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Science, Technology, Innovation Management for Industrial Development in South Africa: Implications for The Fourth Industrial Revolution

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Despite South Africa's strong interest in making sure it takes a global position as a contributor to the implementation of the fourth industrial revolution, literature shows that very little has been done to examine South Africa's readiness. The present study critically explores the opportunities for South Africa to promote technology and economic activities in the context of the fourth industrial revolution. It weighs South Africa's readiness by examining the quality and quantity of the knowledge from both the demand and supply sides. Hence, science, technology & innovation (STI) as the main driver of the fourth industrial revolution was explored by analyzing South Africa's S&T Policy, Innovation System, Knowledge Systems, and Industrial Policy. The study concludes that despite South Africa's numerous challenges, it can significantly contribute to the fourth industrial revolution. However, this will require strong synergy/coordination among its financial, human, natural, and physical resources. Proven strategies that South Africa may adopt for the buildup of capabilities for the fourth industrial revolution include foreign direct investment inflows, trade of technology-intensive products, acquisition of external technologies, reserve engineering, and R&D consortia.

Keywords: *STI Policy, National Innovation System, Research, Development, Industrial Policy, Innovation, Industrialization.*

Introduction

Structural Transformation and Industrial Revolutions in South Africa

Structural transformation has led to the way businesses now operate. Most businesses are increasingly becoming automated these days hence, phasing out low-skilled jobs but creating opportunities for some highly skilled positions. As a result, the labor-intensive/absorbing industries are far thinning while the knowledge-intensive sectors are rapidly expanding. Today, the business world has already moved into the digital age where humans and machines interact to increase productivity. Indeed, conventional ways of doing work involving a large amount of human labor are phasing out gradually and increasingly being replaced by machines, robots, software, amongst others.

History has recorded four paradigm shifts in the way work/labor/industry is structured. These epochs are known as industrial revolutions. The first industrial revolution occurred in the 1800s. Before the first industrial revolution, human labor, the use of animals for transportation, and reliance on agriculture were the tools for sustenance. The first industrial revolution was premised on scientific discovery – Newton's Law of Motion and Law of Gravitation, which informed Thermodynamics and Fluid Mechanics. The first industrial revolution birthed the invention of the steam engine. It also introduced automation. Hence, machines were being used as part of manufacturing. In South Africa, the discovery of a steam engine was deployed to increase mining, agriculture, and manufacturing efficiency. Also, with the steam engine, transportation of goods from manufacturing plants, food from the farm, diamonds from the mines became quicker. This spurred the migration of people from their farmsteads to live closer to work leading to the formation of townships. This series of activities marked the first industrial revolution in South Africa.

The second industrial revolution was premised on knowledge evolution based on the work of Michael Faraday on how movement between a magnet and a conductor produces electricity. Hence, this led to the discovery of the electric motor. Electricity discovered was now used to power equipment, machinery, and tools, thus leading to mass production. The second industrial revolution happened between 1820 and 1900. In South Africa, the second industrial revolution occurred when electricity was first introduced to light up the dark tunnels in the mines. Then use of electricity spilled over for use in cities, homes, and industry. The broader use of electricity marked South Africa's second industrial revolution.

The third industrial revolution was based on the discovery of materials that conduct electricity under certain conditions – semiconductors. The use of semiconductors led to the digital revolution. The third industrial revolution happened in the 1900s. The discovery of semiconductors led to computers and other digital products like phones, television, etc. In 1952, IBM set up its first head office in South Africa. This marked South Africa's third industrial revolution.

The fourth industrial revolution is evidenced by intelligence being introduced into machines. This enables machines and humans to interact to bring about higher productivity. World Economic Forum described the fourth industrial revolution as "a fusion of technologies that is blurring the lines between physical, digital, and biological spheres" (TIPS, 2018). The fourth industrial revolution is known as the second wave of the internet, fueled by the increasing number of digital connections between people, and between people and things, and between things and other things. The fourth industrial revolution introduced new technologies such as artificial intelligence, augmented reality, blockchain, drones, the internet of things, robotics, virtual reality, 3D printing, simulations. The fourth industrial revolution is already changing the way we live and work. Workplaces are going smaller with fewer people working there. In addition, some kinds of jobs (repetitive and overly stramineous jobs) are now being automated. The fourth industrial revolution is quite disruptive because it will render some known economic theories null and void. This is because digitization and automation will reduce the influence of human behavior in business operations. Hence, information asymmetry in markets will significantly reduce, thereby increasing market efficiency.

Industrialization around the world

All successful industrial economies of the 20th century developed through active industrial policy. The industrial policy was the key to the development of the United Kingdom, the United States, Germany, Japan, and East Asian economies after World War II. UNECA (2016) reports that the experiences of industrialized countries show that there are different avenues how to develop manufacturing capabilities from using infant protection (Britain, Brazil), low and targeted protectionism (Belgium), import substitution (the US) and export promotion (Korea and Taiwan). Industrial policies in some countries included the prohibition of FDI (Japan) or targeting FDI in specific sectors (China). In other, the industries were built on domestic natural resources (Chile) or import of raw materials (South Korea) or a mix of both (Malaysia).

The Newly Industrialized Economies (NIEs) industrial policy was inspired by the policies of the advanced Western countries (Chandra & Yokoyama, 2011; DAS, 2016; Benner, 2019). Traditional industrial policy associated with the advanced countries and the newly industrialized economies in the post-war era encompassed a wide range of targeted policies deployed for industrial development. The current policy space requires maneuvering and more outstanding commitment to economic growth through industrialization (UNECA 2016). However, targeted policies in infrastructure investment, skills development, tax benefits, public finance to establish R&D centres, cooperation between private sectors and universities, export taxes, and public procurement can still be utilized to encourage innovation and industrial development.

The role of the state in industrial development has changed over time. However, the state has always played multiple roles in developing domestic capabilities, including those of the owner, the facilitator, and the selector. While it is true that the current world economy has changed the ways the state inserts itself in governing industrial policy, the state continues to be an important and irreplaceable actor, an enabler of innovation and industrial development.

The Promise of the Fourth Industrial Revolution

The fourth industrial revolution brings with it many advantages. One obvious benefit is increased productivity. Just as recorded in the previous industrial revolutions, the productivity of each industrial era went up significantly. It is also expected that the fourth industrial revolution will lead to improved quality of life. Digitization has already made our day-to-day activities more manageable and more intelligent. Scholars also believe that the fourth industrial revolution will create new markets and growth opportunities. It will blend improvements from several previously separated fields to create a new product or a new service. Also, the fourth industrial revolution is expected to reduce the barriers between inventors and markets. This is because entrepreneurs can now start up lean and test their products in the market quickly with lower costs.

We are now in the era of the fourth industrial revolution. However, only countries with a robust competitive edge can significantly benefit from the industrial revolution. There are also some discussions on the downside of the fourth industrial revolution. It can lead to increased inequality, especially for a country like South Africa that is already plagued with the triple challenge of income inequality, poverty, and mass unemployment. The fourth industrial revolution could also have issues of ethical concerns. With access to more data about an individual and a group of individuals, the risk of using it for personal gain and manipulation is high. Also, now that almost everything is connected, the risk of hacking information and using it for malicious intent will become more prevalent.

Despite South Africa's strong interest in making sure it takes a global position as a contributor in the discourse and implementation of fourth industrial revolution technologies, a scan through literature shows that little or nothing has been done to examine if South Africa has the capacity and capability to do this. Hence, this study sets out to fill the gap in the literature by doing a meta-analysis/synthesis of information from different sources.

Methodology

The study represents a high-level synthesis of grey works of literature and relevant academic literature. Hence, data were sourced mainly from South African Government Departments and Websites. The study critically explores South Africa’s readiness to take advantage of the fourth industrial revolution for economic growth and development by leveraging on the following steps:

- Appraising South Africa’s Science and Technology (S&T) policy documents since 1994 to check the political will of South Africa's government. Some of the critical documents reviewed included the 1996 and 2019 White papers on S&T to determine if the existing policies, instruments, and institutions are adequate to make South Africa effectively contribute to the fourth industrial revolution.

- Evaluating the robustness of South Africa's National Innovation System by sourcing data from reports by the National Advisory Committee for Innovation (NACI), and Centre for Science, Technology, and Innovation Indicators (CeSTII) and Department of Science and Technology (DST) to investigate if the country's innovation system creates a good platform for the fourth industrial revolution.
- Examining the research and knowledge base required for the fourth industrial revolution in South Africa. Data was sourced from WIPO Statistics database, Department of Science and Technology, Academy of Science of South Africa, and Global Innovation Index report. In addition, other policy instruments of government consulted were the South African Research Chair Initiatives, Centre for Excellence (CoE)s, Research Councils, Innovation funds, R&D funding, National budget for STI, to check the integrity of South Africa's knowledge base for the fourth industrial revolution.
- Reviewing the Industrial Policy and Action Plan (IPAP)s for over the last ten years, National Industrial Policy Framework and Department of Trade and Investment [DTI] Reports (now known as Department of Trade, Investment and Competition) to check the readiness of South Africa's industrial sector to accommodate the looming structural changes. Also, by weighing the potential impact of the government's horizontal and vertical policies on specific industries for the fourth industrial revolution.

Results and Discussion

Appraisal of South Africa's Science, Technology, and Innovation Policy

South Africa's efforts for innovation initially followed the line model of innovation - from research to market (technology push) or from market to research (technology pull) (Juma, 2006; Kahn, 2013; Cassiolato & Lastres, 2011; Daniels, 2017). The conventional wisdom was that the research from universities and research institutes was the primary and most valuable knowledge source. However, a nationwide business innovation survey conducted in South Africa indicated that market sources of research (internal expertise, customers, competitors, and suppliers) were more important than institutional (universities and research institute) sources (Moses, Sithole, Labadarios & Blankley, 2011; Blankley, 2012; Blankley, 2013). Insight from the business innovation survey made South Africa move away from the linear mode of innovation thinking and adopted the "firm-centric" innovation approach (Marais & Pienaar, 2010; Mugabe, 2011; Kahn, 2013; Manyuchi, 2018). In this approach, the firm is seen as the centre of innovation activity. This approach recognizes that the firm mainly carries out innovations in collaboration with other firms, knowledge institutions, and market agents. The role of government was judged to be minimal. The government's role was to ensure that the appropriate framework conditions – macro-economic stability, human resource provision, intellectual property rights protection, regulations, and financial incentives – were in place to support innovation activities. This approach is consistent with the Oslo Manual and business innovation surveys. However, with the diffusion of the National Innovation System approach, South Africa recently moved to the third phase of innovation policy. This is essentially still “a work in progress."

Though the 1996 White paper on S&T policy in South Africa led to South Africa’s National Innovation System (NIS) development (SA. DA, 1996). The policy document had many challenges. An appraisal by OECD in 2007 highlighted that many factors are were constraining South Africa's NIS performance. Some of the fundamental issues raised were lack of policy coherence and coordination, insufficient business, and civil society involvement in the innovation process. The report further bemoaned the inadequate supply of high-level science and technical skills in the economy. To effectively address these significant pitfalls in the 1996 policy document, it was reviewed, and a new policy document was enacted in 2019.

The guiding principle of the 2019 White Paper is that innovation can shape a different South Africa. The 2019 White Paper became the fundamental of policy on science and technology, and it addressed some failures requiring concerted national action.
These weaknesses include:

- “A fragmented and inadequately coordinated Science and Technology system.
- The erosion of innovative capacity.
- Poor knowledge and technology flow from the science base into the industry.
- Poor networking both within the region and in the global context.
- Inefficiencies and poor levels of investment in research and development.
- Imbalances created by past policies and actions.
- A poor competitive position within the global environment”.

While the new white paper prosed the following policy direction proposed:

- “Creation of clear channels for capacity building, science and technology, human resource development, and inequity redress.
- Establishment of mechanisms to re-allocate government spending according to new priorities to promote innovative solutions, particularly related to problems of the disadvantaged.
- Processes that will challenge government research institutions to derive more support from competitive sources of funding.
- Processes that will achieve efficiencies in R&D spend by promoting the diffusion of research and technology development results.
- Introduction of processes allowing longer-term perspectives in planning and budgeting for R&D”.

The intervention provided by the White Paper process covered six themes:

- "Promoting competitiveness and job creation.
- Enhancing the quality of life.
- Developing human resources.
- Working towards environmental sustainability
- Promoting an information society.
- Producing more knowledge-embedded products and services".

Within this shifting technological and economic paradigm, the 2019 White Paper attempted to place innovation at the forefront of helping South Africa address its socioeconomic challenges successfully while adapting to technological changes. According to this policy document, South Africa's extent to achieving these technical and developmental goals would depend on the active collaboration between the private, public, academia, and civil society (SA. DST, 2019). The 2019 White paper recognizes that the innovation outcome of the country would depend on strengthening the networks and relationships between institutions which is consistent will very recent scholar works in South Africa (Daniels, 2017; Kruss, Petersen, Rust, and Tele, 2017; Marcelle, 2017; Manyuchi, 2018; Kotzé, 2019).

Evidence-based policymaking is at the forefront of the 2019 White Paper on STI. Evidenced-based policymaking would require setting up an entirely new STI government plan, the increased collaboration of all STI partners, and the increased participation of all stakeholders to facilitate the learning and implementation of policy and specific STI initiatives. The 2019 White Paper further recognizes the importance of creating an environment conducive to realizing the potential benefits of STI. This necessitates addressing skills shortages, creating and enabling an atmosphere for business development and growth.

Evaluation of South Africa's National System of Innovation

Because the linear model of innovation was still entrenched in the thinking of policymakers in South Africa, South Africa's NIS for a long time followed the narrow view of the NIS (Marais & Pienaar, 2010; Abrahams & Pogue, 2012, ASSF 2013). Until very recently (2019 White Paper on S&T), It was believed that increased investment in basic and applied research would directly lead to higher innovation prevalence (SA.DST, 2019).

When compared to other African countries, the South African NIS may be viewed as relatively advanced. However, there are still systemic weaknesses in the framework. The pre-NSI policy and institutional environment were driven by objectives such as military dominance (in a regional context), food security (in terms of national security), and energy self-sufficiency (SA. DA, 1996).

The 2019 White Paper attempted some notable policy shifts within South Africa's NIS. These include the following:

- "Increasing the focus on inclusivity, transformation, and linkages in the NIS.
- Enhancing the innovation culture in society and government (adopting a whole-of-government approach to innovation).
- Institutionalising approaches to improve policy coherence and programme and budget coordination in the NIS.
- Instituting monitoring and evaluation systems.
- Developing an enabling environment for innovation.
- Including and supporting civil society and business, with a focus on SMEs, in government planning and funding.
- Developing local innovation ecosystems.
- Supporting social and grassroots innovation.
- Improving the human resource development pipeline and instilling an innovation mindset from basic to tertiary education.
- Developing the next generation of researchers and ensuring that PhD graduates fit the needs of the economy.
- Endorsing open data, open science, and open innovation approaches.
- Supporting inter-and transdisciplinary approaches to knowledge development
- Prioritising a pan-African STI agenda.
- Increasing investment in the NIS and optimizing the productivity of these investments".

As the economy became more technologically informed, the 2019 White Paper emphasized the need to restructure higher education to deliver the required knowledge, training, and research. Hence focus on science, engineering and technology became intense. Funding from the government also facilitated linkages between SETIs, strengthening the links between science (institutions) and industries. This policy gradually led to the substitution of labor with technology. Hence, there was a total shift from a closed economy controlled by the government to an open economy.

However, South Africa's National Development Plan 2030 adopts a system-wide view of STI concerning broader society (Zarenda, 2013). The NDP emphasizes continuous learning, partnerships, networks, coordination, and coherence essential for economic growth. The NDP stresses the importance of collaboration among government, business, and knowledge institutions. It also emphasized the importance of opening the skills pipeline to enhance technology and knowledge globally available to solve South Africa's social and economic needs (Zarenda, 2013). The NDP also advocates that local research systems should be integrated into the NIS (Zarenda, 2013). Also, there is a need to develop an augmented new set of output indicators that go beyond the traditional measures that will facilitate the determination of the value of investment and link to the goals of the NDP.

Consequently, South Africa's NIS insufficiently supported a transition from a firm reliance on a resource-and commodity-based economy to one that would be characterized by value-adding and knowledge-intensive activities (Marais & Pienaar, 2010; Abrahams & Pogue, 2012). South Africa's NIS, however, has some fundamental challenges. There seemed to be only limited horizontal coherence and integration between elements of the NIS. This was because there was no coordinating body at the national level. The NACI responsibility of coordinating the NIS was constrained because it was put under the Department of Science and Technology (DST) instead of the presidency. And thus, NACI had no structural location that would afford it the authority needed to coordinate a national system effectively.

Another main challenge was that the business sector had not been fully participating in the NIS. In contrast, the business sector accounts for more than half of the research intensity in South Africa. The business sector only makes funds available for researchers and students to do their research. The business sector needs to be more strategic in the way they fund research. Research funding needs to be problem-based and should not be done haphazardly. Research should be demand-driven (based on the needs in the industry) and not supply (to increase the overall amount of knowledge generated in the country).

Assessment of South Africa's Research System

According to the 2019 White Paper for Science and Technology, South Africa's government strengthens the country's research system by strengthening existing institutions responsible for knowledge production and creating new ones where necessary (SA. DST, 2019). Through the National Research Foundation, South Africa has provided grants, bursaries, and incentives to university staff and students. Also, South African Research Chair Initiative has been expanded as more chairs have been award to researchers (particularly females) over the recent years (SA.DST, 2019). Also, more Centres of Excellence for specified research have increased significantly in response to South Africa's STI policy. The Global Innovation Index (2016, 2020) also recognized that South Africa is strong in market sophistication, innovation investment, knowledge absorption, and knowledge impact. However, patenting remains an area yet to be developed. As a result, South Africa remains a net importer of technology. Academy of Science of South Africa (ASSAf)'s report of 2013 showed that South Africa's STI expenditure had increased nine-fold. However, despite these investments, South Africa's research intensity (Gross Expenditure on Research and Development as a percentage of GDP) stagnates at 0.7% over the years (ASSAf, 2013). Thus, South Africa's research intensity is far below the recommended 2%. In South Africa, private investment remains the major contributor to Gross Expenditure on Research and Development (ASSAf 2013; Brant & Sibanda, 2019; Hart, Booyens, Fakudze & Sinyolo, 2019).

Over the last ten years (2010 to 2019), South Africa's patent filing (Resident and Abroad) has been hovering between 1500 and 2000 (WIPO Statistics database). The patent filing has reduced by a quarter over the last ten years. More specifically, in 2019, the total number of patents applied by residents in South African was 567, while the number of patents granted to residents in South African was 694 in the same year (WIPO Statistic database). However, foreign applicants' number of patent applications in South Africa was 6347 (WIPO Statistic database). At the same time, the number of patents granted to foreign applicants in South Africa was 5468 in the same year. Also, South African residents' patent application made abroad/foreign countries was 947 (WIPO Statistic database). The number of patents granted abroad (in foreign countries) to South African residents was 862 (WIPO Statistic database). Based on this information, it can be deduced that foreign applicants drive the patent system in South Africa. South African patents application in South Africa and abroad is much lower than the number of patent applications by foreign applicants in South Africa. The number of patents in force continues to increase over the years. For instance, between 2013 and 2019, the number of patents in force has increased by approximately 42%, from 54220 in 2013 to 76936 in 2019 (WIPO Statistic database). The technology balance of payments gap is not too large by world standards. Business innovation surveys in South Africa show that not less than half of businesses are innovating. But only 3% of innovating firms usually apply for a local patent (Moses, Sithole, Labadarios & Blankley, 2011; Blankley, 2012; Blankley, 2013). The capacity to generate patents in-house is relatively low. South Africa’s domestic patenting shows a volume pattern spread among many institutions (universities and business organizations) rather than being highly concentrated only in the universities (Brant & Sibanda, 2019). Literatures (De Beer, Armstrong, Oguamanam & Schönwetter, 2014; De Beer, Oguamanam & Schonwetter, 2014; Jegede, 2020; Ncube, 2021) have identified different reasons for the low prevalence of patent application in Africa. These pieces of literature posit that while patents represent an innovation output, relying entirely on patents as proxy for innovation output in Africa will be erroneous. This is because some technologies are not patentable, e.g., software is not patentable in all jurisdictions, while some, such as South Africa grant software patents. At the same time, not all inventions are patented. Most small firms and entrepreneurs do not get to protect their technologies/inventions by patenting. Instead, they use alternative ways to protect their inventions, such as secrecy, product complexity, lead-time advantages, and brand loyalty. Also, some innovations or inventions were not developed for commercial exploitation, and they are more of producer innovation. Hence, the inventors do not attempt to get a patent. All these add substantial doubt to the interpretation of patent count data. Another pitfall of relying on patent data is that patents only represent inventions, not innovation activities nor innovation investments to commercialize new technology. Patents are also just proof of application of scientific knowledge and are not always proof of advancements in the frontiers of knowledge. It remains to be seen how the patenting trends as noted above will be impacted by the grant of a patent naming AI as an inventor in South Africa on July 28 2021, the first in the world (Basham 2021, CIPC South African Patents Journal 2021). This development will generate intense debate and commentary as the IP protection of AI related inventions is very topical (Ncube & Rutenberg 2020).

Review of South Africa's Industrial Policy

The Industrial Policy Action Plan (IPAP) has been in existence for the past ten years. The impact has been felt in various sectors of the economy– most notably, in Automotive, Agro-processing, Clothing, Textiles, Leather, and Footwear (CTLF), Plastic industries (DTI, 2018). The successes were achieved due to the formation of a dais of cross-cutting and sector-specific interventions, comprising of industrial financing, the placement of provisional incentives, domestic procurement, and the introduction of the National Industrial Participation Programme (NIPP) and a widespread change in demand- and supply-side industrial policy instruments targeted to acquiring more sophisticated levels of financing and advancing the competitive edge of the manufacturing industries (Viviers & Steenkamp, 2012; Letsoalo, 2013; DTI, 2018).

Over the last ten years of using IPAP, the exports of manufactured goods have grown four-fold, while imports of goods have only doubled (DTI, 2018). The core sectors in which South Africa has gain core competence in exports of manufactured goods are metals, metal products, machinery, and equipment (DTI, 2018). Although South Africa remains on the deficit side on the balance of manufacturing trade, manufactured exports remained lower than manufactured imports. However, growth in the manufacturing sector in South Africa has been strengthened by growth in manufactured exports to other countries in Africa (DTI, 2018). Hence, the trade balance demonstrates a solid surplus.

The automotive industry drives South Africa's manufacturing sector. With significant support from the government (through the Automotive Masterplan 2020), South Africa has maintained a world-class automotive production capability. The report by DTI (2018) shows that the automotive industry contributes 33% to manufacturing GDP and about 6% to overall GDP. The DTI's Automotive Masterplan 2020 fosters linkages between the automotive companies, component suppliers and labor, to ensure that South Africa sustains a competitive advantage with evidence of increased exports and occupying most of the value chains. Government's intervention programmme (the Presidential Nine-Point Plan) identified the agro-processing industry as an essential sector for labor-intensive growth. The agro-processing industry accounts for contributing 20.3% to manufacturing GDP and 2.7% to total GDP (DTI, 2018). The clothing and textile industry contributes 8% to manufacturing GDP and 2.9% to overall GDP with the government's support through the Clothing and Textile Competitiveness Programme (CTCP). The metal fabrication, capital & rail transport equipment has also enjoyed government support through the National Tooling Initiative (NTI) and the National Foundry Technology Network (NFTN) – initiatives.

Government intervention led to critical skills development and job creation programmes, technology development and adoption, enterprise development, and export promotion. This made the sector contribute as much as 16.7% to manufacturing GDP and 2.2% of total GDP in South Africa (DTI, 2018). While the government's policy intervention in the plastic industry also increased competitiveness and productivity in the plastic industry, the industry accounted for 14.5% of manufacturing GDP and 1.9% of total GDP in South Africa (DTI, 2018).

IPAP interventions have prevented South Africa from plunging from possible disastrous de-industrialization. The enactment of IPAP has sustained a bumpy and uncertain economic recovery for South Africa, against South Africa's structural challenges, which have insistently weaken the manufacturing sector since 1994 -post-apartheid (Letsoalo, 2013). Some of the notable challenges facing industry growth in South Africa include poor implementation of South Africa's industrial policy. Also, there is some incoherence in programme alignment, interventions, and instruments prescribed in the industrial policy. DTI (2018) reported the inconsistencies in South Africa's policy has a severe negative impact on "the effective use of critical industrial policy levers like localization, positioning the country to take full advantage of new growth opportunities related to the Digital Industrial Revolution; and leveraging South Africa's comparative resource advantages by linking the primary sectors of mining and agriculture with the manufacturing sector, across all the key-value chains". Another main challenge in effectively implementing the IPAP is the concentration of ownership and control (Mokhethi, 2017; DTI, 2018). Businesses have a monopoly of market power, thus using it to their advantage, especially to earn good profit margins. Till now, the opening-up of the economy to a diversity of participants has not happened. Other challenges to the implementation of IPAP are associated with high logistics costs, illegitimate imports, misdeclarations on the part of customs, extremely high port tariffs, erratic supply of electricity, and the high price of key intermediate inputs (Zalk, 2014; Mokhethi, 2017; DTI, 2018)

Implications of the Study: Is South Africa ready?

Based on the policy documents and other government documents reviewed, it is evident that South Africa still operates mainly with the 'linear model of innovation' that focuses on increasing investment research and development and creating strong science and technology organizations/institutions. The broader view of the innovation system emphasizes the linkages and interactions within the system. While South Africa has some powerful institutions, the interactions among the actors and stakeholders within the innovation system are still weak. Scholars have stressed the importance of collaboration among government, business, industry, research institutions, science councils and universities, and the public. Hence, the government has an essential role in creating an enabling environment for knowledge development and innovation through the interaction of the actors within the innovation system. Government should make the right external framework conditions necessary for creation. These external conditions include macro-economic stability, social context, political milieu standards, funding, among others. Apart from this, through policies and suitable instruments, the government must ensure the supply and mobility of knowledge workers: human resource development, immigration law, networking mechanisms.

Furthermore, the government needs to encourage the promotion of knowledge exchange/flows within the innovation system. Another essential role of government will be to ensure the timely provision of knowledge infrastructure (public research organizations, provision of scientific and technological services, provision of research and communication infrastructure). In addition to those mentioned above, the government will need to ensure that timely monitoring and evaluation are done as the government provides that its policies are based on evidence.

Universities have played a crucial role in knowledge generation. Still, in South Africa, the outputs are more supply-driven rather than demand-driven. Hence, the vast amount of research/knowledge/technology produced over the years has not sufficiently harmonized with the necessities of the NIS. Another main challenge is that South African technology abroad receipts are deficient compared with those of developed countries. Therefore, there is a considerable gap between payments for technology from abroad and receipts.

The Business sector also has a vital role in preparing the innovation for the fourth industrial revolution in South Africa. However, South Africa's GERD/GDP ratio hovers around 0.7 to 0.8%. The business sector (including state-owned entities) accounts for at least half of this South Africa's research intensity. Hence, the kind of research done or being funded by the business sector plays a vital role in the overall development of South Africa.

Proven Strategies Towards the Fourth Industrial Revolution: options for South Africa

Based on the assessment of South African government policies, policy instruments, and institutions. South Africa cannot take a leadership position in the fourth industrial revolution based on the quality and quantity of skills, knowledge, and technology. However, with a clear strategy, South Africa can leverage external support to fulfil her desire to take a leadership position in the fourth industrial revolution in Africa and the rest of the world. Even developed countries must leverage external support to develop new technologies and innovate. Some options for South Africa are discussed below.

Foreign Direct Investment

Naude, Szirmai, Lavopi (2013) posits that one rapid channel towards industrialization is a domestic investment in facilitating the technological transfer of technologies from abroad for domestic use. FDI enables foreign technologies to be cheaply accessed locally without having to go through research and development. With time South Africa can begin to add its innovations and expanding the global technological frontier. FDI will promote the free exchange of scientific and technological information and the diffusion of the imported technology in South Africa. However, absorptive capacity is the key to taking advantage of foreign technology.

Several studies (Ali, & Guo, 2005; Liu & Daly, 2011; Liu, Daly & Varua, 2012; Liu, Daly, & Varua, 2014) carried out an empirical analysis highlighting the key determinants of FDI inflow across low and high technology manufacturing in China. The studies pointed out that China introduced several foreign investment policies that attracted foreign direct investments, bringing advanced technology and increased manufacturing exports. The resultant effect was that China had seen a decline in low-tech manufactured goods of total exports and an increase in export in high-tech manufacturing. For China, FDI was promoted through Special Economic Zones (SEZs) and National Economic and Technology Development Zones (NETDZ). Liu and Daly noted that breaking up manufacturing into different categories is essential for policymakers to attract the right kind of FDI (natural resource seeking, market seeking, and efficiency seeing of products or process or strategic asset seeking). They found that efficiency-seeking FDI in China has created a movement from low-tech to high-tech manufacturing. The efficiency of FDI is positively correlated to the quality of labor and infrastructure development. Thus, FDI is one strong option for South Africa to achieve the fourth industrial revolution.

Acquisition of External Knowledge

Patents and other intellectual property rights are used as a vehicle for achieving monopoly privileges which militate against conditions conducive to foreign investment and hinder the flow of technology to developing countries while restricting their technological advance through imitation and adaptation (Vaitsos, 1972; Sherwood, Scartezini, & Siemsen, 1998).). These technologies or rights (patents, industrial designs, trade secrets) are transferred from the inventors/technological frontiers to those interested in using them (Vaitsos, 1972; Sherwood, Scartezini, & Siemsen, 1998); in this context, South African Intellectual property rights (IPRs) provide a platform enhancing firms in developed countries to innovate continuously. These avail developing countries can gain access to knowledge and technology on the global frontier (Saggi, Maskus, & Hoekman,2004; Hutchison, 2006). OECD (2018) classifies intellectual property acquisition as an innovation activity, while the adaption/modification of such intellectual property is seen as innovation. South Africa can leverage intellectual property/external technologies such as patents to actualize the fourth industrial revolution.

Trade of Technology- intensive Products

Several studies have linked the trade of new products and production technologies to industrialization. Some pioneering studies include Dagenais, Mohnen & Therrien (1997) on Canada's manufacturing sector showed that output elasticity of Foreign R&D trade is more important than for domestic R&D. The paper by Bernstein, & Mohnen (1998) also showed there was significant knowledge transfer between US and Japan through a trade of technology-intensive products between the two countries. A similar study by Eaton and Kortum (1995) carried out on 19 OECD countries showed that the trade of technology-intensive products helps facilitate the process of technology-intensive spillovers. Important factors responsible for the ability to absorb foreign technology for industrial development were technological gap and absorptive capacity. Other works include Sjöholm (1996) paper in Sweden, which identified that technology proximity and international trade positively affect the inflow of knowledge to Sweden. This was captured through 261 patent references. This result was in line with Verspagen (1997) on 22 sectors in 14 countries and Vuory (1997) Finnish industrial sectors. These pioneer studies, together with more recent studies (Cincera, Kempen, Van Pottelsberghe, Veugelers & Villegas, 2003; Hall, Mairesse, & Mohnen, 2010) showed a positive contribution of trade of technology-intensive products to innovation and industrialization.

Reverse Engineering and Imitation

Revolutionary studies (Kim & Dahlman, 1992; Hikino & Amsden 1994; Frost, 1997; Lee & Lim 2001) have highlighted the importance of imitation and reverse engineering in industry growth and the innovation process. Frost (1997), in his work "Imitation to Innovation," presented the story of Korea's surprising ascendance from a subsistent agricultural economy to a newly industrialised economy within thirty years from the early 1960s to the early 1990s through imitation and reversed engineering in the automobiles, electronics, semiconductors, and the small-firm sector. Today, South Korea is known worldwide for its wide application in the field of semiconductors. They started by copying until they acquired enough competence and capability to develop their brand using their technology. Hikino & Amsden (1994) highlighted one of the benefits of late industrializing economies: the opportunity to adopt and adapt technologies of the technologies of industrialized countries. They cited the case of Japan, South Korea, Taiwan, Brazil, and Mexico succeeded in industrializing even though their leading enterprises have not enjoyed the competitive asset of pioneering technology. They have had to industrialize by borrowing and improving technology already developed by experienced firms from more advanced economies. Lee and Lim (2001) introduced the concept of leapfrogging in their paper that explored the different technological evolution of purposively selected industries in Korea. These sectors were the D-RAM, automobile, mobile phone, consumer electronics, personal computer, and machine tool industries. In their quest to discover the Korean companies' technological capability building, they found three episodes of catching up. First was the path-creating catching-up of the CDMA mobile phone. The second was the path-skipping catching-up associated with the D-RAM and automobile industries and the path-following catching-up in consumer electronics and personal computers and machine tools. They concluded that the path-creating and path-skipping stages of catching-up as leapfrogging. South Africa, a newly industrializing countries could leverage on any of the three paths (path-following or path-skipping or path creating) toward achieving the fourth industrial revolution. However, the path-skipping approach may be the best approach for South Africa without the unlimited capacity in terms of knowledge and technology for the fourth industrial revolution.

R&D/ Technology Consortia

Another viable option for South Africa is collaborative R&D/technology development with countries that are at the frontiers of the fourth industrial revolution technologies. This approach has been known to be very effective in literature. This approached was used effectively in Asia several decades back. For instance, Mu & Lee (2005) and Lee (2005) explored the evolution of R&D consortia in Korea and the effect of technology catching up looking at the telecommunication industry in China. The case studies were the Shanghai Bell, the CIT-led R&D consortium, and Huawei (an indigenous company). They analyzed how the catching-up in the telecommunication industry occurred. They found out that catch-up was possible because of knowledge diffusion from Shanghai Bell to both the R&D consortium and Huawei. As well as market trade for technology with industrial promotion by the government.

R&D consortia also help to minimize the cost of risks associated with new technology development. In developed countries (USA, Europe, and Japan), R&D consortia originated due to the high risk and high cost of R&D. Firms sought new organizational forms to reduce and share these risks through R&D consortia and collaboration. In the 1980s, series of collaborative R&D ventures have emerged in Taiwan within a quite distinctive institutional framework. R&D consortia could be dynamic, unlike the conventional R&D collaboration that occurs mainly among firms. For South Africa, R&D collaboration should bring together firms, public sector research institutes, government agencies, and the financial sector, just as was the case in Taiwan. Very recent studies on Asian countries (especially China and India) have shown that technological capabilities are still being built through technology transfer and spillovers resulting from collaborative R&D or collaborative technology developments (Lee, Park & Krishnan, 2014; Lee, Gao & Li, 2017; Lee, 2019; Lee, 2021).

Conclusion

Thus, the study concludes that while strong institutions characterize South Africa's research and innovation system. However, the relatively low intensity of linkages and interaction among the key actors of the innovation system continues to pose a threat to South Africa taking a leadership position in the fourth industrial revolution. The implementation of innovation policies must follow the broad view of the innovation system, which encourages collective production of knowledge, technology, and innovation by all the actors/elements/stakeholders of the innovation system—as against focusing on building intense research and development institutions with specific mandates, working in isolation or the firm-centric approach that sees firms as the driver of innovation. The study also stressed the role of government in driving the growth of the industry through appropriate industrial policy. The study puts forward that strong coordination among South Africa's internal resources (financial, human, natural, physical, and institutional resources) and external resources (foreign direct investment, trade of technology-intensive products, acquisition of external technologies, reserve engineering, and R&D consortia) could help South Africa build capacity to leapfrog, to be a global contributor to the fourth industrial revolution.

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