Medical Research Council (MRC), and the NRF report that their research agendas are shaped by various national plans (e.g., the

National Development Plan, the Industrial Policy Action Plan [IPAP], the National Research and Development Strategy, and the Ten-Year Innovation Plan). CSIR, the Human Sciences Research Council (HSRC), and Mintek's[13] agendas are shaped by the availability of funding, which can exclude potentially important social research projects from happening because of a scarcity of resources. Public universities face severe funding challenges when they do not have private sector financing or access to competitive grants. Funding models for academic institutions based on research outputs gives an advantage to historically advantaged institutions. Some South African research institutions report partnering with state-owned enterprises and private institutions, while the NRF and HSRC report that they are not permitted to form partnerships to create commercial opportunities. Nevertheless, some universities get global funding for research. Furthermore, some research institutions get income through licences and royalties.

Another area of funding is related to supporting individual students. This can shape the level of skills created in the workforce. A challenge in this area is that bursaries are available for undergraduate students, but do not support postgraduate studies (MRP-STIIL, 2017).

Another area to consider is funding for businesses. Considering the areas of access to innovation finance and conditions that make innovation finance effective, most measures are improving (Genesis Analytics, 2019). Forms of funding have also been changing. While FDI net inflows are low globally, FDI has grown significantly over the last 30 years (see Figure 17). In addition, while levels of domestic credit from the financial sector saw substantial growth from 1990 to 2010, levels have declined over the last ten years (see Figure 18).

Genesis Analytics (2019) found that investment in R&D has been falling because of the falling contribution of the business sector. Businesses have been found to be less willing to engage in risk over the last decade. A large share of firms was found to be taking a "wait and see" approach to technologies. Also, from 2008/2009 to 2017/2018, the contribution from foreign funding dropped from 11% to 3% (NACI, 2020). To facilitate transformation towards higher productivity activities, the rules for South Africa's markets need to be changed to incentivise investment in skills and productive capacity (Bell et al., 2018).

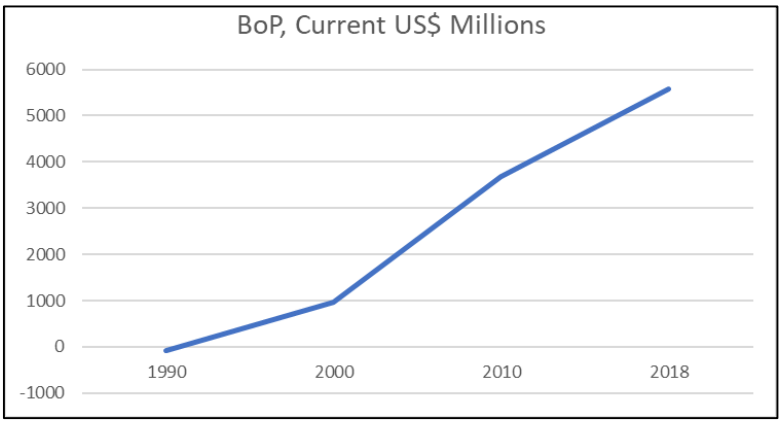
Government funding of business sector R&D has also declined significantly in recent years (NACI, 2020). In 2008/2009, government provided 21% of business-sector R&D funding but, by 2017/2018, government funding only made up 2%, with the value of funding dropping from R2 600 million to R370 million. The government has multiple innovation funding schemes involving DTI, the Industrial Development Corporation of South Africa (IDC)[14], the

[13] Mintek is a public organisation focused on research and development, technology transfer, the promotion of mineral technology, and encouraging the establishment and expansion of industries in the field of products using minerals.

[14] Run by the DTIC, the IDC is a national development finance institution aimed at promoting economic growth and industrial development. They identify sector development opportunities aligned with policy objectives and

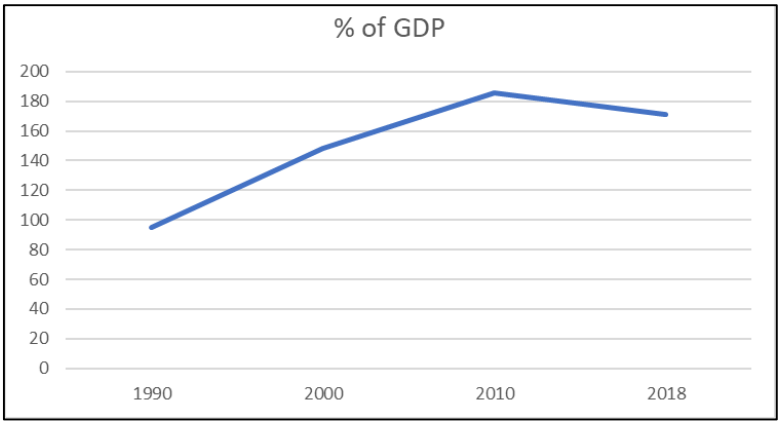
Human Resources for Industry Programme (THRIP), the Support Programme for Industrial Innovation (SPII), the South Africa Revenue Service (SARS), DST, DHET, and the NRF (MRP-STIIL, 2017). Both universities and industry can benefit from tax incentives to support research and innovation, notably section 11D of the Income Tax Act of 1962 (MRP-STIIL, 2017). The management of funding for early pre-commercialisation and commercial implementation is currently divided between different agencies and departments (TIA, IDC, DST, and DTI), without a coordinating system to match needs to appropriate funding mechanisms or to prevent duplication (MRP-STIIL, 2017). The merger of regional funding management agencies into the TIA has been complex, and has created challenges in recent years for commercialising viable technologies (MRP-STIIL, 2017).

Figure 17: Foreign Direct Investment, Net Inflows



Source: World Bank (2021)

Figure 18: Domestic Credit Provided by Financial Sector

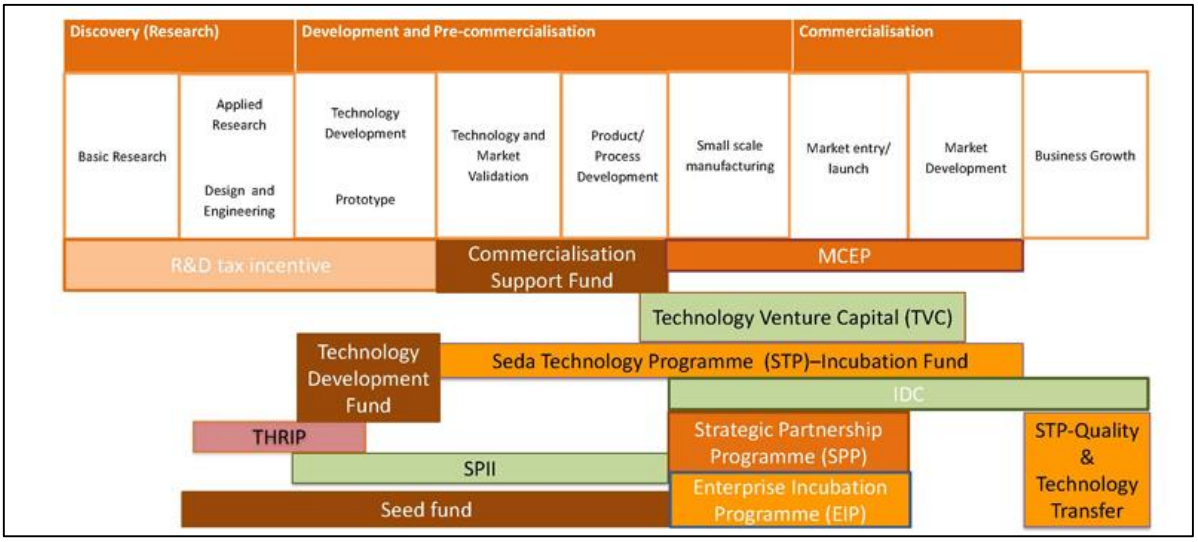


Source: World Bank (2021)

A number of funds are available to support different stages of the innovation process. Figure 19 provides an overview. This overview outlines which stages in the innovation process can be supported by the funding.

develop projects in partnership with stakeholders. Their subsidiary, the SEFA, promotes entrepreneurial development for SMEs.

Figure 19: Innovation and Technology Funding Instruments



Source: DTIC (2021)

Public policy has also helped to secure greater levels of private investment in industry. For example, the Automotive Incentive Scheme helped to secure investment commitments of over R45 billion by auto assemblers and component suppliers, retaining 38 267 jobs (DTI, 2018).

Another source of funding reported in the interviews was supply chain partners (S09-I40). Businesses were reported to receive loans for upgrading from their buyers. These loans are based on ongoing firm relationships.

Finally, venture capital (provided by investment banks, individual investors or firms specifically dedicated to venture capital investments) declined from 2008 to 2012, but has since experienced a period of growth, with 181 venture capital deals reported in 2018 (NACI, 2020). Venture capital in 2018 was mainly from independent funds (35%) and captive government funds (34%), with other sources including captive corporate funds (16%), other captive funds (11%), and angel investors (4%). In 2018, the largest portion of venture capital funding was provided for the start-up stage (41%) (see Figure 20). The industry that attracted the most venture capital funding was manufacturing (14% of funding provided).

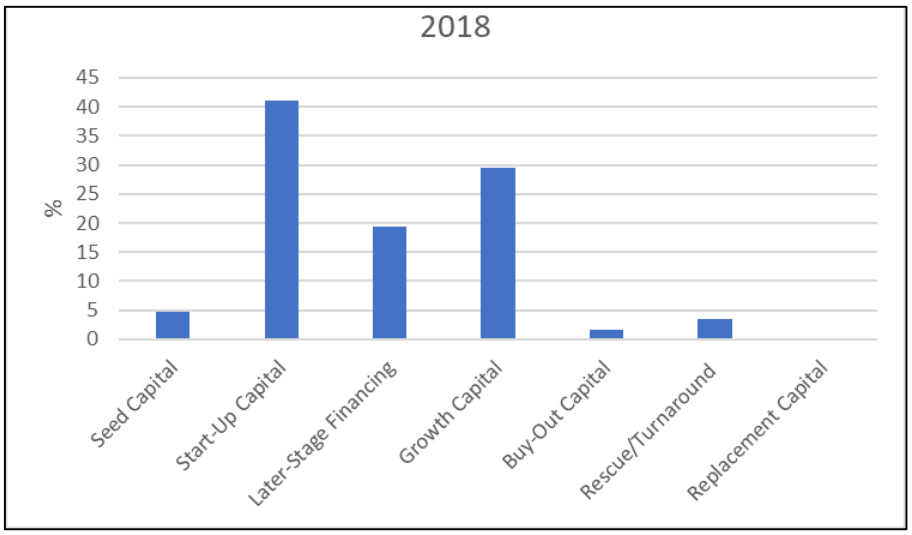
Considering firms' self-reported sources of financial support, the most common source of funding for innovation reported for innovation-active businesses was using their own funds (77%) (see Figure 21). Government financial support was only accessed by 2%. SOEs involved in research get funding from internal investment, commercial partners, and public sources (MRP-STILL, 2017).

About a third (34%) of innovative-active businesses[15] reported being aware of government financial support for innovation, with those in industry more likely to have awareness (42%)

[15] Innovation-active business: a business with innovation activities from 2014 to 2016, including ongoing and

than those in services (29%) (CeSTII, 2020). Non-innovation active businesses had much lower levels of awareness (10%). The most common source of funding sought by businesses to support innovation were incentive grants (8%), and a few applied for loans or guarantees (2%) and equity financing or venture capital (0,3%) (see Figure 22). The most common reason for not accessing government funds was that the process is too difficult (38%), followed by time constraints (19%), and risk of exposure of confidential information (9%). Also, compared to a sample of 50 other countries, people in South Africa were less likely to informally invest in businesses started by someone else (Bosma et al., 2020).

Figure 20: Distribution of Venture Capital Funding



Source: SAVCA's Venture Capital Industry Survey, as cited in NACI (2020)

In CeSTII's (2020) innovation survey, firms expressed challenges with multiple issues related to the costs of innovation (see Figure 23). Challenges experienced can be seen in the difficulties described by a respondent with getting funding for an innovative project.

> When I started this project, something I thought was going to be more my role [pushing technology forward]. But then I realised, okay, funding … is also quite difficult to come by, especially for something that is sort of niche like this is. It's not, let's say a direct application or usage application at the moment, not a real need. (F13-I21)

Genesis Analytics (2019) found that, overall, established firm financing was on track. However, a large, but decreasing, gap was found related to start-up financing. The R&D tax incentive scheme has been found not to be effective for digital SMEs or start-ups with long cost-recovery cycles, and the VAT and corporate tax policies also are not supportive of high-growth digital start-ups, which cannot claim back VAT paid to vendors in the early stages (World Bank, 2018a).

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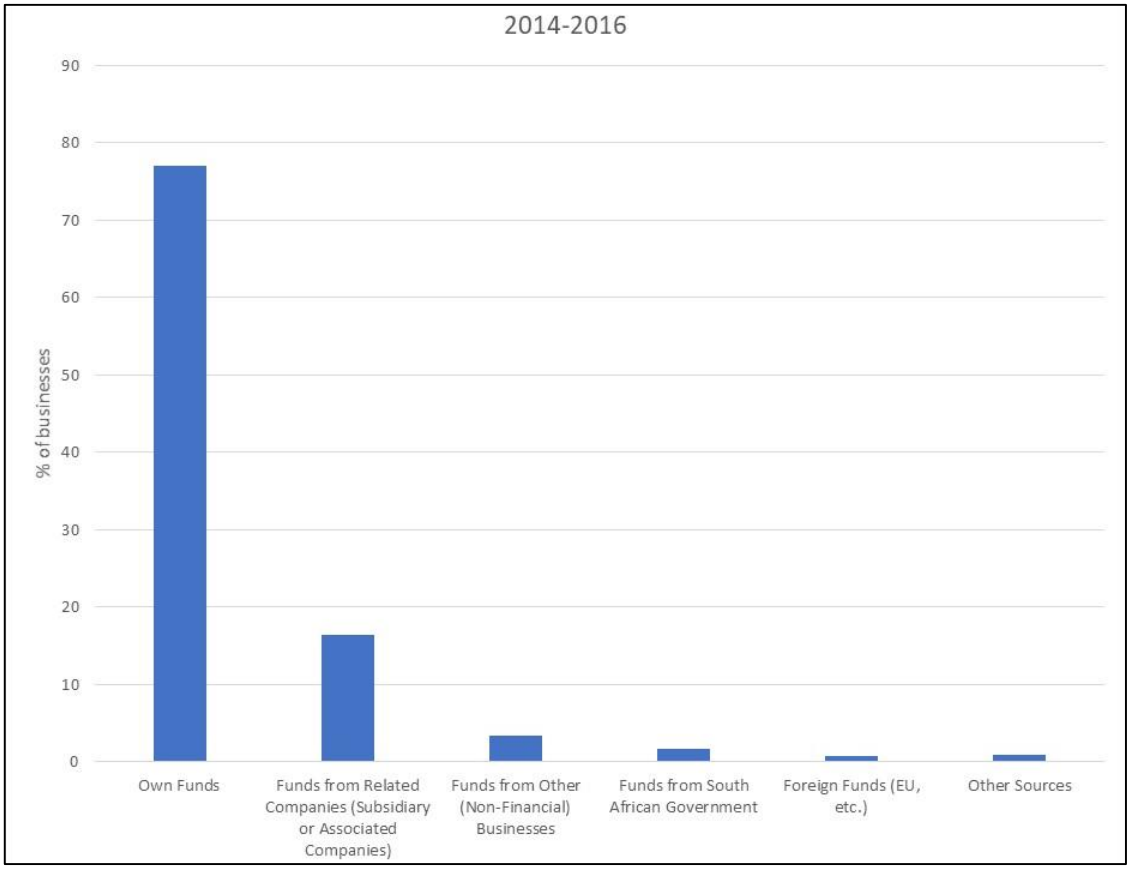
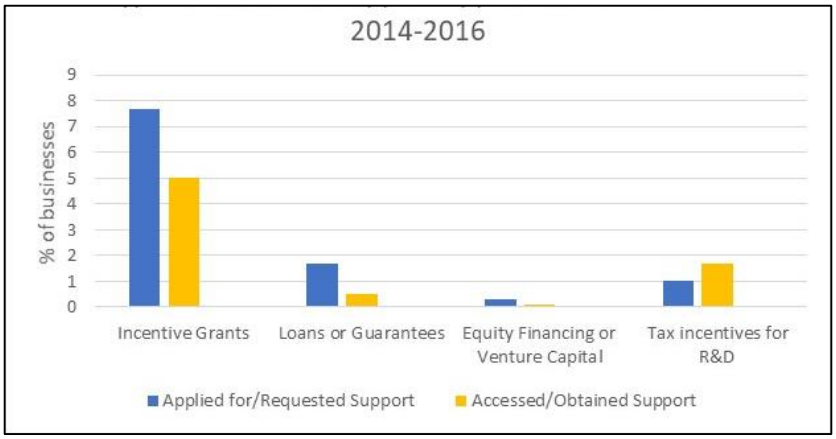
abandoned activities (i.e., it does not matter if the activity resulted in the implementation of an innovation or not); non-innovation-active business: a business without any innovation activities; innovative business: a business that implemented an innovation from 2014 to 2016 (CeSTII 2020).

Figure 21: Financial Support for Innovation Activities for Innovation-active Businesses



Source: CeSTII (2020)

Figure 22: Types of Financial Support Applied for and Accessed[16]



Source: CeSTII (2020)

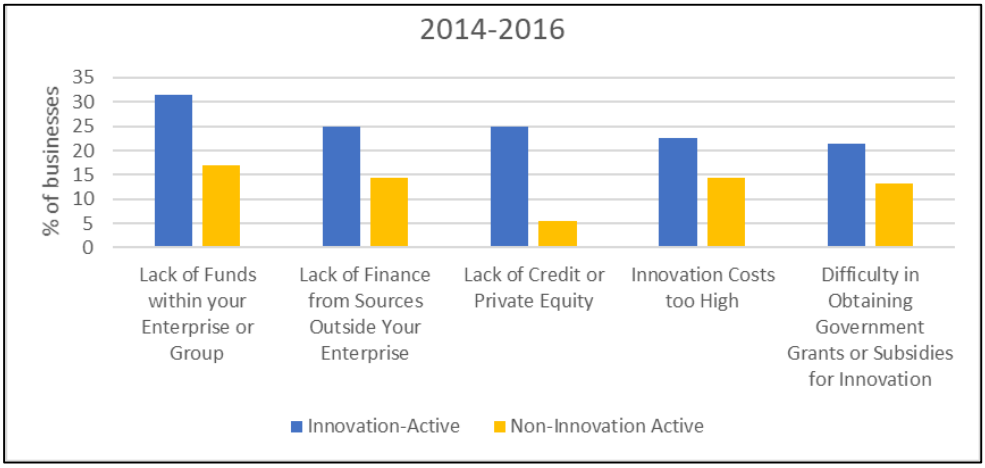
Genesis Analytics (2019) identified a need for more support for start-ups. They said that government can help through multiple measures. These include providing funding for start-ups, using tax incentives to direct early-stage funding to start-ups, and providing incentives

[16] Note: Missing data led to a higher proportion of enterprises that accessed financial support for innovations than those that applied for it.

that direct funding towards innovation and R&D, reducing financial barriers to educational pathways for key groups.

While difficulties experienced by small businesses in accessing finance is an overall problem, one particular concern is that SMMEs are mostly owned by black South Africans, while larger firms are mostly owned by white South Africans (Bhorat et al., 2018). This results in a lack of access to financial products by smaller firms being a detriment to black empowerment, which the government has tried to address with targeted SMME funding programmes. However, these programmes have been fragmented and have had unintended exclusions related to eligibility criteria and the granting process (World Bank, 2018b).

Figure 23: Cost Related Barriers to Innovation



Source: CeSTII (2020)

While the financial services in South Africa compare favourably with those of other upper middle-income countries, and even can compare to some developed countries, a divide exists between access available to larger and smaller firms, with smaller firms having limited access (Newman et al., 2019). Small businesses may have less access due to a lack of awareness of options to obtain finance or because of an inability to qualify for credit (Newman et al., 2019). Nevertheless, micro-firms overall are more indebted than large firms (Newman et al., 2019). To address problems of access, in 2019, the Minister of Small Business Development introduced new measures to make funding more accessible and affordable for small businesses. Elements include making funding available through centres run by the ministry and committing to quick turnaround time; introducing common national funding templates; creating the Small Business Innovation Fund, which will provide grants and loans with an aim to lower costs for small businesses; and providing funding for business incubators (Bosma et al., 2020).

Overall, a number of policies have been implemented that are related to supporting funding for R&D. Specifically, DST (2019) sets a goal of gross expenditure on R&D reaching 1,5% of GDP within a decade and outlines how multiple organisations can contribute to achieving it. Reaching this goal will involve contributions from provincial and local governments based on

national government setting targets in their budgets. Development finance institutions will have additional funding for industrial innovation activities. STI-linked FDI will be sought. A sovereign fund will be set up to leverage co-investment from the public and private sectors. To improve funding efficiencies, some activities of existing institutions (e.g., TIA, National Intellectual Property Management Office [NIPMO], IDC, and NRF) will be harmonised and administrative procedures will be improved through simplified application procedures, shorter turnaround times and standard evaluation approaches.

Tax incentives are also used to promote innovation. Newman et al. (2019) explored the uptake of three types of tax policies related to innovation. One is the Income Tax Act Section 11D R&D incentive, which was introduced in 2006 with the objective of encouraging investment in research; the second, Section 12E of the Income Tax Act, provides a depreciation allowance; and the third, Section 12H of the Income Tax Act, provides a learnership allowance that provides deductions to employers for learnership agreements. Larger firms are more likely to benefit from these initiatives, with over 25% of large firms having learnership incentives and 32% having depreciation allowances, while micro- and small firms are hardly reached. The use of these programmes also varies by sector. In addition, the 12I Tax Allowance Incentive is designed to benefit new industrial projects and expansions or upgrades of existing industrial projects by supporting both capital investment and training.

Finally, multiple forms of financial support are also currently offered through government programmes. Financial assistance is provided by Manufacturing Competitiveness Enhancement Programme (MCEP), part of IPAP, which provides grants and loans to manufacturing firms and clusters of firms for upgrading production facilities, processes, products and people (Andreoni and Tregenna, 2020). THRIP provides cost-sharing grants for applied R&D in science, engineering and technology. SPII supports the development of innovative products and/or processes, focusing specifically on the development phase, which begins at the conclusion of basic research and ends at the point when a pre-production prototype has been produced. South Africa has two industrial financing institutions, the IDC and the Export Credit Insurance Corporation (ECIC). The IDC provides loans and equity funding and ECIC underwrites export credit loans and investments abroad. The MRP-STIIL (2017) notes that the current government incentive schemes that are targeted at both public and private institutions are mostly spent on HEIs and science councils.

3.3 Research Institutions

Overall, technological capability has an important national dimension and countries often put a large amount of public resources into developing it (Fagerberg and Srholec, 2017). This sub-section focuses on the role of research institutions in the national innovation system. While these can be organisations dedicated to research, they also include many HEIs (which were also discussed in Sub-Section 2.3.2). These institutions can be public or private.

3.3.1 Research Ecosystems

A number of key trends related to knowledge transfer from universities and public research institutions (PRIs) can be identified (see Box 5).

Box 5: Key Trends Related to Knowledge Transfer from Universities and PRIs

- Creation of new intermediary organisations (e.g., R&D centres for science-industry collaboration, business incubators, and regional technology transfer organisations)
- Greater emphasis on knowledge co-creation, including industry, civil society, and research organisations (e.g., sharing of resources, engaging in joint projects, long-term research partnerships, joint labs, and two-way mobility of human capital [public sector researchers temporarily joining industry and industry researchers temporarily joining universities])
- Knowledge transfer processes are changing through digital transformation (e.g., university-industry collaboration is growing through online communities of experts, tournaments, open calls, crowdsourcing; and, research results and data are more easily available through digital networks)

Source: OECD (2019b)

As well as training students, universities play multiple roles in a community. Services provided by universities to regions include commercialisation and valorisation of knowledge, volunteering, technology transfer, institutional collaborations, media commentary and contributing to regional socio-economic development (e.g., through teaching and research, retention strategies for alumni, participation in public policy debates, providing analysis and opinions to policy actors, and attracting new actors to a region) (van den Broek et al., 2019). Universities can also be important political institutions, particularly in developing countries (Arocena et al., 2018). Teaching and research roles can also be intertwined, as research activities can enrich teaching, and teaching can affect society in ways that enrich research (Arbo and Benneworth, 2007).

Arocena et al. (2018) propose that universities can play a key role in promoting knowledge democratisation. They note the value of extension activities (providing services for disadvantaged social groups) carried out by universities, which has been a tradition in Latin American universities. Also, they provide the example of Swedish universities being formally given a “third mission” to support economic and social development for the broader public. Arocena and co-authors describe developmental universities as having three missions, namely teaching, research and cooperation for development, which would make them active partners in innovation systems. While universities’ extension services could be seen in some cases as a one-way transfer of knowledge from the university to the community, Arocena and co-authors highlight the importance of seeing the interaction as a two-way process, in which knowledge sharing is reciprocal and cooperative problem-solving is pursued.

Notably, universities and PRIs can play pivotal roles in knowledge creation. Demand from industry is related to the kinds of knowledge firms in the private sector require, which can include technology and other types of knowledge streams. University-society knowledge transfers involve not only applied science laboratories, but also social, life and management

sciences, as well as arts and humanities (Hawkings et al., 2007). Benefits of publicly funded research can be considered to be distributed across seven different areas. These include increasing the stock of useful knowledge, training skilled graduates, creating new scientific instrumentation and methodologies, forming networks and stimulating social interaction, increasing the capacity for scientific and technological problem-solving, firm creation, and provision of social knowledge (Salter et al., 2000). Examples of knowledge transfer channels include academic spin-offs, collaborative research, patenting and licensing of university inventions, academic consultancy, and networking (OECD, 2019b). Academics can engage with external organisations in diverse ways (see Table 1).

Different forms of university and PRI engagements with society have their own dynamics. For example, academic start-ups can introduce new technology into an economy and directly create jobs. In an OECD (2019b) study, academic start-ups were found to account for about 15% of all start-ups, with the share being higher in the science-based technology fields. Also, patents were more likely to be filed by PhD students' and academic's start-ups.

Table 1: Ways Academics Can Engage with External Organisations

People based	*Problem-solving*	*Community based*
• Attending conferences • Participating in networks • Giving invited lectures • Sitting on advisory boards • Student placements • Employee training • Standard-setting forums • Curriculum development • Enterprise education	• Joint publications • Joint research • Informal advice • Consultancy services • Research consortia • Hosting of personnel • Contract research • Setting up physical facilities • External secondment • Prototyping and testing	• Lectures for the community • School projects • Museums and art galleries • Performing arts and related • Public exhibitions • Social enterprises • Heritage and tourism • Community-based sports

Source: Hughes et al. (2016)

In terms of technology, Cunningham (2018b) highlights the potential benefits of public technology demonstrations. These demonstrations can be carried out by universities or PRIs. They can promote the adoption of new technology by providing a forum to see or use technologies and make companies think that their competitors might be using them. Experimenting with new technology can provide benefits related to finding new markets, business models, and capabilities.

As evidenced by the growth in jointly filed patent applications, HEIs and PRIs increasingly engage in knowledge co-creation with private sector actors (OECD, 2019b). PRI patent applications to the European Patent Office (EPO) (based on 35 OECD countries and China) increased fivefold between 1992 and 2014. Yet, even at the 2014 levels, these accounted for only 1,6% of total applications. However, the number of EPO patent applications jointly filed by PRIs and industry grew faster than university-owned patents applications. By 2014, 43% of these applications were filed jointly with industry actors, compared to 24% of 1992

applications. In the same dataset, considering all applications from 1992 to 2014, 50% of applications were based within 30 km of a research university.

Flows of people receiving education and training are also an important consideration. International movements of people related to their education has been seen as "brain circulation", which provides broad benefits, and as "brain drain", which results in highly educated people moving to countries with more advanced industrial systems (Arocena et al., 2018). Another key issue relates to where graduates end up working. Some evidence shows that, when social science graduates enter private industry, they can have a positive influence on innovation, including in the ICT sector (OECD, 2019b).

However, being able to engage in diverse forms of public engagement is not inevitable. Hughes et al. (2016) outline potential barriers to academics' external interactions as lack of time; bureaucracy/inflexibility of university administration; insufficient resources; insufficient rewards; unwillingness of external organisation to meet full cost; identifying partners; poor marketing/technical/negotiation skills in university; lack of interaction resources in external organisation; lack of training in marketing, technical or negotiation skills; lack of external interest; lack of experience in external organisation; differences in timescale; reaching agreement on terms (including intellectual property); and cultural differences.[17] Furthermore, key governance practices that influence the transfer of knowledge from universities and PRIs to industry can be identified (see Box 6).

Box 6: Key Governance Practices that Influence Transfer of Knowledge from Universities and PRIs to Industry

- In many OECD countries, universities and PRIs are autonomous. They have their own support programmes for knowledge transfer, such as creating their own function units (e.g., technology transfer offices) and legal entities (e.g., spin-offs); make staffing decisions; and establish rules related to researchers receiving IP revenues.
- Some countries have performance contracts for PRIs and universities linked to national innovation objectives, such as having targets related to knowledge transfer.
- In most OECD countries, industry and civil society representatives shape how universities engage with industry by participating in the governing boards of universities and participating in research and innovation councils.

Source: OECD (2019b)

Key trends of 21st-century higher education are massification, accountability, privatisation and marketisation (Altbach, 2003). These trends have different consequences in different regions, with researchers in developing countries being less able to influence and play leadership roles in established academic communities and often having to depend on industrialised countries for recognition and funding opportunities (Altbach, 2003). In addition, changes to education systems in developed countries have been found to be adopted later in

[17] Listed from highest to lowest level of impact, as identified in a survey of over 18 000 UK-based academics.

developing countries, such as those related to assessment and the use of technology (Echávarri, 2016; Echávarri and Peraza, 2017). As noted by de Otero (2020), individual countries' reactions to global discourses are shaped by national traditions and strategies. Also, the provision of free or fees-based higher education is a highly debated topic (Arocena, et al. 2018).

Arocena et al. (2018) propose that, when countries have weak innovation systems, universities have the potential to be "system builders". However, they note that this role is challenged because only a low proportion of young people reach higher education and there is a scarcity of jobs for graduates. Less knowledge is produced in developing countries, but universities are often more important producers in such countries (Arocena et al., 2018). Furthermore, as mentioned above, the private sector contributes more to R&D in developed countries compared to a higher proportion of public sector funding in developing countries.

In addition, developing countries often face a challenge with businesses not having enough demand for knowledge-production services (Casadella and Uzunidus, 2017; Arocena et al., 2018). Developing countries tend to have fewer connections, with low flows of information and knowledge from universities and R&D labs to external actors (Casadella and Uzunidus, 2017). In the least developed countries, innovation is concentrated more in learning through practice, use and interaction, and is often not formally expressed in firms' strategies (Casadella and Uzunidus, 2017).

A diverse set of actors shape the behaviour of universities. In the 21st century, policy makers have increasingly sought to manage how universities bring value to their host societies (van den Broek et al., 2019). However, multiple societal partners can be considered to have a claim on receiving benefits from a university, which include diverse groups of students, campus-managed housing, research and consultancy partners (such as firms and other universities) and current or potential funders (van den Broek et al., 2019).

Twenty-one types of policy instruments that are designed to support knowledge transfer can be identified (see Table 2). In addition to type (financial, regulatory, or soft), the policies can be classified into who they primarily target (firms, universities/PRIs, individual researchers, or research groups), the type of knowledge transfer being promoted, and their orientation (supply-side, or demand-side).

The effect of each instrument is dependent not only on its own features, but also on the types of other policies that are in place (OECD, 2019b). Positive interactions are created by preconditions (sequence of policy implementation), facilitation (one policy supporting the effectiveness of another), and synergy (multiple policies simultaneously supporting each other). Negative interactions include contradiction (multiple policies decreasing the effectiveness of each other) and complexity (multiple policies creating confusion and increasing administrative costs). Key governance practices that shape knowledge transfer from the public sector include the increasing autonomy of universities and PRIs (allowing them to shape their own knowledge transfer programmes), increasing involvement of

business and civil society actors on university boards and research/innovation councils, and increasing use of performance-based funding rewarding universities for engaging with industry (OECD, 2019b).

Table 2: Policy Instruments to Support Knowledge Transfer

Financial instruments	*Regulatory instruments*	*Soft instruments*
• R&D and innovation subsidies or grants • Tax incentives • Financial support to academic spin-offs • Grants for IP applications • Financial support to recruit PhDs or post-docs • Financial support to host industry researchers • Public procurement • Innovation vouchers • Public-private partnerships creating joint research laboratories • Performance-based funding systems • Funding of infrastructures of intermediaries	• IP rights regime • Regulation of spin-offs founded by researchers and students • Career rewards for professors and researchers • Sabbaticals and mobility schemes • Open access and open data provisions	• Awareness-raising • Training programmes • Networking • Collective road-mapping and foresight exercises • Voluntary guidelines, standards and codes of conduct

Source: OECD (2019b)

The OECD (2019b) provides a number of recommendations for supporting knowledge transfer and innovation processes (see Box 7). These can be implemented in different ways in diverse contexts.

Another important area to consider is technology policy. Such policies cover aspects such as technology imports via licensing and FDI, and incentives for local R&D and training. Technology organisations provide services such as metrology, standards, testing and quality; knowledge-Intensive business services; R&D; and training. These organisations can be run by the government; government founded and run autonomously; or run independently by industry associations or other private actors. In developing countries, governments often play a large role in these areas (Pietrobelli and Rabellotti, 2011).

Box 7: Recommendations for Supporting Knowledge Transfer and Innovation Processes

- Policies should be customised to specific industries and national needs
- Higher education institutions and PRIs should use online methods for knowledge transfer (e.g., online communities of experts, open calls and crowdsourcing)
- Move beyond a focus on knowledge transfer and also promote co-creation among multiple stakeholders from industry, civil society, research and government, which can be facilitated with online methods and aim to solve societal challenges
- Policies should be coordinated and streamlined, with interactions considered
- HEis and PRIs should have autonomy to organise knowledge exchange activities, while stakeholder consultation should be promoted and industry and civil society should be encouraged to participate in governing boards

- Policy makers and researchers incorporate new sources of data for measuring knowledge transfer (e.g., text mining)
- Support PRIs in appropriate knowledge transfer activities, moving beyond a focus on patents to include promoting spin-offs and student entry into industry (supported by aligning curricula with industry needs)

Source: OECD (2019b)

3.3.2 South Africa's Research Ecosystem

South Africa's research ecosystem has strengths and weaknesses. However, it is important to note that South Africa has multiple deficiencies in its education and research systems. These are related to the production of a workforce that meets the need to develop 4IR and the provision of publicly funded research outputs.

Multiple global assessments have looked at aspects of South Africa's education and research system (see Figures 7 and 24). As noted above,[18] South Africa ranks relatively poorly in a large number of categories related to educational outcomes. Looking at categories specifically focused on research, South Africa ranks well. Notable exceptions are that South Africa sits in the bottom half of countries in the categories of FTE researchers in the business enterprise sector and knowledge-intensive employment.

South Africa's public research system faces a number of challenges. Overall, the country has an undersized research system (DST, 2019). Knowledge exchange by universities and PRIs is found to be low (Cunningham, 2018b). Major technological institutions that disseminate technical and expert knowledge between actors, knowledge domains and industries are CSIR and universities (Cunningham, 2018b). In addition, state-owned enterprises, which often have vast experience of implementing technology-driven mega-projects, are playing a key role in South Africa's research ecosystem (MRP-STIIL, 2017). These businesses can work in partnership with universities and R&D institutes. Their activities can play a part in driving competitiveness and seeking to research the country's development goals.

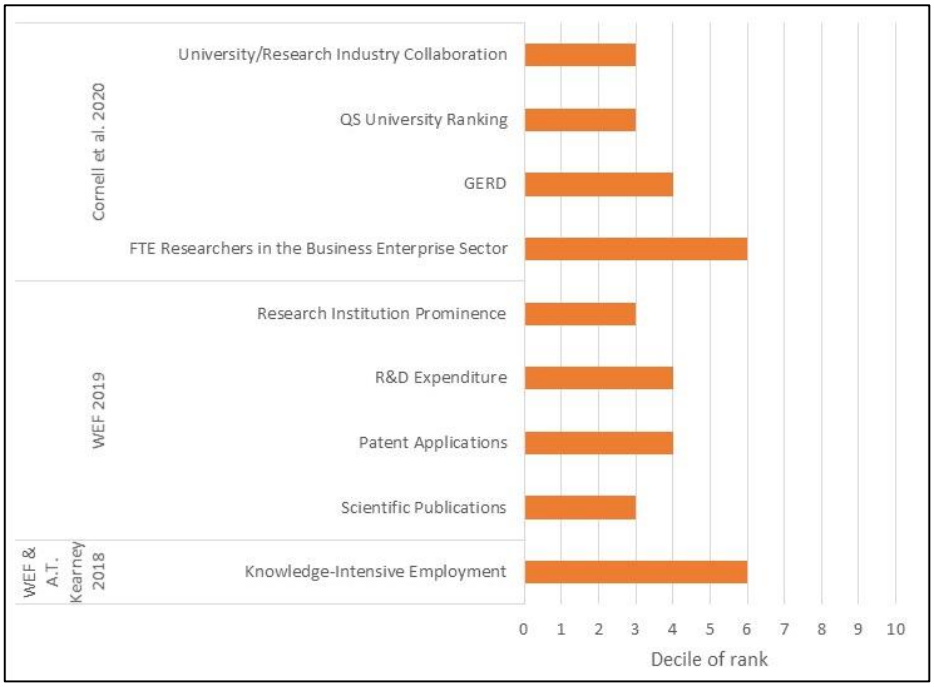
Overall, innovative firms do not report high levels of collaboration with government research institutes (8%), universities (7%), or private research institutions (5%) (CeSTII, 2020). Innovative businesses also reported low levels of using external sources of information, with 8% looking to private research institutes, 7% looking to government research institutes, and 3% looking to universities and HEIs (CeSTII, 2020). Businesses also reported getting information through other sources of knowledge transfer, with innovative businesses reporting getting information from conferences, trade fairs, and exhibitions (22%), and scientific journals and trade/technical publications (7%) (CeSTII, 2020). An industry representative described the divide between public research and businesses.

[18] The discussions of the education system in Sub-Section 2.3.2 and educational outcomes in Alexander (2022a) provide relevant information.

There is the breakdown … academics, pure academics like in scientists and engineers and that, are not engaging enough with us as commerce … A practical example is I was at an event at CSIR where they had business and science coming together was like an expo. And when I got there, there was so many doctors there in the invite list that I thought that I was at a medical convention, there was no business people, I was like one of the very, very few … So, there's this almost shyness of people wanting to engage, because business doesn't have time to pontificate with academics around random stuff, they want to make sales. Now, sales, we need to sell our product. Now, we need to extract, we need to uncover resources, we need to do this and this and this. So, business is business, academia is academia.

But academia is absolutely crucial to help us understand this noise. And where it can all go to, and then they need to feedback. But the feedback loop from academics into businesses is way too long, it's just, it's not there. So that needs to change this whole engagement … what you found mustn't stay within the university. That has to come out into this noise over here and be practical. So, if we can have practical applications of what you find, and we work together much closer, we say, okay, that was very cool inside, what over here can be deployed to make it a reality. (F06-I06)

Figure 24: Global Rankings of Elements of South Africa's Research System



Sources: WEF and A.T. Kearney (2018); WEF (2019); Genesis Analytics (2019); Cornell et al. (2020)

A national review found that the contributions of PRIs to national research productivity need to be improved, particularly in relation to research production, innovation incubation and acceleration, scholarly publications, and human capital development (MRP-STIIL, 2017). Part of the problem is that other actors are not drawing on the outputs of research organisations. For example, energy policy development does not seem to draw on the strong national research capacity in this area (MRP-STIIL, 2017). Other challenges with the research system

include a lack of multidisciplinary research within academic departments, low mobility between academia and the public sector, and limited focus on technology demonstration, knowledge dissemination and public education (Cunningham 2018a, 2018b).

The activities of research institutions are shaped by their experience in the national innovation system. Research institutions have identified a number of challenges in South Africa's STI landscape (see Box 8). These challenges may be contributing to poor outcomes.

However, while key deficits have been identified, research institutions also report having diverse impacts on society (see Box 9). An example of a positive impact was shared by a respondent in one of the interviews reviewed for this paper, who described how public research can help to address safety challenges.

> The challenge of this country is that we need to mine deep and we need to mine far, which means how do we do that? Hence the reason we also have a lot of safety issues because it's getting more and more critical. So, organisations like a CSIR a mining department in particular, are looking into how do we solve that. (F17-I33)

Box 8: Research Institutions' Reported Challenges in the STI Landscape

- Lack of strong relationships to ensure alignment with government objectives; annual plans often involve interaction with single departments
- Distribution of funding for human and social sciences compared to hard sciences
- Difficulty to influence the economy in ways outside the objective of the line department
- Competition between research institutions and government departments
- DST seen to not be fully taking advantage of outputs of research institutions and not supporting regulation and industrialisation
- Lack of independence, which can threaten scientific integrity
- Some services are fragmented across provinces, which could benefit from a national approach
- Limited partnerships with private sector
- Lack of capacity within DST
- Vague understanding of what constitutes research and innovation, limiting the ability to deliver and possibly causing institutions to deal with issues related to the immediate delivery of services as opposed to areas where technical expertise is most needed
- Lack of sufficient funding
- Lack of authority to act
- Retaining and growing scientific skills
- Government's minimal use and recognition of outputs
- Duplication of institutional mandates, leading to replication and competition

Source: MRP-STILL (2017)

One university-based programme is the Technology Stations Programme (TSP), involving 18 technology stations based at 11 HEIs, which seeks to enable universities to provide technology services (innovative science, engineering and technology solutions for engineering challenges) to small and medium enterprises. One respondent described the value of university-held equipment.

> [They] have quite a few robots at the Vaal University of Technology, which they use for internal purposes for R&D works for thesis students, and also as a kind of go to

> environment for industry, for prototyping, or whatever the case. So, they kind of use it as a self-funding mechanism, and learning tool and a service to industry. (F20-I41)

Knowledge sharing between universities and industry can be multifaceted. Different experiences were shared of ongoing communication between industry and higher education. One respondent described a close relationship with a university.

> I have to keep in touch with the university … Actually, after your visit today, there's actually a few lecturers coming over from them as well. Both to see what they're doing in academics, but also is for them to see what's being done in industry. So, I can also bridge that gap. (F13-I21)

Box 9: Self-reported Influences of Research Institutions on Society

- Programmes focused on policy implementation and service delivery
- Programmes to support integrated decision capability at all levels of government related to service delivery
- Supporting improvement in the quality of basic education
- Developing standards to support national priorities
- Supporting socially relevant R&D aligned with the NDP
- Funding research grants, scholarship programmes, postgraduate and post-doctoral fellowships,
- Supporting SMEs and entrepreneurs to access standards and other enablers in product development and commercialisation
- Partnerships and collaborations with universities to supervise postgraduate students
- Running skills-development programmes for researchers
- Encouraging staff to build their skills

Source: MRP-STILL (2017)

According to the OECD's (2021) STIP Compass, South Africa has 92 policy initiatives related to science, technology and innovation. A number of policies and programmes specifically target research and education organisations (see Box 10). Particularly relevant for 4IR-type innovation, the National Digital and Future Skills Strategy was launched in late 2020. It sets out a series of initiatives intended to build digital capacities. The Human Resource Development strategy has been reviewed by a team whose mandate includes aligning the strategy with the needs of 4IR (PC4IR, 2020).

The Human Resource Development Council of South Africa (HRDC) is a national advisory body, headed by the office of the Deputy President of South Africa, which seeks to increase productivity and human resource development to transform South Africa into a knowledge economy and improve economic growth through increased competitiveness (HRDC, 2021). The council includes members of government, civil society, organised business, professional bodies, and HEIs. It seeks to match skills and demand for the workforce through the development of high and intermediate skills and to increase demand for large-scale employment, including lower skill levels. The strategy involves the Department of Basic Education, DST, the Department of Public Service and Administration, and the Department of Higher Education and Training.

A number of programmes and organisations are focused specifically on technology and innovation. In addition to the TIA, the Technology Localisation Implementation Unit (TLIU), established by the DST and hosted by CSIR, supports industry by helping local firms enhance their technological capabilities, supply goods to state-owned companies and host interns. They have also helped OEMs to find local alternatives to previously imported items. Key services include: benchmarking and other evaluation schemes; access to technology platforms and facilities; access to technical expertise; technical skills development programmes; design and tooling support; and technology transfer benefits (CSIR, 2021).

Box 10: Policies and Programmes that Target Research and Education Organisations

- C4IR-SA – Centre for the Fourth Industrial Revolution
- Marine and Antarctic Research Strategy
- National Development Plan: A Vision for 2030
- National Intellectual Property Management Office
- Presidential Commission on Fourth Industrial Revolution
- National Space Strategy
- Intellectual Property Rights Act
- Strategic Health Innovation Partnerships
- Activities of the South African Agency for Science and Technology Advancements
- Science Engagement Framework
- Human Capital Development Strategy for Research, Innovation and Scholarship
- African Open Science Platform
- National Research Big Data Strategy for South Africa
- ASSAf Consensus Study on the Ethical, Legal and Social Implications of Genetics and Genomics in South Africa
- South African Research Chairs Initiative
- National Integrated Cyber-Infrastructure System
- South African Research Infrastructure Road Map
- Basic Science Development Support Framework
- NRF Funding Instruments
- The Scientific Electronic Library Online South Africa
- Statement on Open Research Publications from NRF-Funded Research
- The New Generation of Academics Programme
- South African Affiliate Centre of the WEF's Centre for the Fourth Industrial Revolution
- ESKOM Expo for Young Scientists
- Centres of Excellence
- NRF – National Nanotechnology Equipment Programme
- Research Professional Development Programme
- Academy of Science of South Africa
- The National Equipment Programme
- Mandela Mining Precinct

Source: OECD (2021)

Within DST, the Directorate of Sector and Local Innovation specifically seeks to strengthen the national innovation system to enhance economic growth. It is forming sectoral partnerships aimed at increasing participation in research, development and innovation. It also coordinates and facilitates local innovation interventions. The key initiative of the directorate involves building local innovation systems by facilitating the development of regional innovation forums; developing national science parks; running the Industry

Innovation Partnership Initiative, which enables government to partner with industry and co-fund research, development and innovation; and managing sector-specific innovation funds.

DST (2019) produced the White Paper on Science, Technology and Innovation, which outlines medium- to long-term goals for the development of South Africa's national innovation system with the aim of expanding research outputs and transforming the research institutional landscape. Priorities include improving the performance of historically disadvantaged universities; transforming the profile of the research base (e.g., by activating the PhD-qualified "silent majority" who do little research); improving the output of human resources by increasing support for students, increasing supervisory capacity, and transforming the demographics of researchers; supporting diversity for post-secondary opportunities; prioritising the development of technical skills, particularly for digital jobs; ensuring an open, responsive and diverse knowledge system with an open science paradigm and a focus on inter- and trans-disciplinary research to address complex societal problems; formalising a system to focus research on areas related to meeting the NDP's objectives; increasing focus on knowledge diffusion; upgrading and expanding research infrastructure, including cyber-infrastructure; and building international research partnerships.

Several initiatives seek to promote knowledge commercialisation and technology transfer (Department of Science and Innovation [DSI], 2020). The NIPMO plays a role in using knowledge for economic and social development through the Office of Technology Transfer (OTT) Support Fund and provides training for OTTs and SMMEs. The IP Fund supports a range of activities related to securing IP rights from publicly financed R&D. The OTT Support Fund also supports HEIs and science councils to establish and maintain OTTs.

DSI (2020) provides additional services. It promotes innovation partnerships that involve public-private co-investment in research, development and innovation in key strategic sectors, which encourage increased private sector investment. Furthermore, DSI also works with the Department of Higher Education and Training to develop international training opportunities for South African researchers.

3.4 Other Support Service Providers

In addition to financing and research organisations, a number of other support service actors work in national innovation systems, such as business incubators, business associations, and technical service providers. These entities can have broad mandates, or be focused on specific industries and localities. South Africa's innovation system houses a wide range of organisations that provide support services for businesses. Some of these organisations provide services actively sought by businesses, while others seek to incentivise businesses to undertake particular changes, such as improving environmental outcomes.

3.4.1 Support Service Ecosystems

Support organisations can focus on the productivity and competitiveness of incumbents, and also seek to lower barriers to entry for new firms and investors (Cunningham, 2018a).

Synergies exist between different types of support. One synergy is that business support, such as marketing or training support, can enhance financial support for spin-offs (OECD, 2019a).

One type of support actor is a technical institution. These actors can provide a number of functions (see Box 11).

Box 11: Functions of Technical Institutions

- Technical infrastructure (e.g., setting standards, conducting testing)
- Quality assurance, certification, compliance
- Providing technical and management consulting
- Technology and knowledge dissemination (e.g., demonstrations)
- Technology and manufacturing extension
- Research and development support
- Intellectual property protection
- Support with getting financing
- Technology assessment
- Access to scarce or specialised equipment
- Technological or production technology trade fairs and exhibitions
- Prototyping, simulation and design services

Source: Cunningham (2018b)

In addition to support organisations that support individual businesses, meso-organisations seek to improve the business environment (Cunningham, 2018a). Meso-support actors include those that enable technological change and adaptation for businesses and those that enable education and skills development. They also can provide feedback from businesses to policy makers and can play a role in preparing society and enterprises for the future. Meso-organisations should be assessed on their service delivery and governance systems, including how they partner with other organisations. Meso-organisations can play a number of roles that are related to technology (e.g., standards, technology transfer, R&D), education and training (at multiple levels), finance (e.g., providing loans or investing), infrastructure (supporting infrastructure development), foreign trade (e.g., supporting foreign trade, export financing, export credit insurance, marketing advice), entrepreneurship (e.g., training, market facilitation, business incubation or acceleration), and business membership associations (e.g., supporting lobbying or networking) (Meyer-Stamer, 2005). Finally, meso-organisations also play roles in shaping policies and sector strategies (Cunningham, 2018b).

Governments seeking to create well-functioning innovation systems need to be responsive to the needs of industry. Support service organisations can develop in the private sector, but government agencies can fill gaps where private sector support is insufficient. This could involve managing government-run organisations and providing funding for external programmes.

3.4.2 South Africa's Support Service Ecosystem

South Africa houses a wide range of public and private sector support actors. NACI (2021) has published a list of about 100 institutions that provide various support services to businesses

on its National Science Technology and Innovation Information Portal. Cunningham (2018a) provides an additional list. A World Bank study (2018a) found that South Africa has over 300 active support organisations for entrepreneurs, including innovation districts, incubators, accelerator programmes, innovation hubs, and co-working spaces, event organisers and foundations. Many of these were found to be highly dependent on government programmes. The World Bank noted that 10% to 15% seemed to target digital entrepreneurs.

Programmes can provide a variety of services, which include diffusing technology and knowledge, as well as improving the absorption capacity of firms. These services can involve organising demonstrations, providing technical assistance, or building information networks (Cunningham, 2018a). Other strategies include supporting the creation of participatory sector-wide technology road maps, promoting the use of diagnostic tools and use cases, benchmarking and facilitating university-industry collaboration (Cunningham, 2018a). Support organisations can also promote innovation and entrepreneurship, as described by one of the interviewees.

> We want there to be a commercial person on board and a marketing person as well. So, you will come in front of a panel of judges that will work on a concept the same as the Dragon's Den. They have to sell their project to the Dragon's Den. I am working on a program … where we will do it with our patron members, giving university equipment of a certain value and they have to use junk or whatever they can find to put something together and sell it to us and then when they sell it to us and the successful one will be assisted in creating a business from that or not just a winner but any person that comes with a valid thing … the entrepreneurial skills are there you must just take a look. (S01-I36)

Overall, the services provided are diverse. However, multiple common challenges have been identified (see Box 12).

Despite the difficulties with the structure of programmes and their accessibility, businesses do apply to existing programmes (see Figure 25). The most common support applied for and accessed is training support or internship programmes. Other types of support were all accessed by fewer than 1% of firms.

One type of support service is the creation of model factories. Model factories can use a variety of 4IR technologies, such as digital twins (S01-I36). The DTI is partnering with CSIR and industry to establish "learning factories" across the country (PC4IR, 2020). These learning factories can help to demonstrate technology and be used to facilitate training. Model factories use a variety of techniques to promote knowledge diffusion. For example, they can incorporate foreign technology (S01-I36).

Box 12: Challenges for Support Service Organisations

- Limited scope of support: concentrated on supporting firms in the early stages and geographically concentrated in the affluent urban areas of Gauteng and the Western Cape
- Low-quality services without relevant mentors and/or meaningful monitoring and evaluation

- Programmes not suitably tailored for the South African context or to help firms access foreign markets
- Strong offering, but communicated poorly to potential users, with unclear costs and benefits
- Can be too focused on technical solutions without providing support for organisational change processes
- Focused on pushing their approaches without adequate assessment of impact, particularly for publicly funded institutions
- Skewed towards higher technology services, but needs also exist related to basic technology support
- Often a focus is placed on a linear development process, with deficient attention being paid to sense-making and understanding the trade offer or alternative paths
- Services can be hidden within large organisations and difficult to know about and access
- Some organisations with national public funds are focused on local client bases without easily accessible options for businesses at greater distances
- Low awareness among industry about available services

Sources: Cunningham (2018a); World Bank (2018a); S02-I42

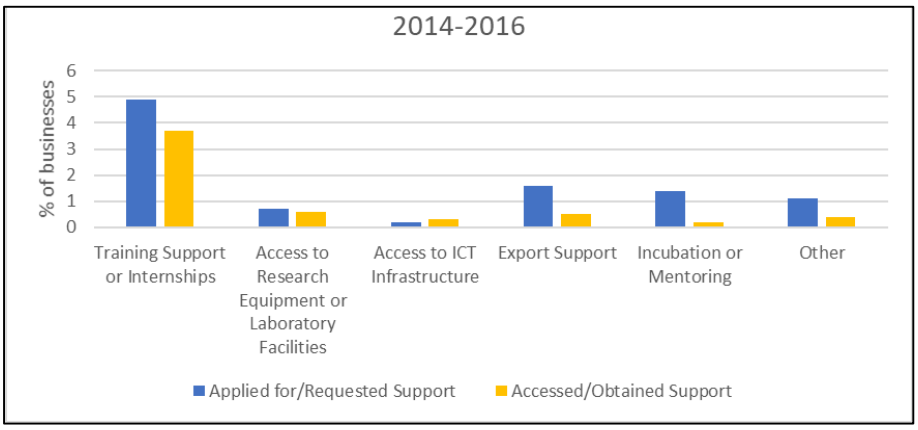
A number of other types of support service programmes exist. These are often collaborations between the public sector and other actors. One example is the Intsimbi Future Production Technologies Initiative, a multi-stakeholder initiative established by DTI and the Production Technologies Association of South Africa (PtSA) to support the tooling industry.

Another area to consider is support available for start-ups. South Africa has a well-developed start-up support system (Cunningham 2018b). In their assessment of the system, Genesis Analytics (2019) found a small and decreasing gap in the efficacy of this system.

Improving environmental performance is another area in which businesses can receive support. South Africa ranked highly on the Global Competitiveness Index related to environmental regulations, at 15th out of 141 countries in the category of "Energy efficiency regulation", 21st in "Renewable energy regulation" and 36th in "Environment-related treaties in force" (WEF, 2019). To reduce carbon emissions, a carbon tax was introduced in 2019. South Africa also has a number of policies and programmes to encourage cleaner (more environmentally friendly) production. The National Cleaner Production Centre of South Africa is a DTIC project that is hosted by CSIR and that seeks to encourage firms to adopt resource-efficient and cleaner production methodologies. These methodologies are presented as being a way to lower costs through reduced energy, water and materials usage, and through waste management.

Environmental policies can also be targeted at creating broad changes in businesses' behaviours. For example, to address greenhouse gas emissions from transportation, the Department of Transport developed the Green Transport Strategy, which aims to reduce emissions by moving 30% of road freight transport to rail and converting 5% of the road vehicle fleet to cleaner alternative fuels and more efficient technologies within five years (Gain Group, 2020). Such changes may be facilitated through the provision of support services or more hands-off approaches, such as tax incentives.

Figure 25: Types of Non-financial Support Applied for and Accessed[19]



Source: CeSTII (2020)

A range of private sector support services are also available in South Africa. Many of these specifically support the spread of 4IR. Companies can sell external services, such as data management or analysis. Notably, a number of businesses provide connectivity services, which is a topic discussed in more depth in the following paper in this working paper series (Alexander, 2022b).

Private sector support can also be intended to help businesses to adopt 4IR internally. One interviewee, who had recently left a government job to found a consultancy firm with this objective, said that there is a growing need for such services (S02-I42). Respondents in the interviews reviewed for this paper included multiple consulting firms with related purposes. These firms offer commercially viable services that help manufacturing and infrastructure-creating firms to incorporate 4IR systems. One respondent described general private sector demand to develop 4IR systems.

> Some of our customers, the problem is they want to do industry 4 … That is a bit of a problem, because that's a very broad statement. And just to do industry 4 is – So even there we need to sort of break it down for them and say, 'Well, how do you want to do it?' (F13-I22)

However, he went on to describe firms facing challenges when they learned about the investments that would be needed.

> A lot of the times it's money, they just don't have the money. And then also there's the perception of in the heads, what the solution should be. So, they've already decided we're going to do or whatever, and we come in and we say something different. And we say you need to add sensors and stuff. And then they go, 'Oh, we need to have sensors'. Okay. That's cool. And then you tell them, but it's maybe ten to one hundred dollars per sensor. And then I go, 'that's gonna be only for vision data. I need $100 000, $10 000 for measuring data?' And it's like … Question of but just for getting the data, why? And it's

[19] Note: Missing data led to a higher proportion of enterprises that accessed than applied for financial support for innovations.

> also that then they see things from ... So, they don't understand. Yeah, they don't understand the value of the data. So, it's but a lot of the times what I've now seen. It boils down to either they are just uninformed. Just because things are moving rapidly. I mean, I'm trying to keep up, but I don't think I keep up because things are changing five times a day. And then money, a lot of times money. And you might you might speak to everybody on the ground floor, you might speak to the managers, you might speak to the production manager, you must speak to all of them. And they all agree that yes, they can actually see the benefit in what they're trying to do, and it always needs to go up to a board. And that board goes, 'this much money! And how are we going to get [it]?' (F13-I22)

Overall, support services for businesses in South Africa involve a wide range of organisations seeking to build the capacities of businesses and targeting a variety of goals. Notably, Bell et al. (2018) posit that the only solution for generating higher incomes and wealth for all in South Africa is to focus on developing industrial capabilities across manufacturing and related services. In addition, support services can be an important way to improve the environmental impact of South Africa's businesses.

4. Networks and Connections in Production Systems

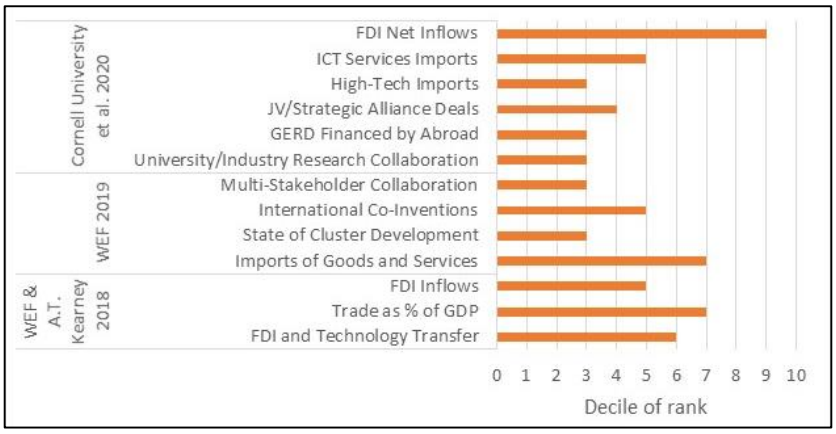
The second and third sections of this paper have provided overviews of the key contextual factors and key actors of the national innovation system. This section discusses the networks that connect the key actors. South African firms work within a national space that involves a variety of relationships with domestic businesses and non-firm actors. They also operate in a global economy and have diverse global connections. The nature of local and global networks shapes the ways in which 4IR is introduced to and developed by South African businesses.

International comparisons have been done covering some elements of South African firms' networks (see Figure 26). From these measures, South Africa's networks can be seen to have strengths and weaknesses. South Africa has strengths in high-tech imports, GERD financed by abroad, university/industry research collaboration, multi-stakeholder collaboration, and the state of cluster development. However, South Africa ranks in the bottom half of countries in the categories of FDI net inflows, imports of goods and services, trade as a percentage of GDP, and FDI and technology transfer.

Nevertheless, innovative South African businesses report networks as a strong source of information (CeSTII, 2020). Businesses reported getting information from suppliers of equipment, materials, components, or software (31%); clients or customers (38%); competitors or other enterprises in their sector (17%); consultants, commercial labs or private R&D institutes (12%); and professional and industry associations (17%). Members of networks were the most highly valued external partners for innovative businesses, with the most important being suppliers of equipment, materials, components or software (mentioned as important by 19% of innovative businesses), followed by clients or customers (17%), and then competitors (15%). However, some firms expressed finding cooperation partners for innovation as a barrier to engaging in innovation (9% of innovation-active and 6% of non-

innovation-active firms). Considering the behaviour of SOEs specifically, MRP-STIIL (2017) found that they engaged in research partnerships with other SOEs and private institutions.

Figure 26: Global Rankings of Elements of South African Firms' Networks



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

The discussion that follows is divided into two parts. The first focuses on exploring the dynamics of national networks. The second focuses on global networks. A more detailed discussion of networks involved in connectivity services and manufacturing is provided in Alexander (2022b), the third paper in this working paper series.

4.1 Domestic Networks

Domestic networks are a key feature of a country's innovation system. This sub-section begins by presenting theory and research findings related to local production networks. The second part presents some key characteristics of the networks that are operating in South Africa.

4.1.1 Dynamics of Local Networks

A key aspect of domestic networks is that the interactions between actors create a national system with unique features. Countries can be considered to have national technological capabilities (Lall, 1992). These capabilities involve the ability to mobilise and efficiently use resources, a skill base involving general education, specialised managerial and technical competence, and the existence of a national technical effort. These capabilities can be observed through aspects such as R&D, patents and technical personnel. Fagerberg and Srholec (2017) emphasise that countries wanting to catch up need to build technological capabilities, and that success levels are dependent on wider economic, social, institutional and political factors.

Hillebrand et al. (1994: 4) proposed four pillars that shape national technological capability, which they describe as "more than the sum total of the capability of individuals, enterprises, and institutions". First, company-level innovation capability, particularly related to imitating and innovating product, process and business models, which is shaped by the level of competitive pressure experienced. Second, whether there are incentives created by economic, political, administrative and legal framework conditions. Third, the level of direct

technological and knowledge support provided by public and private organisations. Fourth, the level of indirect support created through the ability of the education system to produce basic education and more advanced training that is responsive to changing national needs.

When assessing a domestic network, a pivotal element is the nature of the connections that exist between actors. In particular, innovation processes can be shaped by the types of connections that exist between (public and private sector) actors (Zanello et al., 2016). Interactions between local actors can be based on market or non-market relationships (Edquist, 2006). Three types of relationships can be distinguished in a local productive system. One is competition, which involves other actors being rivals. A second is transactions, which involve trading goods and services. A third type is networking, which involves collaboration. All three types can lead to processes of innovation.

Overall, interaction between people is a key element of innovation. Proximity between individuals is important, because many aspects of knowledge are tacit and not easy to transfer. However, proximity in relations can be more or less important in different sectors, as levels of codification can differ across types of knowledge and technologies (Lundvall, 2016b).

Industry is often found to be grouped in clusters, which involve “sectoral and spatial concentrations of firms” (Schmitz and Nadvi, 1999: 1503). Clusters create the potential for economies of scale, scope, agglomeration gains, and joint action (Lund-Thomsen and Nadvi, 2010). Clusters also create regional benefits related to industrial development, which include agglomeration effects and economies of scale. These are particularly important for regions with low density (OECD, 2018a). Clusters can also contribute to learning and knowledge sharing, which can promote innovation (OECD, 2018a).

Government policy can promote and strengthen domestic networks. One method is through the creation of cluster policies, which can take a number of forms. Cluster policies can be divided into three categories (Europe INNOVA and PRO INNO Europe, 2008). First, facilitating policies, which seek to create favourable conditions. Second, traditional framework policies, which include industry and SME policies, research and innovation policies, and regional policies and use a cluster approach to increase efficiency. Third, development policies, which specifically seek to create, mobilise or strengthen a set of clusters.

Governments can provide a wide range of cluster-support activities (see Box 13). Cluster policies can seek to strengthen individual clusters and also focus on strengthening networks between clusters. A network-based cluster model has been associated with strengthening research, building stronger industry-science ties and fostering cross-sectoral linkages (OECD, 2018a). One risk facing cluster policies is to focus on old and mature industries, which are not making attempts to modernise. This can slow down entrepreneurial dynamism by focusing on insufficient diversification and local champion firms (OECD, 2018a). Cluster polices can also be used to promote global networks (which will be discussed in Sub-Section 4.2).

Box 13: Cluster Support Activities that Governments can Carry Out

- Organising public events
- Supporting the improvement of the region-cluster reputation
- Facilitating transmission of information
- Directing financial support to finance specific projects
- Facilitating networking with universities
- Facilitating networking with firms
- Facilitating administrative procedures
- Facilitating trans-national relations with other clusters of geographic areas
- Providing building or other infrastructure
- Supporting incubator development
- Enacting tax-reduction schemes on R&D and innovation expenditure
- Enacting tax-reduction schemes on other activities

Source: Europe INNOVA and PRO INNO Europe (2008)

4.1.2 South Africa's Local Production Networks

South African firms have multiple forums supporting interactions. The country houses many industry organisations. Examples related to the sectors of focus of this working paper series (connectivity services and manufacturing) include the Road Freight Association, the Intelligent Transport Society South Africa, the Chartered Institute of Logistics and Transport, the South African Association of Freight Forwarders, the South African Institute of Mechanical Engineers, the Production Technologies Association of South Africa, the Society for Automation and Instrumentation Mechatronics and Control, the South African Council for Automation and Control, the National Automotive Manufacturing Association of South Africa, the National Association of Automotive Component and allied Manufacturers, the Mining Industry Association of South Africa, the Mining Equipment Manufacturers of South Africa and the Construction and Mining Equipment Suppliers' Association.

Despite this, Genesis Analytics' (2019) digital readiness assessment found insufficient levels of between-business coordination in the country. They found a large yet declining gap in the support of inclusivity. They described a need for champions and increased trust.

Industry associations can play multiple roles, such as lobbying, regulating professional status, and providing training. One respondent described how associations can help with facilitating mentorship processes for young professionals. When individuals in private companies have roles in associations, it helps make strong connections between practical experience and professional communities. Industry associations can support upgrading programmes on their own, and in collaboration with other actors, such as government agencies. This was described by one of the respondents.

> Via the [*Association Name*], remember that automation sector organisation, we are now getting more involved with what they are calling the new technologies implementation program, the MTIP …It's an initiative from the DTI and it holds on an initiative that is called INTSIMBI FTP: Future Technologies Programme. And, and they're all those automation companies that are sitting on the table, including ourselves, but I'm

> generalising now, because we are all experiencing the same issue. It's 'what are the requirements of the manufacturing side of tomorrow?' … How do we fill all the skills we need or is education providing the skills needed? And it also partially brings us to the need for dual vocational training for dual training models studying and, and working at the same time. (F17-I33)

Individual businesses that are laggards can connect to industry associations that promote progressive practices. When speaking about his company's adoption of 4IR technologies, one respondent spoke about learning about them through industry associations.

> We're at a very raw stage for a better word. I attended a while ago, one of the … presentations, I'm also part of [an industry association], so there we do discuss it but internally in the company, it is something we are raw with. I'm starting to get like more into it more exposure, what it's all about, that is something, as a company, I think we can take to the next level. So, it's really at the infant stage, to be honest with you. (F14-I27)

Another way to look at local networks is to explore the development of partnerships. CeSTII's (2020) Business Innovation Survey provides insight into South African firms' experiences. Not many businesses (21%) reported collaborating in innovation processes. When people did collaborate, the reported reasons were for accessing information (16%), accessing R&D (16%), accessing expertise (16%), cost sharing (14%), accessing new markets (13%), prototype development (11%), accessing new distribution channels (9%), and scaling up production processes (7%). For businesses that engaged in process or product innovation, private sector research-focused organisations as partners were not very common, with 13% of industry businesses (mining, manufacturing, and utilities) reporting collaboration with consultants, commercial labs or private R&D institutes and 8% reporting collaboration with private research institutes. Fewer service businesses (trade, logistics, finance, and engineering) reported collaborating with the aforementioned partners, with the numbers at 12% and 3% respectively.

A number of informal networks also connect businesses and other stakeholders. For example, a representative from a company that works on transportation infrastructure described building connections in the industry.

> From a company perspective, what we do is we spend a lot of time talking to people in all of the spheres of government, all of our customer bases. And that is a double-edged sword. Because one … it keeps people abreast of what we're doing, and where we're going and what the plans are. And we pull in their ideas from them, and we give their ideas to them. And, by and large, that's a very good functional perspective. (F21-I38)

These field-level, national-level, cluster-level or community-level interactions are very important and create a baseline that shapes opportunities for technologies to be developed and implemented in a society. Another respondent described the benefits of being part of a supportive professional community.

> The space in Jo'burg for AR-VR is not actually a competitive space. We have meet ups. We all have beers once a month. We all collaborate and talk, share ideas, talk about clients that are rubbish, talk about clients that are great. There is a more collaborative ecosystem here than ever before … Yeah and I think it's because all of us come from that same background.
>
> Entertainment isn't competitive. Entertainment is collaborative. You get people to help you with projects. You do production. You do shoots. You make things that are entertaining. You bounce ideas from everyone. It's not a case of competing against a product or a client. There's enough clients in the country. The industry is still small. There's probably fifty people in the whole country that are AR-VR specialists. We are not in each other's throats and we don't believe that we should be in each other's throats. We all believe we should be expanding globally.
>
> I know [one company] has got presence in the States. We have a presence in Asia. Other companies have pushed for presences in Europe … We all work with each other because we know that people might move from organisation to organisation. The thing is, if we don't have an open conversation about that, and we don't have an open conversation about where we need to be moving as an industry, we are going to cannibalise and kill each other and we shouldn't be doing that because there's enough of a global market for everybody.
>
> I think that, especially millennials are not as competitive as the older generation. We are more collaborative in nature. We've seen that. Everyone who runs an AR-VR studio that I've ever met in the country is a millennial. I think it's because we see the future and we know that competition is good to like push you forward but it's not there to actually stifle and kill businesses. It's not our mentality, we don't do that. (F16-I31)

The World Bank (2018a) finds that South Africa has a strong start-up community that hosts a lot of events, with growing importance placed on including previously disadvantaged individuals as both entrepreneurs and customers. However, the Bank notes that the start-up community remains mostly white, male and middle class.

Sometimes certain individuals can act as connectors to help bring together diverse skillsets.

> I'm the connector. Yeah, that's my role. I connect everybody. So, my talent lies in seeing the very, very big picture, and bringing all the people together and seeing the opportunities and being open to talking to absolutely anybody and everybody. If you stand still long enough, I'm going to talk to you. (F06-I06)

This respondent described the benefits of bringing diverse people together for conferences and workshops where people can exchange ideas.

> The [event was] very informal … We had an agenda and we just sort of semi stuck to it. But what we wanted out of it was people's brains. So, we … split them up into it. We mix them all up and we said 'Okay, you go there'. And then these are the questions we are asking you. 'What are your solutions? What are your problems? What are your issues?' and out of that we extracted huge amounts of valuable information. We cut the loop between the inventors of the product. … Direct engagement with a whole lot of the

> client's potential clients … they told him straight, 'listen; this product is not going to work'. The other guy was like 'now this product will work but you need to make it do this and do this'. Or 'yes, this thing's the best thing since sliced cheese. Bring it. We want to test it' … you got straight feedback.
>
> … So, you have to have a very flexible mindset to be able to handle that criticism and develop something new out of it … So, we get all the people together from a different technology so IoT, or whatever. So, we said, 'okay, this is going to be about IoT sensors'. So, we got everybody together then we got the audience who's the audience so we like okay we want these are our clients. Bring them together. Then, we said to the audience, what we did is we first got them all to understand what is the 4IR … It's a different approach, then we had the solutions, then we had the workshop. And that's where we got the inputs from them. So, we've come with a solution for a problem. But because we were creative over here and we got people thinking and far out and so on, then the change then the dynamic changes. Then the people are like really eager to get involved. (F06-I06)

Another domestic network issue is connections that firms can have with local suppliers and customers. Some firms prioritise local suppliers and building relationships. One respondent shared his process for looking for suppliers.

> So, it's all local manufacturers. So that's, that's rule number one, if you if we want to deal with somebody needs to be local needs to be here, and he needs to create his products local, because remember, I get points on that … So, because what we do is we manufacture the parts for them. They don't import the parts … So, the more we can do here, the more jobs we can create, the more productive we can be and who better to know of what we need than the local manufacturers … Because if you look at your [global brands] and all of that they have a piece of equipment, that's not maybe 100% suited for our conditions. It works in our conditions, but it wasn't designed and built specific for our conditions. (F19-I35)

A key factor in South Africa's local networks is the role of PRIs, which was discussed in Sub-Section 3.3.2. In some cases, strong connections are found between universities and firms. Notably, university-firm relationships in South Africa have been found to be relatively direct, formal and knowledge intensive compared to those in Uganda and Nigeria (Kruss et al., 2012). Service businesses were more likely to collaborate with government or PRIs (11%) and universities or other higher education institutions (8%) than industry businesses, with levels at 3% and 5% respectively (CeSTII, 2020).

Multi-stakeholder networks and interdisciplinary cooperation are particularly important for 4IR. One respondent described how working in silos can be detrimental to getting the best outcomes.

> So, I'm very scared to smother anything out of here to say, 'No, you guys have developed cyber security. So, you fit into that box'. If you put them into boxes, then we are going to smother them [we have] in silos, we don't understand how that could actually have worked with that piece of tech over there … Or where that, it links over there, but you

> have to have this linkage in place, which is linked to there, you understand … this is usually complicated and complex … And then we need to be right out the box. So, we need some of your crazy artists in there as well, talking to the industrialists, so that they can get the creative juices going in meetings and that. So, there has to be a total change … so science, technology, engineering, arts, mathematics, what we need in front here is innovation … And then, universities, we all need to be working together. And then the business side of things, your business chambers, commerce, chambers, et cetera. (F06-I06)

Another respondent described how they benefited from collaborating with diverse organisations.

> Our CEO always say we like to box in a weight class above where we sit. And that's because we are talking to people that have expertise in all these things. We don't have all the expertise, even the technomatic simulations, we are using external companies at this stage still, to do that, through us. For us. We're talking to universities, I mean, I've been at Stellenbosch University. We are talking to their, really the experts there saying, well, this is the need, we see. We are not going to create a division inside this company for simulating technomatics, if it might be one instance, maybe it'll be the next big thing for us. And we will have to bring it in local to the company, simply for whatever. But let's partner I mean, let's partner with Stellenbosch University … partner with individuals, partner with companies that will bring it to us. So, we in any case do that. (F13-I22)

While networks can bring multiple benefits, South Africa has deficiencies in this area. As one respondent from the automotive sector said, a lack of coordination among OEMs is a problem.

> The problem there is that we try to find a solution where all OEMs would work together and they simply don't want to do so. (F18-I34)

A similar sentiment was expressed in relation to challenges with cooperation in the mining industry.

> Now unfortunately, the OEMs, nobody, everybody wants to keep it for themselves. Because the work is so little, you, you don't want to lose any work. So, it's going to take time to actually build that relationship as well. (F19-I35)

One respondent emphasised the need for more industry collaboration.

> [Individual firms] don't have the muscle. It doesn't make sense just for one company. So there has to be industry bodies that have to come together and say, 'Okay, what do we need to carry this economy forward? What is the future generation that we need to define from this country as a whole?' And we need to translate that into an action plan, but also regulations, legislation that guides the industry, going forward as a whole … There has to be collaboration between government, between the private sector and sort of non-profits, organisations, bodies to drive institutions. Absolutely. (F07-I09)

Problems with multi-stakeholder cooperation have been identified as constraining to the national innovation system (DST, 2019). Key problems include the inadequate and non-collaborative means of national STI agenda setting, and weak partnerships between actors in

the national innovation system, particularly inadequate involvement of business and civil society.

4.2 Global Networks

Global production networks are a key feature of production systems in the 21st century. Global connections also play a big role in businesses' ability to adopt 4IR systems. These connections can include roles played by global lead firms in supply chains, FDI, and being in a competitive marketplace with global firms. The position of South African actors in these networks can shape their learning and innovation experiences. This sub-section also begins by introducing theories and research findings before discussing key features of South Africa's global networks.

4.2.1 Global Production Networks

While the national innovation system plays a role in shaping all organisations in a country, businesses are also participants in distinct production networks that shape their experiences and opportunities (Henderson et al., 2002; Coe and Yeung, 2015). A key characteristic of 4IR dynamics is the changing of boundaries between firms in production networks. Consequently, while we can learn a lot from past research and theorising about these networks, some of their characteristics may change as 4IR develops. In production networks, one product or service can be seen to be created through the cooperation of a diverse set of businesses carrying out different stages of production in different locations and using different technologies (Alexander, 2018).

Many production networks involve global connections. Global production networks often have large and powerful actors that play leading roles in relation to other producers (Gereffi, 1994). Lead firms are seen to control access to important resources (e.g., product design, new technology, brand names, and consumer demand). Drivers can be individual firms that are located upstream (end buyers) or downstream (producers) (Gereffi, 1994), bi-polar – with a key actor at each end of production (Fold, 2002), or multi-polar – incorporating a diverse set of key governance actors (Ponte and Sturgeon, 2014).

Different industries have varying levels of control held by lead firms. Gereffi et al. (2005) provide a framework that categorises buyer-supplier relationships based on the complexity of transactions, the codifiability of related information, and the capability of suppliers. Different variations in these aspects lead to the identification of five types of relationships, viz., market (price focused, low cost of switching), modular (design based on buyers' specifications), relational (mutual dependence), captive (suppliers highly dependent on buyers), and hierarchy (vertically integrated suppliers).

Global connections can provide a way for knowledge to enter a national innovation system. Factors shaping the influences of global connections include sectoral characteristics, firms' own efforts at capacity building, and access to foreign technology (Lundvall, 2016b). Global knowledge flows can stem from FDI, international trade, technology licensing, the movement

of people, imitation, capital equipment imports, and selling to demanding markets (Lall and Pietrobelli, 2005; Pietrobelli and Rabellotti, 2011; Zanello et al., 2016; Lema et al., 2018).

The opening up of economies can lead to creating international linkages, including FDI. Foreign investors can create new projects or take over existing businesses and, in the process, bring in new technology and create new supplier networks that incorporate domestic and foreign suppliers (Black, 2020). Multiple studies show that domestic innovation is higher in countries that have more open markets and FDI can be seen to generate productivity growth for host countries through spillovers, linkage externalities, and competition (Zanello et al., 2016).

FDI levels have been found to be shaped by host country policies (Zanello et al., 2016). A number of policies can be enacted to support FDI, such as the creation of special economic zones with benefits for global firms and offering tax incentives for global investors. Furthermore, government policies can be used to shape the ease with which companies can import inputs and export their outputs.

Past studies have shown mixed evidence relating to the influence of FDI on local firm upgrading (Black, 2020). Increased capital entering a market can create a more demanding competitive situation that requires firms to upgrade. This can lead to positive knowledge spillovers in a local economy. However, importing external technology can also reduce the need for local development and involve the downgrading of local firms. When firms are bought by foreign actors there is potential for deskilling, as high-skill activities can be moved to a global headquarters and companies can lose internal innovation capabilities. However, there is also potential to develop new skills through knowledge flows within multinational corporations (MNCs). Local governance has been seen as important for nurturing innovation in local firms that have attracted FDI (Zanello et al., 2016).

Technology transfer is a difficult process. Local learning can benefit from strong national innovation systems, including supporting local conditions such as absorptive capacity in firms and industries, involving investment and learning from local firms and industries through training and skill development, R&D and learning by doing; the capability to identify appropriate technology and transfer mechanisms; sufficient human and financial resources; and appropriate institutions and policies (Fu et al., 2011; Zanello et al., 2016; Black, 2020). In some cases, countries can benefit from tapping into existing knowledge from external sources. However, in cases where technology gaps are wide, countries can be better off by implementing basic technology (Prahalad, 2012). Some research has indicated that South-South trade and FDI may be particularly beneficial for the diffusion of innovation, as the knowledge may be more appropriate for the receiving country (Zanello et al., 2016). Cultural and linguistic distances between home and host countries have been found to have positive and negative effects on innovation diffusion (Zanello et al., 2016).

Innovation capabilities can spread across countries from multinational firms investing in creating R&D facilities in multiple countries or outsourcing innovation to researchers in

different countries. These dynamics have been referred to as innovation networks (Cano-Kollmann et al., 2018). Considering the automotive sector, developing countries have regional design centres with links to global headquarters, which can be located in large, dynamic markets such as China, India and Brazil, or where a large production presence exists with low engineering costs, such as Thailand and Poland. Regional design centres can focus on minor local adaptations, but can include fundamental research (Black, 2020).

The rise of MNCs has reduced the need to build domestic capabilities in some cases. This can involve MNCs providing their affiliates with intangible assets, such as skills, technology, production expertise, and training (Lall and Pietrobelli, 2005). However, local skills are still needed to absorb the technology, especially for more advanced elements (Zanello et al., 2016).

Another way for countries to connect to global technological development is to buy global firms. Two notable examples are an Indian conglomerate, Tata, buying Jaguar and Land Rover, and Geely, a Chinese firm, buying Volvo (Black, 2020). Such acquisitions can significantly change the capability base of firms.

Overall, a number of learning mechanisms can be identified as occurring though global value chains (GVCs). These are knowledge spillovers; imitation; learning through pressure to accomplish international standards' transfer of knowledge embodied in standards, codes, and technical definitions; mutual learning from face-to-face interactions; learning via deliberate knowledge transfer from lead firms confined to a narrow range of tasks; turnover of skilled managers and workers; and training by foreign lead firms or owners (Pietrobelli and Rabellotti, 2011). These processes can take place through diverse global relationships.

Another important issue is that large global firms are often involved in private governance initiatives (Locke, 2013; Bartley, 2018). These can involve the promotion of industry standards and the regulation of behaviours in supply chains, especially related to the labour and environmental effects of production processes. These regulations are often developed through supplier codes of conduct.

Countries can choose to enter into GVCs to achieve different objectives (Lee et al., 2020). One objective can be to increase employment. Another objective can be to upgrade domestic industries.

Another key issue to consider is how national networks and global connections interact. The characteristics of national innovation systems have been found to shape the experiences of local regions when businesses connect to global value chains (Lundvall, 2016b). One perspective on the different dynamics of domestic and global connections is provided by Lundvall (2016b), who states that frequent local interactions can be connected with new production development, whereas global connections may be more important for developing radical innovations. Bringing together "local buzz" and "global pipelines" has been found to provide advantages to firms (Bathelt et al., 2004). Intersections between global value chains

and local production systems are particularly important for the learning processes of firms in developing countries (Morrison et al., 2008; Pietrobelli and Rabellotti, 2011; Lema et al., 2018).

Finally, as mentioned above, cluster policies can be used to support global networks. One aspect is cluster policy intended to shape FDI flows. Notably, clustered FDI has been found to be better at transferring technology than dispersed FDI (Thompson, 2002). Another example is that cluster policies can focus on facilitating learning through connections to GVCs (OECD, 2018a).

4.2.2 South Africa's Role in Global Production Networks

South Africa's connections to global networks have changed over time. While South Africa has a history of trade sanctions and market restrictions, markets have opened since the 1990s and diverse global connections have been developed and strengthened. South Africa now plays a central role in regional trade networks and a strong role in global trade networks (World Bank, 2016).

A key type of international connection for South African firms is being part of GVCs. South Africa's role in GVCs has increased since 2005 (OECD, 2018). These business relationships create connections between South African firms and diverse global businesses using different types of technology. Often, global lead firms can shape how industries develop, which is a dynamic that is particularly relevant in South Africa's automotive sector, as discussed in the third paper in this working paper series (Alexander, 2022b). However, despite increased integration, overall integration remains poor, which means that companies miss out on opportunities to benefit from technology transfers associated with participating in GVCs (World Bank, 2018b). The foreign content of South Africa's exports was 23% in 2016, which was lower than the OECD average of 25% but higher than the G20 average of 16%. OECD (2020) identifies an opportunity in further integration in regional value chains.

By participating in GVCs, policies made by different national governments can influence South African businesses' options and opportunities. One respondent described how policies set in other countries can create changes in the way production happens in South Africa.

> What's important to note is where the automotive industry is heading. And I think it's been driven largely by the big regulations coming out of Europe and the USA, et cetera. (F22-I39)

A key driver in South Africa is FDI, which is introducing new technology and changing the competitive environment. South Africa is an important entry point to the African market for global digital companies (World Bank, 2018a). South Africa houses subsidiaries of many multi-national companies, which bring in diverse technologies. One respondent described how his company had brought technology into South Africa.

> The 4IR in terms of copulated systems was launched in [our head-office country's] plant, that system was copied down here into our plant where we input, the South African

> person size, shape arms everything into the system to work on. … In our R&D department … we send them off to [the head office country] for training. (F22-I39)

While importing technology can lead to innovation on one hand, it can also decrease local innovation capacity. One respondent spoke about the risk of relying on technology transferred from other countries as limiting South Africa's abilities to further develop.

> Everybody's relying on transplant information, transplant business, transplant robotics. And if those companies pull out, what do we have left? We do not have a solid infrastructure to regrow the economy. You know, if we lose, say, five or six German companies here, and they could leave tomorrow, there's no great incentive for them to be here. (F20-I41)

Sometimes when firms are part of global networks, decisions are made at the global level. One respondent emphasised that supply chain decisions can happen at a global level through head offices in other countries and companies have to compete with a global supplier base.

> Especially in the automotive, all the decisions are being made on a global level. Guys with, the guys from Toyota or Ford, tell us that, you know, the guys in Japan, they'll make a decision, they'll decide, okay, we're going to make it happen, we're going to make a million [car model] this year. Okay, show the performance of South Africa. Show the performance of Thailand. Show the performance of Mexico. Show me the performance of the United States. Okay, we've got a million bakkies to make, we're going to give 300 000 to South Africa, bom, bom, bom, that then filters down. So, if we don't embrace this, and don't become as tech not technologically efficient, or savvy as the likes of America, or Germany or Thailand, then we won't have you won't have jobs. So, it's something that we have to do. (F14-I29)

Finally, an important benefit of FDI can be the creation of new domestic jobs. However, this means that if global companies decide to leave, domestic jobs can be lost, as described by one of the respondents in the interviews reviewed for this paper.

> Couple of years ago, [a major automotive company left] so that that is a direct impact … That's x-hundreds of jobs, gone. That's tier one, two, and three suppliers, additional volume gone. So as a ripple effect, it is monumental, really, really is. And we've seen that. (F20-I41)

As described above and in this series' first working paper (Alexander, 2022a), openness, which can be felt through trade regulations and trade agreements, is a key factor shaping national innovation. South Africa benefits from being part of multiple trade agreements. The country is part of SADC, an inter-governmental organisation promoting regional socio-economic cooperation and integration as well as political and security cooperation among 16 countries in southern Africa. It also involves a free trade area. South Africa also has a customs union with Botswana, Lesotho, Namibia, and Eswatini. Furthermore, South Africa has agreements with the EU, the European Free Trade Association, and Mercosur. Finally, South Africa benefits from the Generalised Systems of Preferences and the USA's Africa Growth and Opportunity Act.

Friction at borders can also be a challenge for creating global networks. DTI (2018) identifies a challenge with illegal imports, customs mis-declarations, improper practices such as staged consignments, and the importation of sub-standard products. This could be addressed through a programme to upgrade the capacity and capabilities of the Customs Division of SARS. In the World Bank's (2018d) Logistics Performance Index, South Africa's customs system (efficiency of the clearance process [i.e., speed, simplicity and predictability of formalities] by border control agencies, including customs) ranked 33rd out of 160 countries assessed. However, in an assessment of trading across borders based on time and cost to export and import, South Africa ranked 143 out of 190 (World Bank, 2019).

Challenges exist in particular when trading with other African countries. One respondent described difficulties he faced with doing business across Africa.

> Doing business in Africa is very hard. We rather do business in South Africa, with partners who feed into Africa, as small solutions as small hubs, even to the extent and we use the bakery as an example, where we've created three bakeries in Zimbabwe, again, through our local bakery partner.
>
> … So often the African market sees, not foreign investment, but foreign involvement as kind of conflict of interest. And it's not everywhere, of course. But we see it on the smaller on the smaller playing fields.
>
> … When it comes to automotive, that's different because it's a government level, because government is speaking. No problem, we can do that. That's exactly how [Company A] got into Nigeria. You know, the chief of [Company A], and even then, Angela Merkel was involved. Why? I don't know. But because there's a big trading partner of Nigeria and Germany. Same as South Africa. I mean, I think our second largest trading partner, other than China is Germany. So, there's already a channel. So, for other people to come in, very difficult to be successful … Predefined, pre-developed solutions into the African continent is very possible. There's no real hurdles, other than being blocked by government. (F20-I41)

In order to promote global connections, South Africa has the Integrated National Export Strategy (Export 2030). The strategy has four pillars: improving the export-enabling environment and international competitiveness; increasing demand for goods and services through market prioritisation, diversification and access; developing exporters, increasing export capacity and strengthening exporter performance through the National Exporter Development Programme (NEDP); and strengthening the export-promotion mechanism through enhancing South Africa's value proposition. The NEDP seeks to promote exports from small, micro and medium enterprises, with a focus on products and services that contribute to employment and a green economy. A key component of NEDP is the DTIC's Global Exporters Passport Programme (GEPP), which trains small, medium and large enterprises that wish to expand their exports. The DTIC, in partnership with the Provincial Investment Promotion Agencies, also carries out export-promotion activities, as well as the Export Marketing and Investment Assistance (EMIA) fund. Genesis Analytics (2019) provides a

positive assessment of South Africa's export-promotion activities. However, they questioned the country's ability to research previously disadvantages firms and expand employment.

5. Conclusion

This paper has provided an overview of key features of South Africa's innovation system. The way this system functions is critical to shaping the potential of 4IR to spread. A number of strengths and weaknesses were identified across the areas of contextual factors, key actors, and network structures. This conclusion provides a summary of key challenges and some recommendations for addressing them. However, these topics are dealt with in more depth in the final paper of this working paper series (Alexander, 2022c).

South Africa has a diverse tapestry of contextual factors that shape the experiences of domestic actors. A key challenge related to the competitive environment is that multiple sectors are dominated by large firms. This situation can stifle competition. Promoting increased competition can enable the development and spread of 4IR. However, regulations are needed to ensure that all members of society have equitable access to network industries and other industries providing social services.

Another key challenge in South Africa is the lack of sufficient infrastructure, particularly related to connectivity services. This creates barriers for businesses to develop and expand 4IR systems. The government can address this problem through upgrading existing infrastructure and implementing new projects. Key considerations include meeting industrial needs, planning infrastructure as an integrated system, incorporating 4IR technology to create enhanced features, and seeking to create opportunities for local businesses through participating in infrastructure development and through benefiting from enhanced infrastructure services.

South Africa also faces diverse challenges related to availability of inputs. In terms of material inputs, South African firms use high levels of local suppliers. However, higher-tech inputs are often imported. To address this challenge, producers of higher-tech inputs can be supported to expand their offerings and lower their prices.

In addition, South Africa has metal and minerals with potential to provide inputs for 4IR technology. Opportunities can be explored for developing new 4IR-related industries that harness these metals and minerals. However, another consideration is that it may be difficult to establish industries that rely on skills and experience that are not readily available domestically (Hausmann et al., 2008).

Human resources are another input-related factor. In some 4IR areas, South Africa has a skills deficit. Another issue is that large segments of the population, with diverse experiences that could contribute new and innovative perspectives to businesses, are unemployed or have left the active labour force. To address employment needs, job creation needs to be a priority. Key opportunities exist related to the adoption of 4IR within existing businesses and

supporting the development of new 4IR-related businesses,[20] in-line with the recommendation for supporting higher-tech businesses above.

In addition, to address the challenge of a shortage of skills, increasing the provision of training to provide skills that are relevant to 4IR developments (e.g., managerial skills, technical skills, creativity, and critical thinking) is needed. Financial barriers also need to be addressed to allow more equitable access to education opportunities. Furthermore, education and training institutes would benefit from having higher levels of collaboration with industry to ensure that training is appropriate. This should include a consideration of processes of lifelong learning, such as the development of new short-courses that can support worker upgrading. Also, in the short term, allowing increased freedom of movement can facilitate migration that can bring needed skills into the country.

The nature of demand in South Africa has different elements. A key issue is the high level of inequality amongst consumers. On one hand, large segments of the population have low incomes and need low-cost products. On the other hand, a group of consumers looking for higher cost and more advanced products exists. Overall, end consumers and domestic businesses looking for inputs have a growing demand for products and service with 4IR features. These demands are being met by both local products and services, as well as imports.

Opportunities exist to develop more 4IR-enhanced products and services targeted at low-income communities, such as mobile digital products. Additionally, as suggested above, support can be given to businesses that provide 4IR-related products or services. Finally, existing local procurement policies can be assessed and improved to provide better outcomes.

Another contextual issue is that the high risk of crime can inhibit innovation. However, this risk has also created opportunities for 4IR businesses providing security services. To address the underlying problem, the root causes of crime need to be explored and addressed. Interventions that are developed may benefit from harnessing 4IR systems, which can also create new business opportunities.

Current systems that are operating in South Africa (e.g., business communication systems) can also create challenges and opportunities for the expansion of 4IR. In some case, legacy systems can inhibit the introduction of 4IR systems as changing the current systems can be a monumental task. In other cases, a lack of legacy systems (e.g., a lack of connectivity infrastructure) can create opportunities for innovation as demand for new systems grow and old systems do not need to be dismantled or replaced. When developing new systems, 4IR

[20] However, the impacts of 4IR on overall job levels are still unclear. This topic is discussed further in the final paper of this working paper series (Alexander, 2022c).

can be incorporated and designs can be conscious of being able to incorporate potential future upgrades as technology progresses.

Another issue related to legacy systems is that the existing employment system relies on high numbers of jobs with high health and safety risks. This situation is creating a driver for developing 4IR systems which can reduce risks. Public policy and business support organisations can support the development of businesses using 4IR technologies to provide products and services that can reduce health and safety risks. This can include subsidizing businesses in the purchases of new health and safety systems.

This paper also considers key actors in South Africa's innovation system. Business actors are shown to be diverse. The economy involves large long standing, slow changing SOEs and a set of newly emerging small start-ups that are increasingly incorporating 4IR. SOEs can benefit from increased support to modernise and adopt 4IR technology and systems. While the start-up environment has strengths, support services can be improved to increase opportunities.

South Africa also has a diverse set of funders. A key challenge related to funding is that many firms do not have easy access to financing. While many funding programmes are available, they are not well coordinated and known. They can also often have complex application requirements. Funding options can be improved by seeking to ensure the process is accessible to smaller and black-owned businesses, continuing ongoing harmonisation efforts, and actively reaching out to firms and industry associations to let them know what funding is available.

South Africa has some world-class research organisations. However, connections between research organisations and the private sector are weak. Consequently, opportunity exists to improve the services of public research institutions to better cater to businesses' needs. Interventions are needed to encourage connections between industry and research organisations. This can involve research organisations actively reaching out to businesses to share opportunities related to research. Additionally, start-ups based on public research could be encouraged.

South Africa also has a wide range of business support service providers which involve public and private organisations. Key challenges in this sector include a lack of awareness and use of existing support services, and low quality of some support services. Business support service providers could benefit from actively reaching out to businesses to let them know about available support services, considering how the designs of support services meet the needs of businesses, and conducting monitoring and evaluation of existing programmes to identify areas for improvement.

Another area that is important to consider related to the roles of different actors in the national innovation system is the role played by policy actors. This is a topic that was discussed in more depth in the first working paper in this series (Alexander, 2022a). One key challenge is that there is a lack of central planning for 4IR development. This is an issue

which is being addressed by the creation of the PC4IR and future developments should continue to work on harmonising innovation policies. Another key challenge is lack of capabilities within some public sector organisations. Challenges include corruption, mismanagement, and a lack of capacity to effectively carry out targeted tasks. These challenges can be addressed through increased training, improving recruitment processes, and establishing performance targets. New and diverse 4IR opportunities exist that can shape society at all levels. Policy makers can consider these opportunities across all of their decisions and seek to harness 4IR elements that can improve public services at all levels, including increasing the efficiency of internal systems and improving qualities of public goods and services.

Finally, this paper explores the characteristics of networks which shape the interactions between these actors. Existing domestic networks provide benefits to local businesses. However, local collaboration has room to be strengthened. Strengthening domestic networks could facilitate higher levels of innovation. This could be achieved through promoting the creation of local networks and clusters by supporting existing and new industry associations and cluster initiatives.

Evolving global networks are creating both barriers and opportunities. South Africa could benefit from increasing trade with other African countries. This trade can be encouraged by making trading processes easier. In addition, when building global connections at all levels, opportunities for South African businesses to learn need to be considered and enhanced to enable future innovation opportunities.

Overall, this paper identifies key characteristics of the national innovation system. Individual actors and industries can experience this system in different ways. The next working paper in this 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), considers how four South African industries experience the national innovation system.

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Annexure A: Overview of Interviews

A key source of data for this paper is a set of 51 interviews conducted in 2019 and 2021 with businesses and key stakeholders involved in connectivity services and manufacturing. An overview of companies that were interviewed is provided in Table 3, and an overview of the stakeholders that were interviewed is provided in Table 4. The interviews typically included one or two representatives of the organisation. Interviews were recorded and transcribed.[21] Transcripts and notes were reviewed and coded using qualitative data analysis software to systematically draw out key findings.

Table 3: Companies Interviewed

Firm identifier	Interviews	Type	Firm size[22]
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 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
F18	I34	Consulting for 4IR 5	Missing
F19	I35	Mining equipment manufacturer 2	Medium
F20	I41	Robot manufacturer 2	Small

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

[22] Size is measured by the 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[22]
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 4: 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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