9

South Africa

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9.1 Introduction

South Africa is the thirty-fifth largest economy in the world with a population of 57 million and an estimated per capita income in 2016 of USD 13,500 in purchasing power parity (PPP). It is rich in natural resources and has well-established industries, including mining, manufacturing, and agriculture with a strong financial, transport, and communication infrastructure. However, it faces substantial economic challenges, including a low rate of economic growth, one of the world's highest levels of income inequality, deep structural unemployment, and high mortality rates during the 2000s among the working-age population due to epidemic HIV and tuberculosis.

South Africa's unique history of apartheid between 1948 and the early 1990s influenced the structure of the public science system and consequently knowledge transfer. During the apartheid period, individuals who were classified as "African," "Indian," or "Coloured" (essentially those regarded as being of mixed ethnicity) had limited access to tertiary education and were restricted to attending higher education institutions (HEIs) in predetermined disciplines such as technical training, healthcare, education, administration, and teaching. Only one institution offered medical training. In contrast, the HEIs for the white population, including a network of public research institutions with advanced research capabilities, enabled the early careers of four Nobel Laureates in science and medicine, and supported innovation to circumvent sanctions (Van Vuuren 2017).

Sanctions during the apartheid years drove a need for self-sufficiency, which was met through government-owned enterprises in key sectors, including water, energy, transport, iron and steel, and timber, and major

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public research institutes known as science councils (Basson 1996). The apartheid-era public research system of HEIs and public research institutes operated according to an implicit social contract of "walking on two legs" (Kahn 2013): one leg encouraged "own" science, where research programs were determined by academics and resulted in internationally recognized research papers, while the other provided science and technology for the state, including military equipment and nuclear weapons (Kahn 2006; Maharajh 2011). Sanctions-induced innovation pressure was met through a mixture of adaptation and reverse engineering involving close collaboration between government, public research, and industry. In this period, the ratio of gross expenditure on R&D (GERD) to GDP reached a peak of 1.04 percent in 1992.

After the adoption of constitutional democracy in 1994, the public research system entered a period of transition in which existing universities were desegregated and new universities established, while research priorities shifted due to the end of economic sanctions. However, the distinction in research capabilities between the historically white institutions (referred to as "traditional universities") and the historically disadvantaged institutions continues, although efforts are underway to remedy this disparity. This context remains relevant for knowledge transfer in South Africa.

After 1994, there were both new opportunities and challenges. On the plus side, South African services firms were able to take advantage of new opportunities in neighboring African countries. Among the challenges was a decline in domestic manufacturing and mining, a rise in rural–urban migration, a large influx of foreign economic and political migrants, and strains on infrastructure. Various interventions have failed to significantly increase economic growth (Hausmann 2017).

South Africa's National Development Plan (NDP; Vision for 2030) was developed over the period 2009–11 to tackle the three challenges of unemployment, inequality, and poverty. The plan recognizes science, technology, and innovation as a means of economic development and the necessity for "public funding to help finance research and development in critical areas." To date, its implementation has been inconsistent.

9.2 The National Innovation System

Over the period of South Africa's industrialization, a modest-sized, effective national innovation system with sectoral subsystems emerged, notably in viticulture, fruits, cereals, mining and metallurgy, forestry,

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chemicals, military equipment, health, and telemetry. These sectoral innovation systems survive into the present and have been joined by sectoral systems for automobiles and financial services.

Prior to 1994, the public science system consisted of thirty-six HEIs, including universities and technikons (polytechnic institutes), and several public research institutes, including seven science council research institutes, four national research facilities, over twenty departmental research institutes, and R&D divisions in state-owned enterprises. The technikons had close ties with industry, reflecting their origins in technical and vocational education and training colleges. In addition to public research, the national innovation system was supplemented with private sector research, regulatory bodies, industry associations, and the South African Patent Office (SAPO).

After 1994 the higher education system restructured and merged into a unitary system of twenty-six institutions comprising twelve "traditional" universities, six comprehensive universities, and eight universities of technology (Nongxa and Carelse 2014). One medical school and two of the comprehensive universities were founded after 2009. For ease of reference, the term "university" is used in this chapter for all of these higher education institutes.

Five of the universities are research intensive, while another seven are emerging research universities. The higher education system is the strongest in Africa, with two universities among the top 200 in the *Times Higher Education* World University Rankings 2016–17.[1] All five research-intensive universities (the University of Cape Town, the University of the Witwatersrand, Stellenbosch University, the University of Johannesburg, and the University of KwaZulu-Natal) are listed in the ARWU top 500 rankings.[2] However, the changes to the higher education system weakened the previous linkages between the technikons and industry (Kruss et al. 2015). Institutes that had focused on teaching during the apartheid era largely retained this focus, except when merged with institutes that had prior research competences.

Government is the main source of research funding to the public science sector, via budget allocations from the Ministry of Higher Education and Training and the National Research Foundation. The public research institutes (science councils) include the Medical

1 www.timeshighereducation.com/world-university-rankings/2017/world-ranking#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats.

2 www.shanghairanking.com/World-University-Rankings/Shanghai-Jiao-Tong-University.html.

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Research Council, the Council for Scientific and Industrial Research (CSIR), the Agricultural Research Council (ARC), the Council for Geosciences, the Human Sciences Research Council, the Council for Mineral Technology, and the South Africa Bureau of Standards (SABS). Most public research institutes are sector-specific, with the exceptions of the CSIR and SABS.

State-owned enterprises are an important component of the innovation system and include Eskom (power), Transnet (communications), Telkom (telecommunications), Denel (defense industries), Armscor (defense industries), NECSA (nuclear engineering and products), and Onderstepoort Biological Products (veterinary medicines).

The R&D expenditures of the leading research universities, science councils, and state-owned enterprises are given in Table 9.1. In 2013–14 the “big five” research universities accounted for 70 percent of total higher education R&D expenditure, of which 52 percent was for basic research. The two leading science councils accounted for 65 percent of R&D expenditure, of which 23 percent was for basic research, 49 percent for applied research, and the balance for experimental development. This ranking, led as it is by the older institutions, has barely changed in the last fifteen years. Such historic path dependence is true of many other innovation systems.

In addition to the universities, public research institutes, and state-owned enterprises, the government research and innovation infrastructure includes national facilities (nuclear research, optical, and radio astronomy) managed by the National Research Foundation and research units in environmental science, geomagnetism, and seismology, military R&D, metrology, forensics, biotechnology, and public health.

A unique characteristic of the South African innovation system is that SAPO was and remains a non-examining patent authority that does not assess the novelty of patent applications. Although the cost of obtaining a patent is low, the patent system leads to a proliferation of low-value domestic patents, provides protection to foreign intellectual property, and creates extra costs for firms that need to monitor non-novel patents (Pouris and Pouris 2011). The system is also likely to reduce the domestic use of formal knowledge transfer based on patents.

The potential economic value of South African patents is therefore best assessed through patents granted in foreign jurisdictions with a patent examination system. Unless otherwise specified, this chapter limits all evaluations of patents to patents filed through the Patent Cooperation

Table 9.1 *R&D expenditure of leading universities, public research institutes, and state-owned enterprises, 2013–14*

Universities	ZAR '000s	USD '000s*
Science Councils (public research institutes)		
University of Cape Town	*1,178,888*	111,122
University of Witwatersrand	*896,566*	84,510
University of Stellenbosch	*827,137*	77,966
University of Kwazulu-Natal	*648,942*	61,169
University of Pretoria	*644,215*	60,724
University of South Africa	605,001	57,027
North West University	585,124	55,154
Free State University	330,182	31,123
University of Johannesburg	252,049	23,758
Nelson Mandela Metropolitan University	216,191	20,378
Rhodes University	211,956	19,979
University of the Western Cape	171,979	16,211
State-owned enterprises (SoEs)		
CSIR	2,095,576	197,529
Agricultural Research Council	1,008,401	95,052
National laboratories†	480,000	45,245
Medical Research Council	390,820	36,839
Council for Mineral Technology (Mintek)	281,883	26,570
Human Science Research Council	244,938	23,088
Council for Geoscience	109,577	10,329
Denel	507,000	47,790
Eskom	130,200	12,273
Transnet	83,200	7,842

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Table 9.1 (*cont.*)

Universities	ZAR '000s	USD '000s
NECSA*	74,800	7,051
Onderstepoort Biological Products	32,000	3,016

Sources: Universities and public research institutes (DST 2015a); SoEs (annual reports)

* Exchange rate as at 29 June, 2014 of 1 ZAR = USD 0.9426.

† Author estimate.

Treaty (PCT) system or other foreign registries such as the US Patent and Trademark Office (USPTO).

Financing for innovation in the private sector comes primarily from cash reserves, but also through equity and loan financing from the market, the modest-sized venture capital sector, the state Industrial Development Corporation, and the Public Investment Corporation. More risky innovation activities may be funded from the incentive programs of the Department of Trade and Industry. An estimate of total private sector expenditure on innovation (including R&D and other innovation activities) can be obtained from the Innovation Survey 2005–7 (DST 2011). Adjusted forward, the value would be approximately 100 billion South African rand (ZAR) (USD 8.1 billion) in 2017, with most expenditure on purchases of equipment, technology, and software.

9.3 Post-1994 Science, Technology, and Innovation Policy

Policy on science and technology is vested in the Department of Science and Technology (DST), while industrial policy resides with the Department of Trade and Industry (DTI).

The 1996 White Paper on Science and Technology (DACST 1996) introduced innovation system thinking to shape and manage science and technology policy for economic, sociopolitical, and intellectual benefit. Subsequent policy acts or programs included the National R&D Strategy (DST 2002), the Innovation Fund, the Ten-Year Innovation Plan (DST 2008), an enhanced R&D Tax Incentive (RSA 2008a), and the Intellectual

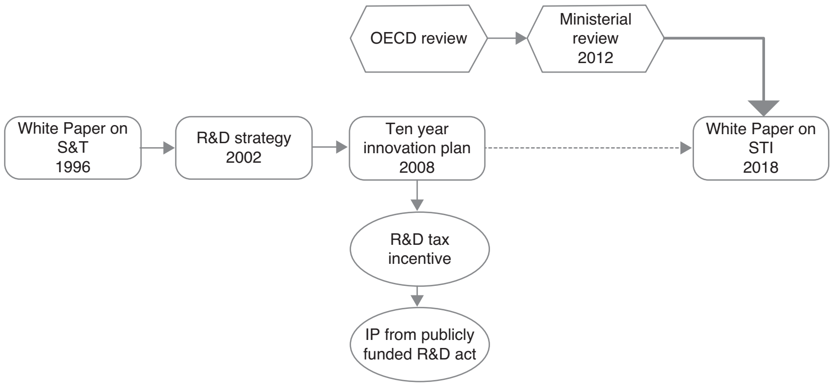

Figure 9.1 Major STI policy documents or acts
Source: Authors

Property Rights from Publicly Funded Research and Development Act (hereafter “the Public Research IP Act”) (RSA 2008b) (see Figure 9.1). New organizations that were established as a result of policy changes included the National Research Foundation as the major grant funder, the National Advisory Council on Innovation, the Technology Innovation Agency (TIA), and the National Intellectual Property Management Office (NIPMO).

The R&D Strategy and its successor, the Ten-Year Innovation Plan, outlined objectives and targets that were taken up in other government policy statements, notably the New Growth Path (EDD 2010) and the seminal National Development Plan (Presidency 2012). Constrained by shortfalls of funding, skilled labor and coordination, the goals achieved varying degrees of success. They continue to inform policy, but are not highly directed, with the exception of megascience astronomy projects.

The R&D Strategy shifted from the innovation systems approach advocated in the White Paper to that of a linear, research-led system, whereby investment in R&D was understood to be a precursor to socio-economic development. This emphasis on R&D influenced the Ten-Year Innovation Plan, the strategy of the National Advisory Council on Innovation, the TIA, and NIPMO.

The next three sections describe South African policies to support the supply of public research, consisting of the outputs of universities and public research institutes, policies to support the innovative capabilities of firms, and policies to support linkages and knowledge transfer between public research and firms.

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9.3.1 Policies for Public Research

The public research sector in all countries has multiple goals, commonly consisting of training individuals in useful skills, including the ability to absorb, understand and replicate leading-edge knowledge produced abroad, providing assistance to industry, and producing new discoveries, some of which may have commercial applications.

The DST is not directly responsible for higher education, but has developed mechanisms to boost university research capacity, including the Researcher Rating Scheme, the 200-strong SA Research Chair Initiative, sixteen Centres of Excellence and five Centres of Competence. These receive generous funding and entail a mix of open and directed selection. The National Research Foundation implements these programs, and, in the case of the last three, requires beneficiaries to report on industry and community impacts. In addition, there are a large number of industry-endowed professorial positions (chairs) in mining, engineering, and agricultural sciences as well as chairs funded by state-owned enterprises in roads, water, and telecommunications.

To provide necessary skills, the DST invested heavily in the universities, as well as in the CSIR, the National Facilities and the National Research Foundation. Between 2010–11 and 2014–15, the number of researchers at universities increased by 36.5 percent, from 32,571 to 44,457, compared to a small decline at public research institutes.[3]

The CSIR had a history of "knowledge transfer" through organizational development and transfer (Basson 1996), but its effectiveness declined in the 1980s, leading to a restructuring during the 1990s around strategic business units.

The Higher Education National Funding Formula allocates baseline funding to universities and includes a "publication output" variable that supports science (essential for understanding advances in knowledge) through funding for approved types of publication. This provided funding of ZAR 3 billion (approximately USD 250 million) in 2016.

The Innovation Fund provided competitive funding for research with commercial applications. It initially allocated three-year grants for predefined research areas and encouraged knowledge sharing by prioritizing awards to consortia of universities, science councils, and industry. This restriction was subsequently eased so that any research proposal with

[3] National Survey of Research and Experimental Development, 2010/11–2014/15. In comparison, the number of researchers in the business sector increased 25.6 percent, from 14,933 to 18,743.

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commercial applications could be supported. As of 2009, the Innovation Fund was merged into the new Technology Innovation Agency.

Innovation Fund projects that resulted in successful commercialization include microwave technology for egg sterilization and the Smartbolt™ rock stress detection device. A costly but unsuccessful project was the Joule electric vehicle, abandoned after the prototype failed to elicit funds for production.

Other publicly funded ventures included four Biotechnology Regional Innovation Centres, structured as single-purpose not-for-profit companies. The combined funding for the Innovation Fund and the Biotechnology Research Centres was approximately ZAR 300 million (± USD 30 million) per year. No evaluative study is available on the contribution of the Innovation Fund or the Biotechnology Research Centres to measures of potential commercial outputs such as IP, startups, or job creation.

The South African Research Chairs Initiative was established in 2006 by the DST and the National Research Foundation with the goal of expanding the research and innovation capabilities of South African universities by attracting and retaining high-quality researchers and increasing the output of master's and doctoral graduates. The initiative has been successful in fostering cutting-edge research, retaining skills in the country and contributing to the stock of doctoral graduates (Fedderke and Velez 2013).

9.3.2 Policies for the Business Sector

From a systems perspective, policy should improve the innovative capabilities of firms. This often takes the form of subsides to encourage firms to invest in capability-building activities such as R&D or to provide skills that would otherwise not be provided by the market. To support firm capabilities, the South African government provides an R&D tax incentive that is designed to boost private sector R&D spending (DST 2015b). Firms initially filed a post hoc claim that would be verified by the DST, but this system was open to misuse. After four rounds, it was replaced with a preapproval model that required detailed submission of the intentions and expected outcomes of corporate R&D. This process appears to have deterred many would-be applicants, particularly SMMEs (small, medium, and micro-enterprises), reflecting a tension between a user-friendly incentive regime and company willingness or capacity to engage in a detailed submission process.

The government has used industrial policy to correct market failure, such as the National Foundry Technology Network to provide skills training, knowledge transfer, and diffusion of state-of-the-art technologies. The 2015–17 iteration of the industrial policy aims to strengthen "linkages between knowledge production, utilisation and innovation and industrial growth" (DTI 2015: 69). The Industrial Policy Action Plan supports R&D-led industry development programs for titanium metal powder manufacturing, fuel cell development, and additive manufacturing. All three are focal areas of the Ten-Year Innovation Plan (DST 2008).

An agency of the DTI, the South Africa Bureau of Standards Design Institute, seeks to use "the broad nature and bridging capacity of design to address the existing innovation chasm by linking R&D with the user, the market, the social environment for the benefit of the country's socio-economic growth." To this end, support is given to SMMEs and individuals to move from idea to prototype. The Institute has set up the Transnet Design, Innovation, and Research Centre for SMMEs to research and develop innovative and commercially viable ideas. This is largely a private-to-private knowledge development channel that partially involves universities and public research institutes, for instance, for micro-satellite development.

9.3.3 Policies to Support Linkages between Public Research and Businesses

A common assumption is that the public research sector in South Africa is failing to transfer knowledge with commercial value to the business sector. For example, the annual surveys of the Global Entrepreneurship Monitor (GEMS 2016) find that South African experts believe that universities are not playing a sufficiently constructive role in facilitating knowledge transfer and stimulating innovation. This next section examines the possible causes of low rates of knowledge transfer from the public research sector to firms and then describes policies aimed at addressing those causes.

Failures in Knowledge Transfer

There are two main potential causes of failure. First, the public research sector could be producing very few discoveries with commercial applications. This could occur as a result of a failure in the *design* of the public research sector, for instance, if there are few incentives for academics to

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conduct research of potential commercial value (Zhang et al. 2011) or to take part in knowledge transfer activities. Sibanda (2009) identified an absence of an entrepreneurial culture among researchers at public research institutes, while Goldberg and Kuriakose (2011) found that insufficient attention was given to the needs of startups, especially business services and IP management. In a study of university research centers, Cooper (2011) argued that knowledge transfer was problematic as long as universities focus on “own” research, rather than committing to use-inspired basic research, even though there was strong evidence that research group survival and use-inspired research (on the MIT and Stanford models) went hand in hand. In other words, the nature of the research was a strong determinant of its future commercial value, resonating with similar results in studies by Fedderke and Velez (2013) and the National Research Foundation (2016) . Kruss et al. (2015) claim that a policy emphasis on “Big Science, knowledge transfer and the growth of niche competences and capabilities” has created “islands of innovation,” but prevented the widespread diffusion of public research knowledge to industry. The consequence is large variation by sector in the relevance of public research to industry.

Second, the public sector could be producing commercially valuable outputs that are not taken up by firms for a number of reasons: lack of communication between the public and private sectors (*network failure*), a shortage of funding to support the activities of firms to develop discoveries into commercial products or processes (*finance failure*), or public research discoveries not meeting the requirements of firms, particularly if firms lack the internal capabilities to exploit them (*demand failure*).

Kruss (2008a) found very few new knowledge networks in evidence in South Africa’s research-oriented universities. The capacity and desire on the part of industry to forge research and innovation partnerships were generally limited. In a subsequent study, Kruss (2008b) argues that the lack of commercialization of research arises from a combination of network failure and a lack of “interactive capability” with industry.

Kahn (2006, 2013, 2016) identified the influence of the linear innovation model on policy (instead of an innovation system model) as underlying poor performance in knowledge transfer. Ideographic research based on case studies in South Africa found that poor performance is partly due to a lack of two-way communication between public research and firms. Instead, there is implicit adherence to a linear model of innovation whereby scientists follow their own research interests, often in basic research such as the Square Kilometre Array radio telescope. This is reflected in the high proportion of South African gross expenditures on R&D (GERD) for basic research, currently standing at 26.7 percent. Although "blue sky" research can, over time, result in commercial products or processes, such research is rarely of short-term value to firms. Zhang et al. (2011: 14) noted that the influence of the linear model was made worse by the fact that the DST was a science-driven organization whose staff had little knowledge of industrial practice.

De Wet (2001) introduced the idea of the "technology colony" to explain low rates of knowledge transfer in South Africa. This idea became known as the "innovation chasm" due to a lack of funding (finance failure) for early-stage commercialization. Zhang et al. (2011) question the reality and utility of the construct of an innovation chasm and suggest that the problem could be due to demand failure, arguing that policy gave insufficient attention to strengthening the absorptive capacity of firms. Kaplan (2011) used patent data to show that mining equipment was the only industry where local expertise was at the technology frontier. Phaho and Pouris (2008), in a study of original equipment manufacturers (OEMs) in the automotive sector, determined that most OEMs failed to take steps to improve their capabilities. They did not conduct in-house R&D, did not engage in innovation activities that were new to the market, and did not use government incentives to improve their competitiveness through technology diffusion or intelligence. Fongwa and Marais (2016) studied knowledge transfer in a developing region of South Africa and found that the rate at which knowledge was transferred through the available channels was strongly influenced by the absorptive capacity of firms.

Policies to Address Design, Network, Finance, and Demand Failures

The South African government has implemented policies to address all of these factors affecting knowledge transfer, although their execution has been fragmented and is focused on a linear model of innovation that emphasizes the role of public research in supplying new knowledge.

The Ten-Year Plan for Innovation declared bridging the "innovation chasm" (addressing finance failure) as a key goal, alongside the need to support human resource development, R&D, and knowledge infrastructure (DST 2008: 23).

The Department of Science and Technology's Sector Innovation Fund and Sector Innovation Programme are responses to a Ministerial Review (DST 2012) to promote networking between researchers, innovators, businesses, and business associations. The Sector Innovation Programme brings together public ministries, industry, industry associations, and public research institutions around common innovation needs. The Programme has been extended to nine sectors, including forestry, sugar, aquaculture, and boatbuilding (DST 2015c: 11).

Both networking and demand failure are targeted through the long-standing Technology and Human Resources for Industry Programme (THRIP) of the DTI. THRIP supports partnerships between industry and public research on a cost-sharing basis. It promotes use-oriented R&D and offers associated high-level training and education for technology development. THRIP supports the mobility of researchers and students between universities, public research institutes, and industry, and improves the competitiveness of the participating business organizations. External evaluation (DPME 2015) found it to be cost-efficient in terms of technology development, with an estimated average commercial revenue of ZAR 24 million (USD 2.4 million) five years after the conclusion of projects.

Other programs to address network and demand failure include the DST's regional innovation forums, four of which remain functional, and the Bio-economy Strategy. Several regional innovation strategies to promote knowledge transfer and commercialization were also developed. These moves reflect a shift in thinking toward "innovation-enabling ecosystems." The Bio-economy Strategy seeks to harmonize R&D among various actors in agriculture, health, industry, and environment (DST 2013). In comparison to the earlier linear Biotechnology Strategy (DACST 2001), the new strategy argues for a demand-led, incentive-based approach to build absorptive capacity and stimulate knowledge transfer.

Design failure is partly addressed through changes to the management of IP produced in the public research sector. The 1996 White Paper proposed harmonizing South Africa's IP regime with international good practice. The 2002 R&D Strategy argued that a version of the US Bayh-Dole Act could promote patent activity in the public sector (DST 2002: 67; DNSH 2017). The subsequent Public Research IP Act instituted benefit-sharing obligations for license income earned by specified public research institutions[4] and other policies of relevance to the generation, disclosure, exploitation, and transfer of IP toward small enterprises and BBBEE[5] entities. The Act required universities and public research institutes to establish knowledge transfer offices, with part of the costs funded by the NIPMO. The Southern

4 Public universities, Science Councils, the Water Research Commission, and NECSA.
5 Broad-Based Black Economic Empowerment.

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African Research and Innovation Managers Association (SARIMA) supports the training of innovation managers and the establishment of KTOs, and works with NIPMO and regional equivalents to advance the commercialization of research discoveries.

9.4 Literature on Knowledge Transfer Channels

How knowledge transfer occurs in South Africa has been examined in a number of studies (Kaplan 2004, 2008, 2011; Goldberg and Kuriakose 2011; Kuriakose et al. 2011; Morris et al. 2011; Zhang et al. 2011). Most of this research is based on case studies, in part due to a lack of representative data on knowledge transfer activities.

9.4.1 Informal and Contractual Knowledge Transfer

South African automotive OEMs mainly rely on universities as providers, where needed, of highly qualified personnel, rather than as partners in use-oriented research collaboration that could upgrade their technological capabilities (Kruss 2008b).

In the "low" technology wine sector, Cusmano et al. (2010) found that the relationships between industry and public research were based on a mix of informal contacts and industry-commissioned research. Kruss et al. (2012) reported that most academics interact with the outside community through traditional mechanisms such as training and capacity development, conferences and workshops, action research, contract research, demonstration projects, and services. Consultancy and entrepreneurial engagement was less common, informal, indirect, and not knowledge-intensive. From the industry side, there was low demand for knowledge from, or direct cooperation with, universities on the part of larger innovating firms, but stronger demand from a smaller number of R&D-performing firms.

9.4.2 IP-Mediated Knowledge Transfer

In the six years prior to the promulgation of the Public Research IP Act in 2008, Kaplan (2009) found that there was a dearth of economic studies on the IP system and low awareness of the value of knowledge transfer to the resource industries. IP activity between 2001 and 2007 was low, with only twenty-one patent-based startups produced by the public research sector.

Alessandrini et al. (2013) note that formalized knowledge transfer is still emerging in local universities and public research institutes.

A case study of three firms active in the southern node of the telemetry sectoral system of innovation (Kahn 2014) found that two firms made extensive use of government innovation incentives, while one maintained independence. The case studies show the initial importance of mentorship and academic research to the startup pioneers. As the companies matured they shifted their search for knowledge exchange toward their own value chains. This autonomous behavior accords with the international pattern revealed through innovation surveys.

In a study of the patenting activity of academics, Lubango and Pouris (2007) concluded that most academic inventors or co-inventors had prior experience with firms or state-owned enterprises. Rorwana and Tengeh (2015) surveyed thirty-six academics with research projects with industry and employed at a single university of technology to identify the effect of different factors on their participation in commercialization activities. They report that the personal interest of the academics in innovation had the largest effect on their participation in commercialization activities. No results were reported on the use of IP.

9.4.3 Case Studies

Four case studies (see Box 9.1) of sectoral innovation systems show that the main channels for knowledge transfer in South Africa are informal methods and research agreements. The case studies are based on desk research and interviews.

The four case studies fall into two groups. The first two, on oil and gas and platinum group metals, display similar hub-and-spoke models with universities, with the main companies (Sasol and Anglo-American Platinum) forming the hubs. Interviews revealed that neither company relied on the flow of research information from universities for its core business. The other two cases, for pulp and paper and viticulture, resemble triple helixes, with universities, companies, and government contributing to research of commercial value. None of the cases exhibits demand-led characteristics; all are supply-side driven, although capacity development is an important goal.

Breschi and Malerba (2005) stress the importance of networking and other forms of knowledge exchange in sectoral innovation systems. They note that these systems evolve organically and cannot easily be developed through government fiat. Sasol was a state initiative, although its evolution into a research-led organization was driven internally. Including the

BOX 9.1 CASE STUDIES OF SECTORAL INNOVATION SYSTEMS

Oil and Gas The South African government established Sasol in 1950 to address uncertainty in fuel supplies. Sasol developed proprietary technologies and is currently a world leader in hydrocarbon synthesis and the largest private sector R&D performer in South Africa. Working with the CSIR, the University of Witwatersrand, and other universities, Sasol developed a gas-to-liquid process that has been implemented internationally. Sasol has a portfolio of 200 product lines. It had 262 co-publications with universities in the period 2011–015. Knowledge transfer to Sasol occurs through formal research projects, the THRIP channel, staff and student mobility, conferences, and seminars. Sasol sees itself as a coordinator of activities across universities to develop expertise rather than specific technologies (Morgan 2006). Its technical success is a demonstration of the importance of early-stage government support.

Pulp and Paper The two main firms in this sector are Sappi and Mondi. Sappi is the largest South African R&D performer in pulp and paper and the biggest producer of fine paper in the world. Sappi is part of the Gauteng Province Innovation Hub, where it has a pulp R&D laboratory. Its research center in Kwazulu-Natal specializes in genetically improved planting stock. Sappi and Mondi sponsor chairs in forest genomics and tree pathology at Pretoria University. The Tree Protection Cooperative Programme brings together all forestry companies, Forestry South Africa and the Ministry of Agriculture, Forestry, and Fisheries. Sappi collaborates on genetically modified breeding with the Forest Molecular Genetics Programme of the University of Pretoria. The independent, "quasi-public" Institute for Commercial Forestry Research is supported by contributions from its members and hosts its own forty-five-person R&D lab.

Platinum Group Metals This sectoral system is among the oldest in the country. The leading producer and researcher is Anglo Platinum, followed by Impala Platinum. To boost demand for platinum metal, Anglo-American Platinum constructed a hydrogen fuel cell technology demonstrator for off-grid electricity generation using platinum catalyst fuel cells from the Canadian firm Ballard. The hydrogen Centre of Competence developed local fuel cell technology including the necessary catalysts, membrane technology, casings, and control systems, and has collaborated with Impala Platinum to trial the fuel cell prototype in a forklift vehicle. A Web of Science search shows fifteen co-publications with Anglo-American Platinum, one public research institute, and South African universities. Knowledge transfer occurs through formal research projects, the THRIP channel, staff and student mobility, conferencing, and seminars.

Viticulture Centers of viticulture research include Stellenbosch University, the Distell Group, the Agricultural Research Council, and the Elsenburg Agricultural Training Institute. Distell is among the top ten producers of wine worldwide. Its in-house R&D is supported by science and technology service firms, specialist manufacturing, yeast providers, and irrigation firms. Cusmano et al. (2010)

BOX 9.1 (cont.)
identify post-1994 deregulation and engagement with world markets as the driver of wine quality improvement. Industry players founded the South African Wine and Brandy Company with both industry and public research participants to provide open-access generic research. Stellenbosch University works closely with industry players and makes ongoing use of the THRIP channel. Informal contacts and industry-commissioned research are an important part of this sectoral innovation system (Cusmano et al. 2010).

Centres of Competence within a sectoral system seems to be left to an evolutionary process.

9.5 Evidence and Metrics of Knowledge Transfer

A major challenge in evaluating knowledge transfer in South Africa is a lack of metrics. Basic metrics are available for innovation activities in South Africa (see Table 9.2) and show a modest level of foreign patents and a low level of high-technology exports. Some metrics are available on the IP-mediated knowledge transfer activities of universities and public research institutes, but there are little comparable data over time. However, the main drawback is a lack of data on informal and contractual forms of knowledge transfer.

South Africa has sought to develop a regular series of innovation surveys similar to the EU Community Innovation Survey (CIS). The best quality data are from the 2005 survey, which achieved a satisfactory response rate. The question on knowledge sources in that survey is relevant to knowledge transfer. The most widely cited important sources of information for innovation are suppliers and customers, cited by 43.9 percent of industrial firms and 26.2 percent of firms in the services sectors (see Table 9.3). Universities and public research institutes are less commonly cited as important sources, with only 9.9 percent of industrial firms citing higher education institutes and 6.1 percent citing public research institutes. Within industry, a higher share of manufacturing than mining firms give a rating of high importance to higher education and public research institutes, while firms in transport and communications and scientific and technological services (STS) are more likely to report linkages with public research than firms in trade or financial services.

The results in Table 9.3 indicate that the South African public research sector is less important than several other sources of information for

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Table 9.2 *Innovation outputs in 2015*

High-technology exports as a share of total exports (UN Comtrade)	6
US patent awards (USPTO)	144
Patent Cooperation Treaty (PCT) applications	442
Trademark applications (ZA resident) (WIPO)*	19,522
Trademark applications (ZA abroad) (WIPO)*	5,694
Plant cultivars in force; world share (%; global rank) (UOPV)	2,710; 2.6; 8
Sales of innovative products, billions (Innovation Survey 2005–7)	ZAR 370 (USD 30)

Sources: http://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS?page=4

innovation, but this is a common pattern in many countries. Comparable data are available from Eurostat for the CIS 2008 survey, covering the three years from 2006 to 2008.[6] Limited to innovative manufacturing firms in six high-income countries (Belgium, Finland, France, Germany, Italy, and the Netherlands), an average of 22 percent of firms gave high importance to suppliers and 29 percent to customers as sources of knowledge for innovation. The comparable share of innovative European manufacturing firms that gave high importance to universities and public research institutes is much lower, at 2.7 percent and 1.6 percent. Note that this is considerably lower than the percentages for South African manufacturing firms of 10.2 percent for universities and 6.3 percent for public research institutes, indicating that the public research sector plays a greater role in private sector innovation in South Africa than in high-income European countries.[7] One explanation could be a continuing tradition in South Africa of greater state involvement in economic activity.

The results in Table 9.3 indicate that there are ample linkages between the public and business sectors in South Africa compared to Europe. The common assumption that this is not the case could be due to the lack of

[6] Eurostat, Innovation Statistics, "Highly important source of information for innovation during 2006–2008" [inn_cis6_sou]. Results for the 2006 survey covering years 2004–6 are comparable, but data are available for fewer high-income countries.

[7] The average share of innovative manufacturing firms in ten lower-income European countries that accorded high importance to knowledge sourced from universities was slightly higher than in the high-income countries, at 3.5 percent for universities and 2.5 percent for PROs.

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Table 9.3 *Share of innovative firms rating sources of information for innovation as "highly important"*

	All industry	Mining	Manuf	All services	Trade	Transport and comms	Financial services	STS*
Within the firm	54.3	56.1	54.3	44.9	44.8	41.2	75.0	47.8
Suppliers	25.7	14.0	25.9	23.1	23.0	18.9	12.5	29.3
Clients/customers	43.9	45.2	43.7	26.2	27.3	18.0	8.3	26.4
Competitors	15.9	33.0	15.5	9.7	9.8	9.3	4.2	9.5
Consultants, labs or private R&D	6.2	10.2	6.1	1.8	0.7	6.4	4.2	7.2
Higher education	9.9	0.0	10.2	1.1	0.1	4.5	0.0	6.2
Govt. and public research institutes	6.1	0.8	6.3	0.9	0.1	4.3	0.0	4.8
Conferences, trade fairs, exhibitions	3.5	0.0	3.6	1.1	0.8	2.3	0.0	2.6
Journals/trade publications	5.7	1.4	5.8	2.2	0.5	9.6	0.0	9.4
Professional assoc.	0.8	2.0	0.8	15.5	16.1	12.2	0.0	14.8

Source: Innovation Survey 2005

* STS = scientific and technological services.

representative metrics on informal and contract-based knowledge flows, with the available data on IP-mediated knowledge transfer not capturing the main knowledge flow channels in South Africa.

There are several other sources of data on knowledge transfer from public research to firms, including bibliometric data on co-publications between public research and industry partners, R&D survey data, data published by universities and public research institutes, and a recent survey of KTOs on IP-mediated knowledge transfer.

The major research universities publish annual reports that include the number of research contracts, rated researchers, research chair holders, publication units, invention disclosures, patent applications, patent grants, and outbound transfer agreements. Even so, these reports do not follow a standard format, so comparable data are not readily available. In addition, some financial data are provided for total research income, the value of research contracts, equity held in spinout companies, and income from the exploitation of IP.

In general, the universities provide little information on their formal involvement in promoting new businesses and jobs. One exception is the University of Cape Town (2015), whose annual research report provides details of earnings, licensing, patent activity, and spinouts. Table 9.4 provides results for four research-intensive universities. Little is known about the performance of the various private companies established by universities, since private companies are not required to place such information in the public domain.

Three of the public research institutes, Mintek, the ARC, and the CSIR, use sector-specific metrics to demonstrate socioeconomic impacts, knowledge transfer, and commercialization success. The ARC collects data on the number of registrations for plant breeders' rights for plant cultivars. The CSIR provides metrics on "demonstrator" implementation such as the Technology Readiness Level, characterized by protocols for rolling out a demonstration project. These "metrics" of knowledge transfer are certified for validity and reliability through the Office of the Auditor General prior to their submission to Parliament.

9.5.1 Metrics of Non-IP-Mediated Knowledge Transfer

Non-IP-mediated knowledge transfer includes informal methods such as hiring university graduates and contacts with university staff that are not based on a payment to the university, plus formal methods such as collaborative research, consulting, and contracting.

Table 9.4 *R&D expenditure and knowledge transfer metrics for four leading universities in 2014*

	Total R&D expenditures (ZAR billion)	IP cost (ZAR million)	KTO cost (ZAR million)	Number of invention disclosures	Number of technologies*	Number of licenses	Number of patent families
University of Cape Town	1.18	4.8	3.3	41	108	17	104
Witwatersrand	0.89	9.2	4.6	37	126		111
University of Kwazulu-Natal	0.65	0.5	1.0	10	18		7
University of Johannesburg	0.25	0.8	4.2	14	8		

Source: Author's enquiry to NIPMO

* A technology is the embodiment of a single innovative idea. Multiple technologies can arise from a single invention disclosure or a single technology can result from a combination of disclosures.

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South Africa's total publication output rose from 0.39 percent of world publications between 1996 and 2000 to 0.63 percent between 2011 and 2015 (NACI 2016). There is also extensive co-authorship between South African and foreign academics, creating opportunities for inward knowledge transfer. However, a search on the Web of Science for the period 2005–15 did not find any co-publications between the major foreign patentee firms active in South Africa and South African universities.

The South African R&D Surveys record a greater number of R&D collaborations between local firms and universities than with public research institutes, supporting the results of the innovation survey. The flow of funds from firms to universities amounts to 8 percent of higher education R&D (HERD), while that to public research institutes is 10 percent of their expenditure on R&D (DST 2015a). Given that universities use some of these funds for studentships, this suggests more extensive R&D collaboration with public research institutes. In addition, industry R&D collaboration with public research is highly concentrated, with only one-sixth of 600 firms that received an R&D tax incentive reporting collaboration with either universities or public research institutes.

9.5.2 *Metrics of IP-Mediated Knowledge Transfer*

The 2008 Public Research IP Act gave incentives to public sector researchers to patent and commercialize their inventions, while funding to defray patent application costs was also provided. The preferred patenting route is the Patent Cooperation Treaty (PCT), to which South Africa acceded in 1999. The output of commercially valuable knowledge from universities and public research institutes can be tracked via PCT filings and USPTO assignments. South African patent applications via the PCT nearly tripled between 2000 and 2013 in three stages – up to 2004, from 2005 to 2012, and from 2013 onward. The post-2004 increase could be due to the support of the Innovation Fund for IP activity and subsidization of the costs of PCT filing. The distribution of PCT filings over the period 2009–15 shows a shift from the private sector and public research institutes toward universities, with Stellenbosch University the most prolific, followed by industry giant Sasol and the University of Cape Town. The five universities with the most patents are Stellenbosch, Cape Town, Witwatersrand, North West, and Pretoria. The top two public research institutes are the CSIR and the ARC.

The number of USPTO patent awards by South African organizations has increased slightly from 2011 onward, with Sasol in first place followed by the CSIR and United States of America (U.S.)'s company Amazon. There has been a significant shift away from the mineral resources sector – hardly surprising in that gold production has declined by 83 percent from its 1970s' peak, while platinum exports have remained static. Gold and PGM miners have restructured and in some cases moved their primary listings abroad. Eskom, Denel, and Mintek (previously important patentees) recorded no USPTO patents in the period 2011–15. Another significant change in the identity of assignees is the participation of local universities, namely Witwatersrand, Cape Town, and Northwest.

A survey by the DST, NIPMO, SARIMA and HSRC (DNSH 2017) (the inaugural *South African National Survey of Intellectual Property and Technology Transfer at Publicly Funded Research Institutions*) collected data on formal knowledge transfer activities of up to twenty-five universities and eleven public research institutes for fiscal year 2013–14. The questionnaire followed that of the Association of University Technology Managers (AUTM) in the U.S. Most of the questions collected data on inputs (research expenditures) or outputs (invention disclosures, patents, startups, etc.).

The results, given in Table 9.5, identified fifteen startups in the 2013–14 fiscal year and 315 international patent applications, which is almost 50 percent higher than the number of domestic patent applications. The survey also found that there were twenty-eight licenses in 2013–14. License revenues totaled ZAR 35.6 million (USD 3.4 million) compared with aggregate expenditures of ZAR 86 million (USD 8.1 million) for knowledge transfer costs such as maintaining a KTO. Based on the experience in Europe and the U.S., some institutions are likely to have earned revenues that more than covered their costs while the majority were likely to have revenues below costs.

Of particular interest is the finding that 79 percent of licenses were given to foreign-owned firms, suggesting that there is very little IP-mediated knowledge transfer to domestic firms. This could also explain the higher number of international patents. With data for only one year, it is not known whether the large role of foreign-owned firms as recipients of formal knowledge transfer is a one-year anomaly or a long-term characteristic of the South African innovation system.

With greater experience, it is likely that knowledge transfer outcomes will increase in the future. During 2013–14, 52 percent of the 100 staff employed by KTOs had under four years' experience. Many are on contract, with their salaries paid by NIPMO. This intervention has been critical to establish capacity and build experience, which is mostly obtained on the job.

Table 9.5 *Metrics of the knowledge transfer activities of South African universities and public research institutes, fiscal year 2013–14*

	N	Metric
KTOs		
Share of universities/PROs with a KTO	36	92 percent
KTO budget (ZAR) for all reporting KTOs (ZAR)*	24	86 million
Total expenditure on patent applications (ZAR)	24	36 million
Non-patent IP metrics		
Number of invention disclosures	22	306
Plant cultivars filed	21	19
Designs filed	22	10
Number of startups established	22	15
Patenting		
Number of international patent applications	22	315
Number of domestic patent applications	22	216
Number of international patent grants	21	76
Number of domestic patent grants	21	32
Licensing		
Number of licenses with firms (including startups)	22	28
Share of licenses with internationally owned firms	22	79 percent
Percentage of licenses based on a patent	20	69 percent
Percentage of licenses earning revenue	19	35 percent
Total license income earned (ZAR)	22	35.6 million
Share of license agreements with startups or SMEs	21	88 percent
Share of exclusive license agreements	23	54 percent
Amount of research funding provided by businesses (ZAR)	-	1.08 billion
Share of license revenue in total business research funding	-	3.3 percent

Sources: NIPMO
N: number of reporting universities and public research institutes.
* Excludes expenditures for patent applications.

Unfortunately, the study did not collect data on non-mediated forms of knowledge transfer such as through research agreements, but it did collect data from twenty-four KTOs on the level of impact (high, moderate, or no impact) of four obstacles to knowledge transfer: (1) inadequate awareness on the part of research staff of the need to disclose and manage IP, (2) inadequate funding for the KTO,

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(3) inadequate funding for IP registration costs, and, (4) a lack of specialist resources. Two obstacles were given a high impact rating by 42 percent of respondents: inadequate KTO funding and a lack of specialist resources, while the other two (inadequate awareness and lack of funds for IP registration) were given a high impact rating by 25 percent of respondents. In addition, 75 percent of respondents cited a lack of awareness among research staff of the need to disclose their inventions as a medium-impact obstacle. This indicates that formal methods of knowledge transfer are in a state of infancy.

9.5.3 Impacts of Knowledge Transfer

The Technology Innovation Agency commissioned an Economic Impact Assessment for the period 2011–16 (Urban-Econ 2016) which estimated that expenditures of ZAR 6.0 billion (USD 600 million) contributed to ZAR 1.7 billion (USD 170 million) of economic activity with an aggregate employment multiplier of 4.66. Specific cases of knowledge transfer were not studied in this evaluation.

The largest science council, the CSIR, has not provided an impact assessment of all its activities, although individual CSIR divisions have published occasional impact studies.

In contrast, the ARC publishes impact assessments of a range of its activities.[8] For example, an assessment of grain crop activities (involving the ARC, Grain SA, the University of Pretoria, seed companies and its parent government department) reports that the knowledge transferred through new cultivars between 1997 and 2012 resulted in a massive 3,700 percent return on investment to maize production. ARC research on peach and nectarine cultivars released to local producers demonstrated a rate of return of 56 percent, while that for plums was lower at 14 percent.

Until recently, there was a poor track record of independent evaluations of public research institution activities, let alone use of their findings. The establishment of the Department for Planning, Monitoring and Evaluation (DPME) and a Centre of Excellence in Scientometrics and Science Policy at Stellenbosch University signal new capabilities for conducting evaluations to advance policy learning.

The above discussion points to significant gaps regarding knowledge transfer from universities and public research institutes to businesses that may lead to economic or social impact. There appear to be no studies of

[8] See www.arc.agric.za/Pages/Economic-Analysis.aspx.

the links between university/public research institute activity and the formation of new enterprises and job creation. Impact assessment post hoc – let alone ex ante – is also thin on the ground. The fact that a compliance culture is in place may serve as the starting point to engender more routine impact assessment with associated data collection. An evaluation culture is emerging, although organizations tend to prioritize compliance with Auditor General reporting requirements over engaging in evaluation to serve as corrective and learning devices.

9.6 Conclusions

A number of factors have limited the flow of knowledge from public research to businesses in South Africa. These include high levels of basic R&D that support the "own science" agenda of skilled researchers. Without top-down steering toward national imperatives, a shift toward use-inspired basic research, built on close interactions between public research and businesses, will not occur in the foreseeable future. In any case, a change toward use-inspired research will also require actions to improve the demand for university research, which requires greater capabilities on the part of a broad spectrum of South African firms. Otherwise, the national innovation system will continue to consist of "islands" of expertise in research and innovation through which researchers advance their professional and commercial interests.

South African universities have adjusted to the requirements of the 2008 Public Research IP Act by establishing KTOs and implementing practices to support knowledge transfer. All universities had already set up or were in the process of setting up a trading entity to house startups or IP, and to put a stop to academics acting as commercial service providers. This was balanced with a range of staff incentive schemes to promote commercialization.

Those universities that had experience in IP management before the Public Research IP Act were well-equipped to adapt to its introduction. Some universities developed full-cost business models to encourage firms to contract R&D while retaining full IP rights. This would appear to have induced some new contracts, yet there were concerns that the substantial business funding of university research would decline. Interviews found that universities were generally positive as to the role of NIPMO and financial support for the cost of patenting, although in one case it was argued that serving the broad community should trump the acquisition of IP rights, which was considered to be "a prestige activity."

All research universities and public research institutes currently have internal IP management policies. In many instances, these predate the Public Research IP Act. Moreover, "getting close to customers/communities" has been part of the general ethos of universities and public research institutes over the last two decades, in part because of the widespread adoption of "value for money" thinking, but also because of post-apartheid development imperatives. University interviewees noted that pressure to address public and commercial needs comes from institutional boards, communities, and public representatives. This does not mean that public institutions have abandoned their traditional mandates of teaching and research. Actual promotion of the generation of IPR varies considerably. Detecting latent IP does not come easily, and, to this end, some organizations have brought in IP scouts who work with researchers to identify potential invention disclosures. In some cases, staff with commercially valuable IP are allowed to place their students in a business incubator and are given time out to support commercialization.

In contrast, interviews with managers from public research institutes showed that they were less enthusiastic about the Public Research IP Act, arguing that the requirements to share benefits with inventors would put further stress on their bottom line in an already constrained operating environment. This stress is evidenced through a comparison of government funding for R&D. From 2005 to 2014, funding to public research institutes (unadjusted for inflation) rose 3.4 times compared to a 3.8-fold increase for universities. Yet not all public research institutes were concerned about benefit sharing in all circumstances. A major public research institute experimented with giving equity stakes to its researchers and introduced the idea of the "entrepreneur in residence" to promote practical approaches to commercialization.

The interviewees from public research institutes and government also expressed concerns over a lack of policy coherence between the DTI and the DST and believed that differences in mandates hindered knowledge transfer rather than helping it. Policy confusion and mandate creep also limited the effectiveness of incentive schemes that often failed to attract high-quality proposals supported by well-crafted business cases.

More broadly, the underlying and continuing "two legs" social contract characterizes the innovation system and ensures the persistence of supply-side thinking. This in turn creates barriers to knowledge transfer outside the islands of excellence, since the needs of clients or users are of little immediate concern.

The present period in South Africa may be characterized as transitional, as the old order yields to new interests. To support this transition, considerable policy experimentation has taken place since the 1996 White Paper. One of the overarching goals of the government's National Development Plan was to deploy science, technology, and innovation for economic development. This would necessarily demand effective knowledge transfer. Subsequent policies such as the Innovation Fund, the R&D Tax Incentive, the Public Research IP Act, the Technology Innovation Agency, and the Sectoral Innovation Programmes were designed to support this goal.

The current Presidency of Cyril Ramaphosa is actively soliciting foreign direct investment to modernize and expand infrastructure and equipment in South Africa. The long-term benefits of new investment and modernization will in turn depend on domestic capability to absorb and learn how to use the associated technologies. This is another form of knowledge transfer in which the public research system can play an important role.

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