Review of the State of
the Science, Technology and Innovation System in South Africa

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The Academy of Science of South Africa (ASSAf) was inaugurated in May 1996. It was formed in response to the need for an Academy of Science consonant with the dawn of democracy in South Africa: activist in its mission of using science for the benefit of society, with a mandate encompassing all fields of scientific enquiry in a seamless way, and including in its ranks the full diversity of South Africa's distinguished scientists.

The Parliament of South Africa passed the Academy of Science of South Africa Act (*Act 67of 2001*), as amended, and the Act came into force on 15 May 2002. This has made ASSAf the official Academy of Science of South Africa, recognised by government and representing South Africa in the international community of science academies.

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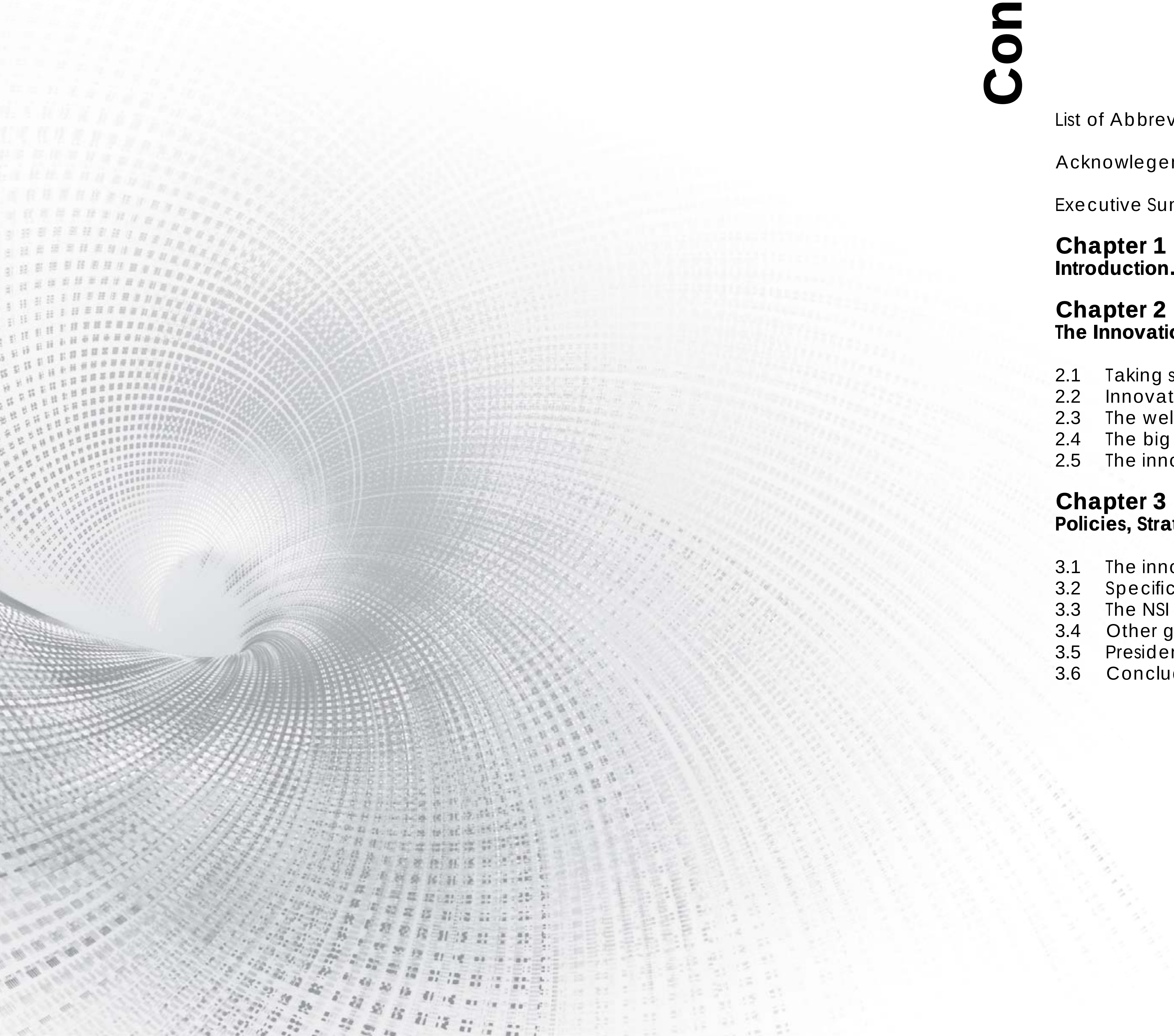

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List of Abbreviations

AAAS	American Association for the Advancement of Science
A&HCI	Arts and Humanities Citation Index
AIDP	Automotive Industries Development Programme
ANC	African National Congress
ARC	Agricultural Research Council
ASSAf	Academy of Science of South Africa
AsgiSA	Accelerated and Shared Growth and Skills Initiative for South Africa
AU	African Union
BAC	Biotechnology Advisory Committee
BERD	Business expenditure on research and development
BRICs	Biotechnology Regional Innovation Centres
BRICS	Brazil, Russia, India, China, South Africa
CAGR	Compound annual growth rate
CEO	Chief executive officer
CESM	Classification of educational subject matter
CHE	Council on Higher Education
CoC	Centre of Competence
CoE	Centre of Excellence
COFISA	Co-operation Framework on Innovation Systems between Finland and South Africa
CSIR	Council for Scientific and Industrial Research
DACST	Department of Arts, Culture, Science and Technology
DBE	Department of Basic Education
DEDEAT	Department of Economic Development, Environmental Affairs and Tourism
DHET	Department of Higher Education and Training
DORA	Declaration on Research Assessment
DST	Department of Science and Technology
ESASTAP	European South African Science and Technology Advancement Programme
EU	European Union
FDI	Foreign direct investment
FET	Further education and training
FOSAD	Forum of South African Director-Generals
FTE	Full-time equivalent
HEI	Higher education institution
HEMIS	Higher education management information system
GEAR	Growth, employment and redistribution
GERD	Gross expenditure on research and development
GCI	Global Competitiveness Index
GDP	Gross domestic product
GEM	Global Entrepreneurship Monitor
GII	Global Innovation Index
HE	Higher education
HMO	Hermanus Magnetic Observatory

HRD	Human resources development
HRD-SA	Human resources development – South Africa
HSRC	Human Sciences Research Council
HySA	Hydrogen South Africa
IBSA	India, Brazil, South Africa
ICT	Information and communication technology
IDC	Industrial Development Corporation
IDRC	International Development Research Centre
IEI	Innovation Efficiency Index
IPAP	Industrial Policy Action Plan
JIPSA	Joint Initiative on Priority Skills Acquisition
JSE	Johannesburg Stock Exchange
KAT	Karoo Array Telescope
KEI	Knowledge Economy Index
MCST	Minister's Committee on Science and Technology
MRC	Medical Research Council
NACI	National Advisory Council on Innovation
NCRI	National Council for Research and Innovation (Proposed)
NDP	National Development Plan
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organisation
NGP	New Growth Path
NIPMO	National Intellectual Property Management Office
NPC	National Planning Commission
NRF	National Research Foundation
NRTF	National Research and Technology Foresight
NSDS	National Skills Development Strategy
NSF	National Science Foundation
NSI	National System of Innovation
NSMM	New Strategic Management Model
OECD	Organisation for Economic Cooperation and Development
ORIP	Office for Research and Innovation Policy (Proposed)
PBMR	Pebble-bed Modular Reactor
PCT	Patent Cooperation Treaty
PRI	Public research institution
PRO	Public research organisation
R&D	Research and development
RDP	Reconstruction and Development Programme

SAAO	South African Astronomical Observatory
SADC	Southern African Development Community
SALT	Southern African Large Telescope
SAQA	South African Qualifications Authority
SARChI	South African Research Chairs Initiative
S&T	Science and technology
SCI	Science Citation Index
SEDA	Small Enterprise Development Agency
SETA	Sector Education and Training Authority
SETI	Science, engineering and technology institutions
SKA	Square Kilometre Array
SME	Small and medium-sized enterprise
SMME	Small, medium and micro-enterprises
SPII	Support Programme for Industrial Innovation
SSA	sub-Saharan Africa
SSCI	Social Science Citation Index
STA	Scientific and technological activity
STEM	Science, technology, engineering and mathematics
STI	Science, technology and innovation
STP	SEDA Technology Programme
SU	Stellenbosch University
TBP	Technology balance of payments
the dti	Department of Trade and Industry
THRIP	Technology for Human Resources and Industry Programme
TIA	Technology Innovation Agency
TIMSS	Trends in International Mathematics and Science Study
TVC	Technology venture capital
TYIP	Ten-Year Innovation Plan
UCT	University of Cape Town
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organisation
US	United States
USPTO	United States Patent and Trademark Office
VC	Venture capital
WEF	World Economic Forum
WIPO	World Intellectual Property Organisation
Wits	University of the Witwatersrand
WoS	Web of Science
WTO	World Trade Organisation

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This Report was commissioned by the Department of Science and Technology (DST), who funded the project. The work was undertaken by an Academy panel over the period March 2012 to August 2013. The panel was chaired by Professor Robin Crewe and consisted of panel members Professors Ahmed Bawa, Wieland Gevers, John Higgins, Johann Mouton, Francis Petersen, Tshilidzi Marwala and Dr Petro Terblanche. They were supported in their activities by Prof Michael Kahn and Dr Neville Comins who were responsible for writing the initial draft Report.

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Executive Summary

This Report follows a request from the Department of Science and Technology (DST) to the Academy of Science of South Africa (ASSAf) for an independent critical appraisal of the State of the Science, Technology and Innovation (STI) System in South Africa.

It follows and builds on two other system reviews, the 2007 Organisation for Economic Cooperation and Development (OECD) Review of Innovation Policy and the 2012 Ministerial Review Committee report on the STI landscape. Most importantly, the Report considers how the National System of Innovation(NSI) is conceived of within the National Development Plan (NDP) and the expectations that attach to its functioning in this context.

The six chapters of the Report take stock of where the country was in 1994, and where it is now, two decades after the first democratic election. The Report provides a critical analysis of the NSI and, where possible, seeks to make better use of economic analysis and draws on international experience to tease out the issues. It identifies knowledge deficiencies and offers some immediate recommendations and suggested areas for future research.

The main body of the Report starts with Chapter 2 that offers a *précis* of the evolution of innovation policy through its three phases since 1945: 'the linear model'; the 'firm-centric innovation system'; and the 'whole economy innovation system' approaches. International experience and good practice then points to five actions that governments take to influence, manage and promote a well-functioning innovation system: *viz*. framework conditions, knowledge workers, knowledge exchange, knowledge infrastructure, and policy learning. These actions inform the remainder of the Report.

Note is taken of various international metrics that characterise South Africa as a 'factor-driven economy' at a level similar to Brazil and Chile. A concern is expressed at the country's slippage on the Knowledge Economy Index (KEI), while believing that there is cause for celebration in the good scores that some of the research universities enjoy. The above assessments indicate that if government policies pertinent to innovation are out of alignment, the national innovation system will not prosper. This is most clearly demonstrated in the Global Competitiveness Index (GCI): excellent financial performance, but poor general education and hence low overall rank.

Chapter 3 offers a brief analysis of selected policies, strategies, plans and reviews of relevance to the innovation system that have emerged since 1994. The object of the analysis is to interrogate how the innovation system idea has been considered in these various pronouncements – the Reconstruction and Development Programme (RDP); the Growth, Employment and Redistribution (GEAR) strategy; Accelerated and Shared Growth Strategy (AsgiSA); Joint Initiative on Priority Skills Acquisition (JIPSA); Biotechnology Strategy; Nanotechnology Strategy; National Research and Development Strategy; Ten-Year Innovation Plan; Industrial Policy Action Plan (IPAP); science, engineering and technology institution (SETI) reviews; Human Resources Development (HRD) Strategy; National Research and Technology Strategy; OECD Review; Ministerial Review Committee; Ten-Year Review and Fifteen-Year Review. The Report agrees with the 2007 OECD Review comment that there was a lack of understanding of the broader concept of an innovation system since there was no cross-cutting and authoritative source communicating a unified vision across government, let alone to business. The NSI might be thus described as 'pilotless', a situation that for better or for worse has barely changed over the last 19 years.

The National Development Plan (NDP) represents novel thinking about innovation. It gives greater prominence to STI than any of the preceding policy documents and, importantly, adopts and advocates a system-wide view of STI in relation to broader society. It takes the concept out of the sole domain of the DST and considers it to be relevant across government. In brief, the NDP considers the NSI as a vital means for improving the quality of life and improving economic competitiveness. It emphasises continuous learning, partnerships, networks, coordination and coherence as essential for economic growth. Of utmost importance is collaboration among government, business and industry, research institutions, including science councils and universities, as well as the public at large.

Any recommendations to re-energise the NSI cannot be seen in isolation from the NDP, and innovation actually becomes a key enabler for many of its elements. The

government's acceptance of the NDP as the blueprint for the country over the next 20 years presents a unique opportunity to reposition the NSI by communicating correctly the significance of innovation and why it is important for the nation's future.

The goals of the NDP, with its emphasis on the need for the NSI to serve the needs of society, are aligned with World Bank conceptions of innovation. The key issue for developing countries is to strike the right balance between using and attracting existing technology and knowledge, and adapting these to the local context, while simultaneously pursuing focused research and development, including that regarded as 'frontier technology', in domains where there is local advantage.

The next section, Chapter 4, provides quantitative evidence of the inputs to, and outputs and outcomes arising from the innovation system. The characteristics of the skills pipeline, from school to higher and further education, are presented, along with interpretation of the time series of research and development (R&D) surveys. One gains the view that there is no real overall shortfall of funds, but a more or less general shortfall of R&D personnel.

Next follows data on research outputs (publications, citations), South Africa's international standing and the steep rise in foreign co-publication. At this stage it is not possible to ascribe a single cause to this escalation, and further research is needed to determine the reasons and, more critically, whether the growth will be sustained.

The concentration of research output shows important shifts since 1994, with infectious diseases emerging as a major research area, despite confusing signals previously emanating from the highest level of government.

On the other hand, the data on the inputs to R&D point to a system that is moving to embrace the potential of all its people. The demographics of the science council sector have shifted dramatically toward 'African' participation, even when bearing in mind that 'African' includes many staff from north of the Limpopo River, a fact of life that is true across the economy and society as a whole. In turn, this supply-side failure pushes up the cost of labour, so that the growth in gross expenditure on research and development (GERD) is strongly driven by salary inflation.

The innovation outputs – patents, trademarks, plant cultivars – reveal the following:

- South Africa's high relative United States Patent and Trademark (USPTO) standing in the 1980s has fallen; as a commodities exporter its profile is now similar to that of Norway, not Korea.
- Domestic patenting shows a volume pattern similar to Malaysia, but is spread among many institutions rather than being highly concentrated in the universities as is the case in Malaysia.
- Our country continues to excel in the registration of plant cultivars.
- The technology balance of payments gap is not large by world standards.

In summary, the data suggest that the innovation system continues to display robustness, but like the greater economy is not growing as fast as it should. All things being equal, the stretch targets for human resources laid down in the Ten-Year Innovation

Plan will be unattainable, and if these are unattainable, so too will be the stretch targets for GERD:GDP, research publications and PhD production. Growth requires people – their nurturing, retention and recruitment, from all communities, worldwide.

Chapter 5 provides further analysis and a synthesis, commencing with a concept map of the research and innovation landscape. The choice of a concept map is deliberate, as it is felt that a conventional tabular or matrix diagram does not reveal the complexity of the landscape. It is of course recognised that research and innovation systems are dynamic, and in principle it would be valuable to depict this time evolution using a software engine such as Gapminder™. Unfortunately, this lies beyond our limited scope.

The evolution of science council mandates is then examined, followed by a discussion of the innovation activities of firms, and the ways in which university research capacity is supported. This leads to an analysis of the evidence of Innovation Survey 2005, the Global Innovation Index, and Global Entrepreneurship Monitor (GEM).

The discussion of the research and innovation landscape also covers the knowledge infrastructure, including science and technology parks, and Centres of Competence (CoCs). Attention is given to the roll out of internet broadband, noting that vested interests continue to be an obstacle to its deployment to support research and education efficiently and economically. The chapter concludes with a consideration of the key elements of a successful NSI and the strengths and weaknesses of the South African NSI. The Report relooks at the 2007 OECD Review and Ministerial Review report recommendations on NSI coordination focusing on the annual STI Summit held in July 2013 and the transformation of the National Advisory Council on Innovation (NACI).

Arguably, 'big science' has taken the place of the strategic missions of the apartheid era. Simply being awarded the Square Kilometre Array (SKA) is a significant achievement; building the sixty-dish MeerKAT telescope will stretch our capabilities and capacities yet further. Exactly how this effort will enhance local manufacturing R&D and innovation outputs remains to be seen. The experience of the European Southern Observatory in the Atacama Desert of Chile will be particularly instructive and is deserving of close study.

From the onset of democracy to the 2030 endpoint of the NDP is a critical time for South Africa and the country is now halfway through that period. The war-ravaged countries of Western Europe, Japan, and the Asian Tigers were able significantly to raise their living standards in a generation. Others, such as Malaysia, will take perhaps two generations to reach high-income status. South Africa is in a hurry, and to prosper and develop needs to think as smartly as did the Asian Tigers who recognised that their main resource was people. This is what the NDP sets out to do. But it does so without a crisis-driven base of support. The country is perhaps too complacent, and has not developed a sufficient sense of urgency.

Based on the key findings, the STI panel suggested a set of recommendations for reinvigorating the NSI even though in the remit from DST this was not requested. The recommendations could usefully be considered for improving the South African NSI system:

1. The major message of the Report is simple: everything possible must be done to open the skills pipeline and ensure that quality emerges from it.
2. Regular studies of linkages among NSI actors need to be undertaken to determine what improvements are needed to the system. There is a need for a careful review of the positioning and expectations of outputs of all the actors and institutions in terms of their optimum roles in serving the regional and local system of innovation.
3. Mechanisms need to be put in place to enhance the selection and use of technology and knowledge that is globally available, in order to develop the capacity to utilise these for the most pressing social and economic needs.
4. A comprehensive and fully inclusive communications strategy for the NSI and its role in the NDP should be developed and implemented.
5. There is a need to integrate education and local research systems into the NSI approach to get the alignment, the focus, societal support and the enhanced cohesive energy to meet the country's needs.
6. There is a need for coherent opportunities for 'lifelong learning' as the speed of change in technology and knowledge is so rapid that individuals need assistance to stay abreast.
7. There is a need to develop an augmented new set of output indicators that go beyond the traditional measures that will facilitate determination of the value of investment and link to the goals of the NDP.
8. Scoping studies of priority sectors (e.g. those identified in the NDP, the Industrial Policy Action Plan (IPAP) of the dti, etc.) and, in particular, the knowledge-based sectors, such as information and communication technology, biotechnology, pharmaceuticals and health, should be carried out to identify large and small business contributors and the related industry associations in each case.
9. Reviews must be conducted of policies and instruments to determine their effectiveness and to suggest enhancements or changes that should be made. The reviews should be placed in the public domain to canvas further input and the formulation of recommendations.
10. In re-establishing the NSI, Regional Innovation Forums should be supported and strengthened. An assessment should be carried out, by region, of the regional determinants and the active linkages.

Chapter 1

Introduction

This Report follows a request from the Department of Science and Technology (DST) to the Academy of Science of South Africa (ASSAf) for an independent, critical appraisal of The State of the Science, Technology and Innovation (STI) System in South Africa.

While the discussion of an innovation system framework started in the late 1980s, it was only in the early 1990s when attention was given to the idea of a formal South African National System of Innovation (NSI) and the new role that STI might play in the country's development. Subsequently, efforts have been devoted to policy development, the roll out of interventions, and reviews of institutions consisting of the evolving innovation system. This appraisal comes after two important system reviews: the 2007 Organisation for Economic Cooperation and Development (OECD) Review of South Africa's Innovation Policy and the 2012 Ministerial Review of the STI landscape. Most importantly, this Report follows the publication of the National Planning Commission (NPC) national diagnostic, and the adoption of its subsequent National Development Plan (NDP) as government policy.

The ASSAf Report builds on two important system reviews: the OECD Review of South Africa's Innovation Policy (2007) and the Ministerial Review of the STI Landscape (2012).

The NDP has been adopted as government policy and offers an opportunity to interrogate the links between the NSI and the NDP.

The NPC diagnostics report, which identified nine challenges experienced in the country, provides a good platform to determine whether the NSI is geared towards addressing the challenges such as unemployment, poor quality of education, ailing health system, inadequate infrastructure, etc.

The NDP seeks to eliminate poverty and reduce inequality by the year 2030 and, amongst many other themes, identifies STI as key drivers of the changes that will be needed to bring about necessary reduction of poverty, unemployment and inequality (Presidency, 2012). These three scourges are not unique to our development condition; some countries have faced even more challenges and have found a way to restructure and build prosperity.

The STI study panel has quite justifiably asked the following obvious questions: What will this Report offer that is markedly different from its predecessors? What new analysis will it bring to bear? Are there really aspects of the NSI that have thus far eluded understanding?

We expressly hope that this Report does provide insights and suggestions that are new and useful in the present and future context. The period 2007 to 2012 has been so turbulent domestically and internationally that one cannot assume that the OECD and Ministerial Review reports represent the last word on what is happening in and to the innovation system. In this short period we have also seen a political realignment within our country, and serious strain in the international financial system since 2008.

There are a number of reasons that make this study essential. The first is to take stock of where the country was in 1994, and where it is now, two decades later. The NDP diagnostic has given much attention to addressing this question, but there were gaps in what it had to say regarding education, science, technology and innovation. The second is the need for a detailed analysis of the STI system for use by decision-makers. The third is to draw on international experience to tease out the issues as they present, to identify the shortfalls in our knowledge, to offer some immediate recommendations and to suggest areas for future research.

This Report was not designed or resourced to carry out primary research and has therefore not investigated the process of policy formulation in depth. As is the preferred practice of the Academy of producing a 'consensus-style' report[1], this Report is confined to the critical analysis of secondary sources assisted by the now greatly magnified power of Internet search. Document search and retrieval are now almost instantaneous, the main problem being the sheer volume of material. Additionally, even where a panellist was part of an original policy-formulation process, that person was never privy to all the vagaries of that process, and not always part of the events leading to the final version of the resultant position paper or policy document. Herbert Simon's 'bounded rationality' applies, so that the conclusions one draws from a reading of policy may not get to the heart of the matter.

The Report comprises six chapters including this Introduction. It follows an innovation systems approach to consider the role of the system actors and the way that they interact over time and in context. Evolution and niche are important themes throughout the Report with the post-1994 policy frameworks of the SA STI. The main body of the Report starts with Chapter 2 that commences with a discussion that serves to highlight some of the main issues confronting all innovation systems, and the way that these have evolved over the years.

Chapter 3 offers a brief analysis of polices, strategies, plans and reviews of relevance to the innovation system that have emerged since 1994. The object of the analysis is to interrogate how the innovation system idea has been included in these various pronouncements.

The next section, Chapter 4, provides quantitative evidence of the inputs to, and outputs and outcomes arising from the innovation system. The characteristics of the skills pipeline from school to higher and further education are presented, along with interpretation of the time series of research and development (R&D) surveys.

[1] The ASSAf panel comprised Prof Robin Crewe (Chair), Profs Ahmed Bawa, Wieland Gevers, John Higgins, Johann Mouton, Francis Petersen, Tshlidzi Marwala and Dr Petro Terblanche.

Chapter 5 provides further analysis and a synthesis, commencing with a concept map of the STI landscape. The evolution of science council mandates is examined, followed by discussion of the innovation activities of firms, and the ways that university research capacity is being supported. The chapter concludes with consideration of the key elements of a successful NSI and the strengths and weaknesses of the South African NSI.

The concluding chapter offers a synthesis, some recommendations and suggestions for further research.

Chapter 2

The Innovation System Approach

2.1 Taking stock and moving forward

South Africa is now in its twentieth year of democracy, is politically stable, and has made significant achievements in reducing absolute poverty, providing affordable housing, access to electricity and water, and mitigating the impact of the burden of infectious diseases. Whilst still unacceptably high, violent crime has also come down. However, despite large investments in schooling and further education and training, the quality of both leaves much to be desired, especially in the key areas of mathematics and science and language use/academic literacy. Higher education is performing better, though there are large pockets of dysfunctionality, dropout rates are unacceptably high, and the overall efficiency is low. On the labour front, persistent unemployment mirrors inadequate labour productivity, ultimately translating into sluggish growth, and a worrying balance of payments deficit. There is some concern that we are facing a 'middle-income trap' and that we might indeed be fortunate in having maintained a 3% growth rate for two decades. That argument is flawed for the simple reason that our upper-middle income country displays very high inequality that remains stubbornly high despite large social transfers. These are the challenges that the NDP seeks to address, and to do so with urgency since the present equilibrium is unsustainable.

More people must enter employment; new industries must be developed; all this whilst promoting environmental sustainability and preparing for the impacts of climate change. In 1990, foreign exchange reserves were around six weeks of imports, and the foreign debt stood at the equivalent of 60% of gross domestic product (GDP).

The economy was highly concentrated – on the one side, the state-owned industries and utilities; on the other, the 'big six' of Anglo American Corporation, Sanlam, SA Mutual, Rembrandt, Liberty Life and Standard Bank that in 1994, controlled 83.7% of the Johannesburg Stock Exchange (JSE) capitalisation (McGregor, 2008). From 1963 to 1987, the total number of patents awarded to South African inventors filing in the United States was 1 744 compared with the 343 awarded to Korean inventors. In the production of military weapons, the country had reached stage 10 on the 11-point Krause scale and was able to carry out independent R&D and the design of advanced weapon systems with foreign high-technology inputs (Batchelor and Willettt, 1988). South African universities had launched the initial careers of four Nobel Laureates in the sciences and medicine. With appropriate re-orientation and stimulation, technological and economic take-off seemed a reasonable prospect.

On the negative side, apartheid had balkanised the country into a myriad of administrations and pseudo states that had absorbed money from the central fiscus, but had contributed only a small share to GDP. Even so, the 'Bantustans' and other administrations built an African, coloured and Indian[2] middle class, albeit without political rights. When the apartheid government ended in 1994, the security services were already 50% black. Teaching, nursing, and police services were largely black as well. But Africans were essentially frozen out of participating in the economic heartland as business people. Trading licences were rarely granted to Africans, with business opportunities reserved for the minority groups of the Tri-Cameral Parliament.

In the first few months of majority rule after the 1994 election, the problem facing the new government was how to put together that which apartheid had rent asunder, to effect redress, and to invigorate the economy. This called for an astute balancing act, the more so as gold production had been in decline since its peak of 32 Moz of refined gold in 1970 and was down to half by 1994. Industrial growth also declined steeply from the 1970s onward.

The new government introduced the Growth, Employment and Redistribution (GEAR) Strategy (RSA, 1996) that sought to create a positive investment economic climate in order to drive growth to 6%. In the event, buoyed by rising commodity prices, the economy grew, but at an average rate of only 3%, peaking at around 5.5% in 2005/06. The increasing burden of infectious disease, with its human, social and financial costs, added to the problems facing government, as did absence of a compact among state, labour and capital that could have expanded job opportunities, but instead saw salary awards that exceeded baseline inflation. According to Jafta and Boshoff (2008), the rate of profits accruing to business was excessive; others estimated that these were no higher than the United States (US) average .

While GEAR was still being implemented, the Accelerated and Shared Growth Initiative for South Africa (AsgiSA) was introduced. AsgiSA growth diagnostic analysis identified binding constraints and possible opportunities and promised a more balanced footing growth (Presidency, 2006). Before the AsgiSA policy could be taken further, President Thabo Mbeki was replaced by Jacob Zuma as President, and in sequence, three new economic policy documents appeared: the New Growth Path (EDD, 2010); the Industrial Policy Action Plan (IPAP) 2 (the dti, 2011); and finally the overarching NDP (Presidency, 2012).

In common with the vision statements of many other countries, the NDP, or *Vision for 2030*, identifies STI as key pivots for achieving a more inclusive society (Presidency, 2012: 93):

[2] Prior to 1994 the South African demographics were classified as blacks, whites, coloured and Indian; after 1994, black is inclusive of Indians and coloureds.

> Science and technology are the differentiators between countries that are able to tackle poverty effectively by growing and developing their economies, and those that are not. The extent to which developing economies emerge as economic powerhouses depends on their ability to grasp and apply insights from science and technology and use them creatively. Innovation is the primary driver of technological growth and drives higher living standards.

As such, the NDP gives much stronger prominence to STI than the earlier Reconstruction and Development Plan (RDP) had done. Most importantly, the plan adopts a system view of the interrelationships among STI and broader societal influences. In short, it advocates the innovation systems approach (Presidency, 2012: 325-7):

> The system of innovation has a key role to play. It is the principal tool for creating new knowledge, applying knowledge in production processes, and disseminating knowledge through teaching and research collaboration… The national system of innovation is about networks and partnerships. Research and development happens in many sites outside universities, including the science councils, state-owned enterprises and industry.

This is an important development, given the observation of the 2012 Ministerial Review Committee that the innovation system concept appeared to lack currency beyond the walls of the DST.

What then is meant by the concept of an innovation system, and indeed, what is meant by the very term innovation? Some clarity and common understanding must be brought to bear on these concepts lest a clutter of meanings is bandied about with resulting confusion. The next section seeks to clarify these.

2.2 Innovation and innovation systems

Innovation has become the new catchphrase in discussions concerning the drivers of economic growth and societal well-being in developed and developing countries (EU, 2010; Government of India, 2010; Farrell and Kalil, 2010). 'Innovation' has attained canonical status, as a panacea to revitalise flagging economies. Sometimes the term is closely associated with the terms 'knowledge economy' or 'knowledge-based economy', adding to a welter of ideas that places the layperson at a disadvantage. In a sense 'innovation' now holds sway, much as the phrases R&D or science and technology (S&T) did in the past.

Innovation is rarely defined, as if its meaning is obvious to all, citizens and policymakers alike. This lack of definition spawns confusion that elides innovation with invention, if not with S&T and R&D. And in the social domain, innovation is often interchanged with the verb 'change' as in educational change, or social change. So innovation means different things to different people and communities of practice, and where there is lack of commonality, misunderstanding will proliferate.

The most widely adopted definition of innovation is that laid down in the *Oslo Manual* (OECD, 2005). This definition informs the thinking about the South African STI system, the Southern African Development Community (SADC), African Union (AU), European Union (EU) and the World Bank. Specifically, (OECD, 2005: §146):

> Innovation entails the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organisational method in business practices, workplace organisation or external relations.

This definition is catholic: it implicitly embraces both technological and non-technological innovation, and does not limit the act of innovation to firms. By this definition, innovation occurs across society, in firms, health, education and the informal sector, even if the *Oslo Manual* method does not tell us how to measure these.

The OECD definition stands at the heart of the OECD/Eurostat survey methodology that is widely used to measure firm-level innovation activities and results, alongside codified intellectual property rights, such as patents, business processes, trademarks, copyright, registered designs and plant cultivars. The OECD/Eurostat innovation survey methodology is of course open to the criticism that it focuses on firms and thus neglects public sector, social, and informal sector innovation, as well as innovation in indigenous knowledge systems. Innovation in the public sector and social domain is of interest to government, and calls forth its own set of approaches for determining *ex ante* and *post facto* outcomes and impacts. Such studies are done using various evaluation methodologies, including counterfactual studies, randomised controlled trials, quantitative surveys and qualitative investigations.

In practice, there are many other definitions of innovation, so for example, Peter Drucker saw innovation as “change that creates a new dimension of performance”, while for Joseph Schumpeter, it included the introduction of a new good or method of production, conquest of a new source of supply or half-manufactured goods, or the implementation of a new form of organisation (Godin, 2008). To innovate is to bring about change on a detectable scale. It is pertinent to emphasise that invention is not innovation.

In this context, it is also useful to acknowledge South Africa as an emerging economy and thus it is useful to explore relevant definitions developed by the World Bank (2010a:):

> Innovation should be understood as the dissemination of something new in a given context, not as something new in absolute terms. While economically advanced countries naturally work at the technology frontier, developing countries have considerable opportunity for tapping into global knowledge and technology dissemination in their domestic context. This ability will be decisive for initiating new activities, notably in service industries, for improving agriculture and industrial productivity, and for increasing overall welfare in areas of health and nutrition.

This Report makes use of the World Bank (2010) definition of innovation which means technologies or practices that are new to a given society. They are not necessarily

The World Bank (2010) provides a more recent definition that should be considered for developing countries. In their understanding “innovation means technologies or practices that are new to a given society”. They place emphasis on the ‘dissemination’ of technologies and emphasise that innovation, which is often about finding new solutions to existing problems should benefit the poor.

A direct link between local R&D and innovation may not be an appropriate model for an innovation system in an emerging country.

new in absolute terms. These technologies or practices are being diffused in that economy or society. This point is important: what is not disseminated and used is not an innovation. Dissemination is very significant and requires particular attention in low and medium-income countries.

Innovation, which is often about finding new solutions to existing problems, should ultimately benefit many people, including the poorest.

For understanding innovation, distinguishing high technology from low technology is not very useful, particularly in low and medium-income countries. High technology may not generate jobs and wealth, while low technology developments and the exploitation of indigenous knowledge can lead to significant economic growth and improved welfare. The use of high technology in all sorts of products, processes, and services can be more important than producing it.

Innovation is distinct from research and in fact need not result from it. Innovations come from the entrepreneurs who make them happen and ultimately depend on a society’s receptiveness. Thus, even in considering the most appropriate definition of innovation for a particular situation, the socio-economic status of the country plays a role and sets the framework for later planning.

It is clear that to see innovation as a direct link to local S&T, and even more so to local R&D, which may be more relevant in a highly developed country (e.g. the OECD countries), may create an inadequate model for an innovation system in an emerging country.

Science - ‘knowing why’, and technology – ‘knowing how’, require no definition, and we shall assume that the reader is comfortable with the meanings assigned to these. But the meaning of R&D is another matter. Again it is the OECD (2002) that provides the standard definition:

> ‘Basic research’ is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view. ‘Applied research’ is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective. ‘Experimental development’ is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to pro-

ducing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed.

This definition masks great complexity. The systematic measurement of R&D dates from before World War II, and it took another three decades before the definitional issues were (provisionally) settled through the adoption of the *Frascati Manual* (OECD, 1963). The *Frascati Manual* is now under revision toward a 6th edition. The fact of these periodic revisions attests to the changing nature of science, technology, industry and society so that what is termed the 'Frascati technology' (Gault, 2010) remains a work in progress. The most recent addition to the *Frascati Manual* is the Annex on Measuring R&D in Developing Countries (OECD, 2012).

It is clear that there is a need to create a common understanding of innovation and the NSI applicable to this country, and to use this as a tool to interrogate the role of the NSI in the NDP.

The *Frascati Manual* lays out the guidelines for measuring the financial and personnel inputs[3] to R&D. For these to be internationally comparable, it is essential to agree on what counts as R&D, and what is assigned to the category 'other scientific and technological activities'. So, for example, mining exploration, geological mapping, social surveys, policy research and market research are not generally counted as R&D. The guidelines specify what is in and what is out, with some countries completely excluding research in the social sciences and humanities.

Godin (2007) has reviewed the OECD work on R&D and innovation policy from the first *Frascati Manual* through to the first *Oslo Manual* arguing that from the outset a systems approach informed the *Frascati* methodology. This, he claims, is evident in the tracking of the flow of funds among the key economic actors or institutions that perform R&D – universities, industry, public laboratories and not-for-profits, thereby pointing to their systemic relationships. According to Godin (2007), the idea of a research system was therefore already taking shape in the 1960s. Godin (2007) then shows how these ideas naturally flowed into the 1980s articulation of the 'innovation systems approach' under the leadership of Chris Freeman, author of the first *Frascati Manual*, and that of Bengkt Äke Lundvall, former deputy head of the OECD Science and Industry Directorate. The innovation system approach developed and was carried forward within a small community of practice, a network.

The 'approach' remains essentially that – an unfolding way of thinking, so that strictly speaking, one cannot refer to the innovation system 'paradigm'. Writing for the World Bank, Jean-Eric Aubert characterises innovation policy as moving through three phases (World Bank, 2010a).

2.2.1 Linear model of innovation

In the first science-led phase, innovation arose through the conversion of the findings of basic research and subsequent applied research and development into useful products (Figure 1).

[3] Bibliometrics offers a proxy measure of the outputs of R&D by studying the characteristics of peer-reviewed scientific publications.

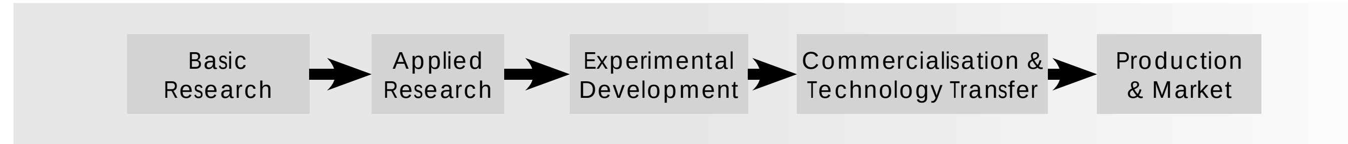


Figure1: The 'linear model of innovation'

The 'linear model of innovation' defined as 'basic research → applied research → experimental development → commercialisation & technology transfer → production & market', has become entrenched in our thinking and continues to dominate policy formulation. It is responsible for concluding that an increased investment in basic and applied research will necessarily lead to innovative products and services in the market place, and where this does not happen, has given rise to the concept of an 'innovation chasm', which has also become an entrenched idea.

This 'linear model' underpinned the emergence of numerous national research laboratories in the wake of World War II, which joined an already existing constellation of public goods (health as in the Pasteur Institute; animal as in the Onderstepoort Veterinary Institute) and research institutes associated with commodity production already founded in an earlier stage of industrial development and globalisation of markets. The linear model is famously captured in Vannevar Bush's report to President Truman in which he extolled the virtues of publicly-funded R&D.

Accepting such a model, one is led to the conclusion that by increasing the investment in basic and applied research, there will be a natural flow of new knowledge, ideas, inventions through to the overall objective of innovative products and services in the market, growing the country's economy.

The simplicity of the linear model remains a common way of thinking about the needs of science in relation to society, notwithstanding a number of shortcomings documented by Mahdjoubi (1997). Chief among these are the use of R&D expenditure as an input proxy for innovation and the assumption that technology always follows science.

In an important South African paper by Jafta and Boshoff (2008), many of the above issues are identified with much the same conclusion. They quote Caracostas (2007):

Whether he or she likes it or not, a policy-shaper trying to defend the need for more funds for R&D relies implicitly on the famous 'linear model of innovation'. The view of innovation sees the relations between research and the market as forming a 'chain', a straight line extending from research to market ('technology push') or from market to research ('technology pull'). Despite the fierce criticism they have attracted from the more popular systemic approaches, these linear models paradoxically continue to influence thinking amongst decision-makers and public opinion because they have the virtue of being simple (or appearing to be so).

In order to obtain some feel for the validity of such a model in the South African setting, it is useful to explore the results of the

South African Innovation Survey (2008). If we accept that the linear model applies, there should be a strong indication that business receives considerable information for innovation from the research sources such as universities and research institutions. In the most recent survey, such sources were regarded as 'highly important' by less than 3% of the respondents, while the major sources were internal expertise, customers and suppliers. It is thus difficult to correlate the 'user perspective' with the 'direct linkage' to R&D. Nevertheless, this model still dominates thinking with the on-going reference to the 'innovation chasm' developed as part of the DST's R&D Strategy (2002) and reinforced by the Ministerial Review making its recommendations in terms of 'research and innovation'. Again, both these are indicators that there is not a good understanding of the necessary components in a successful innovation chain, and this needs to be urgently explored.

The concept of the innovation chasm (DST, 2002; DST, 2008; Kaplan, 2008; Pouris, 2008), is widely referred to by the DST, as well as the Technology Innovation Agency (TIA), National Intellectual Property Management Office (NIPMO) and the Council for Scientific and Industrial Research (CSIR)[4]. TIA places the existence of the innovation chasm as a given in its outlook on innovation strategy[5]. The idea of an innovation chasm has migrated across our borders into SADC discourse (Neba, 2012).

The innovation chasm concept appears to originate from De Wet (1997), the CSIR's former head of policy, who depicted South Africa as a 'technology colony' in which "there is an almost insignificant flow of technology from the local R&D community to the local industrial sector, mainly because the relevant R&D is mainly done 'back home abroad'". What has been missed in the subsequent evolution of the idea is that De Wet (1997) did not view technology colonies as dysfunctional. Instead he argued that what he called a 'Type 1' technology colony that developed its human resource base could soar, as for example the case of Singapore. A second group, called a Type 2 technology colony, was rich in natural resources, e.g. the oil-producing states and South Africa, and they would face the eventual reality of resource depletion. Accordingly, they had to find ways to diversify their industries before the inevitable dawned. This required a joint approach between local enterprises and government, in short, a system-wide approach.

The technology colony concepts are highly complex. Essentially the notion of an innovation chasm amounts to the claim that there is market failure, hence the need for mechanisms to smooth the path. What then is the evidence for the failure to commercialise? And, if there is a chasm, what is government doing about it?

To answer the first question, appeal is made to three sources of information: the Innovation Survey 2005 for the period 2002 – 4 (Blankley and Moses, 2008), the country findings of the INSEAD/WIPO Global Innovation Index (GII), and the Global Entrepreneurship Monitor (GEM). The Innovation Survey 2005 was conducted during the economic upswing, and this should be borne in mind when interpreting the results.

[4] http://streaming.csir.co.za/View.aspx?ID=3331~4k~jEaHVhFO.
[5] http://www.tia.org.za/News/Innovation-agency-eyes-Africa.

The survey involves primary data collection from a stratified random sample of firms, rather than from a small panel of CEOs of large companies as tends to be the case for the Global Competitiveness Index (GCI). Innovation Survey 2005 results of primary interest to this Report may be summarised as follows:

51.7% of firms claimed to be innovating:

1. New technology, machinery and software constituted the main cost involved in innovation.
2. Most innovation was incremental, with 10% being 'new to the market'.
3. Information for innovation came first from within the firm, and then from industry or industry associations; very little information (5%) was sourced from public research organisations (PROs) or higher education institutions (HEIs).
4. Some 15% of innovating firms had collaborative partnerships with HEIs, a finding that seems to contradict 3 above.
5. Only 3% of innovating firms applied for a local patent.

With the exception of the low patenting rate, this picture of the relationship between firms, PROs and HEIs is quite similar to what pertains in the advanced economies. Innovation primarily involves market players, not the non-market organisations. Innovation Survey 2005 gives an impression of confidence.

So does the above evidence point to the existence of an innovation chasm? On the one hand large firms see themselves as innovating, and their bottom line would suggest a healthy rate of profit. On the other hand, GII and GEM tell a different story, namely that of insufficient growth in new firms. This points more toward a problem of the investment climate, than an innovation chasm *per se*.

Basson (1996) described the CSIR researchers of the 1980s as having developed two lines of research: personal interests *versus* politically-driven, the latter term being her euphemism for security and weapons research. Kahn (2013) describes this period as one in which 'own agenda' science existed alongside 'technology for the war machine'. That was how science of the day prospered.

The 'linear model' of innovation thinking peaked in the early 1970s when the high cost of the US wars in South-East Asia forced cutbacks at home with calls for 'value for money'. Already in the 1960s, the US Army Planning, Programming and Budgeting System had started a process of reigning in defence and science expenditures. In the United Kingdom (UK), Rothschild (HM Government, 1971) enunciated his 'customer-contractor' principle to bring accountability to publicly-funded science: "However distinguished, intelligent and practical scientists may be, they cannot be so well-qualified to decide what the needs of the nation are, and their priorities, as those responsible for ensuring that those needs are met". Politically accountable principals would decide on the priorities, not the heads of scientific institutions. The tension between these groups persists to this day, and not only in the UK. Research contractors were expected to find customers who would pay for their research.

'Stagflation,' the phenomenon of stagnant growth coupled with high inflation, became widespread in the Western economies in the 1970s, yet somehow Japan prospered. With empirical evidence accumulating from industry studies, the recognition grew that innovation was rather more complex than the apparent simplicities of the 'linear model' and its treatment of R&D as a public good, freely available to all-comers. In the early 1980s, Freeman, after studying the Japanese industry and its relationship with the Ministry of International Trade and Industry, and Lundvall, with his work on the Danish industry, were instrumental in reviving interest in Schumpeter's ideas on innovation. This, together with the appreciation of the role of the economic actors (universities, industry, non-governmental organisations (NGOs), PROs) as part of a larger system, led to the formulation of what became known as the 'innovation systems approach'. Alongside was a reappraisal of economic assumptions and economic theory, with the rise in status of evolutionary economics and 'New Growth Theory' with their emphasis on the role of institutions and knowledge as factors in production (Romer, 1986; 1990).

In the firm-centric innovation approach, the firm is at the centre of innovation activity.

2.2.2 Firm-centric innovation approach

In its early form, the innovation systems approach understood innovation as arising when economic actors searched for information in response to changes in markets. The prime mover in the process of innovation was a firm that interacted with other actors – firms, universities, and PROs. In this formulation, the role of government was mainly 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. Despite the obvious government role in democratic Japan's success, and in authoritarian states, such as Taiwan, Hong Kong and South Korea, this formulation was essentially consistent with free-market principles that were held to be the *sine qua non*.

In this second formulation of innovation policy, embodied in the *Oslo Manual*, firms stood at the centre of innovation activity, and innovation surveys were thus designed to focus exclusively on the private sector. One consistent finding of innovation surveys worldwide is that firms obtain information for innovation mainly from other firms, the market actors, and not from universities or PROs, the non-market actors. Universities' main contribution to innovation is to generate the reservoir of the highly skilled and to conduct basic research, while the PROs are sites of scientific and technological services (testing, mapping, breeding, disease control, vaccine production, standards), as well as performers of public goods applied research, especially in health (e.g. Medical Research Council (MRC)), agriculture (e.g. Agricultural Research Council (ARC)) and security (e.g. the Council for Scientific and Industrial Research (CSIR)). The Triple Helix movement may be viewed as an attempt to re-emphasise the role of universities as sites of knowledge production whence new techniques for measurement and analysis diffuse into industry (Etzkowitz and Leydesdorff, 1997).

2.2.3 The whole economy innovation system approach

The third, and present phase of innovation policy is a work in progress, with the innovation system understood to cut across the entire socio-economic structure and government itself, so that effective innovation policy requires 'whole of government' policy, and like a convoy, moves forward at the speed of its weakest member. If one component of policy lags, the entire structure is retarded. This third phase is evolving in the context of the 2008 world financial crisis whose resolution is as yet unknown. The evolution of innovation policy occurs in context – geopolitics, technological change and societal expectations.

The geographic boundaries of innovation systems are in flux. In the face of global manufacturing value chains and the establishment of multinational company R&D laboratories in many countries, the very idea of a 'national' system is under question. Within countries, one finds concentrations as regional systems of innovation, as for example, the Pretoria-Witwatersrand-Vereeniging area, and the Greater Cape Town innovation system. The concentrations are quite typical – one thinks of the Milan region of Italy, the South-East of England, or Silicon Valley, as cases in point.

Then there are geographically dispersed 'sectoral' systems of innovation. Local examples of such sectoral systems are the Telemetry System of Innovation in the Western Cape and Gauteng; the Viticulture System of Innovation in the Cape Winelands; the Mining and Metallurgy System across the minerals belt, and so on. These various concentrations underscore that innovation activity tends to agglomerate in specific regions and industries. This raises the need to explore the potential of regional and local innovation systems in enhancing economic growth in the country.

But the very nature of innovation activity is also changing. One such change is 'user innovation' as described by Von Hippel

(1988) in his book *The Sources of Innovation*[6], in which he offered a fundamental challenge to how innovation was then viewed, namely that product innovations were the work of product manufacturers. Von Hippel (1988) contended that this was generally untrue as the sources of innovation were manifold and then proceeded to amass the empirical evidence to support this contention. By his analysis, the functional benefits that accrued to a firm could make it a user, supplier or manufacturer of an innovation: "the functional role of an individual or firm is not fixed; it depends instead on the particular innovation being examined" (Von Hippel, 1988: 3).

A second is the changing role of the university, as signalled in the seminal work of Gibbons *et al.* (1994) that questioned the social contract for science that had endured since World War II. They argued that the period had seen an erosion of boundaries among state research organisations, industrial laboratories and universities, with basic research and applied research carried out in all three and the penetration of science across the economy and society. For this reason a new social contract was needed that recognised a shift in the balance. What they termed 'reliable knowledge' produced under 'Mode 1' science had to yield to a new reality – 'Mode 2' – whereby for science to advance, it must become 'socially robust knowledge' that displayed a new societal accountability (Gibbons, 1999).

The third aspect of change recognises the phenomenon of the 'network society' (Castells, 1996). For science this has assumed shape as the 'new invisible college of science' (Wagner, 2008), whose networks transcend institutional and national boundaries, allowing for collaborative problem solving that draws on the best minds and resources wherever they may be and is reflective of the early membership of the Royal Society of London. The 'new invisible college of science' holds both promise and peril, with the exponential growth of knowledge and its free exchange raising questions of governance structures. The present stand-off between Western democracies and authoritarian regimes concerning Internet content regulation is but one aspect of the growing tension that the 'network society' is generating.

Lundvall (2012) has described an innovation system as:

A 'social system', with the central activity being learning, and learning as a social activity involves interaction between people. It is also a dynamic system, characterised by positive feedback and by reproduction. Often the elements of a NSI either reinforce each other in promoting processes of learning and innovation or conversely, combine into constellations blocking such processes. Cumulative causation, and virtuous and vicious circles are characteristics of systems and sub-systems of innovation.

National systems play an important role in supporting and directing processes of innovation and learning. The uncertainties involved in innovation and the importance of learning imply that process calls for a complex communication between the parties involved. When parties involved originate in the same national environment, sharing its norms and culturally-based systems of interpretation, interactive learning and innovation will be easier to develop.

[6] The choice of title appears to be an act of homage to the classic *The Sources of Invention* (Jewkes, Sawers and Stillerman, 1962).

The International Development Research Centre (IDRC) in Canada has useful insights into systems of innovation, as they support the conclusions by Lundvall (2012):

1. Today, successful innovation is considered as the result of a process of interaction and exchange of knowledge involving a large diversity of actors in situations of interdependence.
2. Recent social network theories of innovation lay emphasis on the strategic importance of relationships rather than technical tools, and on knowledge rather than technological networks.
3. Knowledge-based innovation requires not one but many kinds of knowledge.
4. Furthermore, it requires the convergence of many kinds of knowledge retained by different categories of actors. These new criteria require a new organisational and functional paradigm where the performance of innovators depends on the relations and cooperation between actors in the system.

Some large firms also engage in 'open' innovation, a behaviour subtly articulated in the catchphrase 'connect and develop' (Dodgson *et al.*, 2005). This openness includes companies wilfully abandoning unexploited patent rights in order to stimulate the innovation climate.

Last, there are the forms of innovation that are most difficult to quantify and promote, namely innovation in the informal sector and within indigenous knowledge systems. Innovation in both of these sectors attracts enthusiasm in the literature, but dissemination of new products and processes arising from these sectors is very limited. Of course there are exceptions where indigenous knowledge is available in codified form as in Hindu *Ayurveda* or Chinese Traditional Medicine so that in both India and China, traditional remedies are manufactured to pharmaceutical standards and are sold through registered pharmacies.

The evolution of innovation policy spans major world events – World War II, decolonisation, the Cold War, the ICT revolution, the emergence of the Brazil, Russia, India, China and South Africa (BRICS) bloc, and now the financial crisis. All of these events shape and are shaped by technological change (Perez, 2002). The new technological shaper is the green agenda.

The primacy of the Washington Consensus is waning; the hubris of deregulated markets is accountable for the financial crisis, even if no single cause can be identified. Poor risk modelling plus risky innovation in new financial derivatives, such as credit default swaps, were contributors. Non-technological innovation may be as positive, benign or negative as technological innovation. Faced with the financial nemesis it may be tempting to turn to the interventionist 'BeST Consensus' of Beijing-Seoul-Tokyo (Lee *et al.*, 2007). But this could be another naïve attempt to transplant politically and socially embedded systems across physical space and historic time. It is hardly accidental that the footprint of pre-World War II Japanese expansionism is geographically identical with the Asian Tigers of Chinese Taipei and Korea.

Even so, it is clear that the previously unthinkable may well become the new orthodoxy. Great Britain, home to the Hayek-Friedman-Thatcher revolution, and now under the Conservative/Liberal Democrat Coalition government, seems to have become more open to state intervention in innovation activity. Evidence of this is to be found in the UK innovation strategy that uncritically acknowledges the role of the federal government in US innovation activities. While the US has no centrist innovation policy, the combined actions of its Departments of Commerce, Defense, Energy, and Health, with their billion dollar grants for research, amount to an implicit innovation policy. What then is the role for government in promoting innovation?

2.3 The well-functioning innovation system

Governments, especially in emerging economies and developing countries, have an important role to play in fostering the climate in which innovation will flourish. They play a number of complementary roles: regulator; coordinator; service provider; financier; research performer; and even, innovator.

Drawing on the literature (OECD, 1997; Fagerberg, 2004; World Bank, 2010a), one may identify five actions that governments typically play in contributing to a well-functioning innovation system:

1. *Setting the framework conditions*: macro-economic stability; regulation; mechanisms for prioritisation, agenda setting and coordination; maintenance of a standards regime; protection of intellectual property rights; direct and indirect funding incentives.
2. *Ensuring the supply and mobility of knowledge workers*: human resources development; immigration law; networking mechanisms.
3. *Promoting knowledge exchange*: mechanisms for knowledge exchange and technology transfer including codified and tacit knowledge, and mobility.
4. *Providing knowledge infrastructure*: public research organisations; provision of scientific and technological services; provision of research and communication infrastructure.
5. *Engaging in policy learning:* measurement, monitoring and evaluation; impact assessment; foresight study; utilising evidence-based decision-making; consensus conferencing.

These five actions do not display rigid boundaries one from another. So Chapter 3 addresses actions I and V; Chapter 4 discusses actions II and III; Chapter 5 deals with action IV, but there is inevitable overlap of themes from one to another.

2.3.1 Framework conditions

Action I recognises the importance of the financial and regulatory environment, the 'framework conditions' that are needed to support the economy and innovation activity. Firms require a stable and predictable policy environment, sources of funds, infrastructure, and adequate reward for their entrepreneurial activities, be these commercial, social or intellectual. If the intellectual property rights associated with the innovation, or the profits accruing from the innovation are liable to confiscation, innovation will dry up, and migrate elsewhere. Investment climate and innovation climate are intimately linked.

Much has been made of the connection between innovation and economic growth, with numerous governments making pronouncements on the 'grand challenges' that innovation is expected to address (JIIP, 2012). Identification of such 'grand challenges' does not imply that governments are suddenly inclined to 'pick winners' through industrial policy as in the early days of the Asian Tigers, but it does speak to the issue of agenda setting and prioritisation. This is a common concern around the globe and is addressed through a variety of mechanisms. These range from the appointment of government chief scientists (UK; USA) through to vesting authority in an apex body that carries the authority of the highest office.

In Finland for example, the Prime Minister chairs the National Research and Innovation Council; Malaysia in 2011 founded MIGHT – the Malaysia Government Group for High Technology[7] ,also under the Prime Minister; Germany has no equivalent body. South Africa is somewhere between these extremes – it had a Minister's Council for Science and Technology, but dissolved it. The Ministerial Review report call for a National Council on Research and Innovation (NCRI) resonates with apex practice elsewhere.

The 1996 White Paper on Science and Technology proposed institutional mechanisms through which the new Department of Arts, Culture, Science and Technology (DACST) would exercise a coordination role for stimulating South Africa's national system of innovation in general, and in its commitment to the support of science, engineering and technology development in particular, across government, and to provide leadership in forward planning, budgeting, management, and evaluation of the system as a whole and, especially, public sector research. *Inter alia* these actions would turn around the fragmented, uncoordinated and weakening innovation system (DACST, 1996: 82). It was left to the R&D Strategy to provide many of the mechanisms for attaining these goals, in particular those for budgeting and coordination.

For an external appraisal of the situation ten years after the White Paper, one turns to the OECD Review. This assessed the extent of system coordination through a four-level model of policy coordination and found that while there were mechanisms for cross-department coordination at level 2 (the cluster system), there was no such facility at the highest level of government (level 1), nor any means to effect prioritisation (OECD, 2007: 12). It expressed scepticism at the effectiveness of the cluster system (OECD, 2007: 60) and observed a mismatch between identified strategic priorities and implemented programmes that suggested the need "to revisit the National R&D Strategy and to consider the effectiveness of existing coordination and governance mechanisms". As OECD (2007) noted in the case of the Pebble-bed Modular Reactor (PBMR), the prioritisation vacuum apparently provided the opportunity for interest groups effectively to capture parts of the system.

In effect, OECD (2007) claimed that the South African system of innovation was only loosely coordinated. South Africa in 1994 emerged from a period where there had been attempts at central coordination in the form of Grand Apartheid and the later State Security Council. Post-1994, attempts to install central coordination as in the Ministry for the RDP, the subsequent role of Treasury in promoting GEAR, and the present difficulties that the 'adoption' of the NDP is evincing, suggest a resistance to central coordination from many quarters. Whether this resistance is the expression of

[7] http://gsiac.org/newsmaster.cfm?&menuid=8&action=view&retrieveid=15.

a rejection of any form of coordination *per se*, or is ideological – "we want our plan not yours" – will be answered in the fullness of time. Expecting high levels of coordination for the system of innovation when there is disarray at higher levels is perhaps hoping for too much. Then again, even without coordination the system might succeed in fostering and producing innovation.

Jafta and Boshoff (2008), in a thoughtful critique of AsgiSA, consider the role that the innovation system could play in realising its aims (for which one might as well read 'NDP'). They quote Metcalfe (2007) to support the argument that to promote innovation one must move beyond the linear model of equilibrium economics with its notion of market failure, to a system level that provides the appropriate framework for "a competitive process that is ordered but never in equilibrium … the purpose of innovation policy is to ensure that it never is in equilibrium but is continually challenged from within" (Metcalfe, 2007: 452). Looking at existing policy, they find that instead of the firm being at the centre, South African innovation policy seeks to drive "a one-way process where the users of the results of the NSI activities … are the recipients of knowledge, technologies, and innovation and not active participants in the process" (Jafta and Boshoff, 2008: 8). They argue that the most important role of government should be to promote competition, address sectoral barriers of entry through addressing adverse regulatory constraints, and to rectify government administrative failures. Their conclusion: for firms to innovate they must build new knowledge and participate in markets with flexibility: "where policy frameworks do not facilitate, or (even if unintended) prevent firms from participating in markets, it is likely that the absorptive capacity and skills bases in those industries will also be harmed" (Jafta and Boshoff, 2008: 14).

This brings us to the next major consideration under framework conditions, namely finance. Governments offer direct and indirect incentives toward innovation, being mindful that organisations require capacity to absorb such incentives, much as government requires capacity to manage them appropriately. Where capacity is weak it is always possible that perverse behaviours may set in and these must be detected and remediated. One of the most important issues of allocation is that of managing the supply-demand tension. Scientists can always spend money, so that supply-side policies are naturally attractive to their interests (Mazzoleni and Winter, 2007).

Direct funding includes the provision of finance capital, grants, land, equipment and machinery. Indirect funding includes incentives of various forms such as tax exemptions and rebates, customs tariff relief, and the use of state property. In a well-functioning innovation system, financial controls are in place along with measures that provide an indication that resources are well applied. Even so it must be accepted that risk is an inherent part of innovation and research, some loss is to be anticipated. Specialist funding agencies will address the differing requirements of the various innovation activities – collaboration, training, design, prototyping, R&D, engineering and accessing consultancy. All such activities and services are essential to a well-functioning system.

The NSI displays a full range of financial instruments for supporting research and innovation. Given the country's high ranking for financial market development it would

be surprising indeed for funding to stand out as a defect of the system. One might even contend that funding is not the main problem facing the system; it is the effectiveness and efficiency of spending that constitutes the main barrier to advancement. We shall argue that as a whole there is no shortage of funds for research. What then for innovation? This is a complex question whose resolution lies in perceptions of risk and return, the investment climate, and entrepreneurial attitudes. The two official innovation surveys are consistent in showing that the main source of funding for innovation is 'own funds' of firms, namely from cash reserves.

Whilst there are complaints that venture capital (VC) is in short supply, this is not a problem unique to South Africa. According to venture capital fund analysts, the success rate for investment is around 1 in 50, with the funding decision turning on the applicant's assessment of management and entrepreneurial skills, the quality of their business plan and projections, the credibility of the proposed innovation, and the likelihood of achieving the desired rate of return on capital. The recent introduction of a venture capital tax incentive might promote an increase in VC investment, but it is simply too soon to tell. These matters will be dealt with more thoroughly in Chapter 4 below.

After a lengthy process going back to the time of the White Paper, DST was eventually able to persuade Treasury to abandon its objection to subsidies for R&D. The Income Tax Amendment Act of 2008 duly raised tax deduction of current expenditure on R&D from 100% to 150% and also allowed for the accelerated depreciation of capital expenditure on R&D. The amendment excluded claims for R&D expenditure on software development, and in the social sciences and humanities, thereby unfortunately excluding much of the R&D taking place in the service sector. The previous tax regulations allowed all legitimate business expenditures, including expenditure on R&D, to be tax-deductible, with company auditors providing the standard proof of purpose. The SA Revenue Service could of course institute its own audits to verify if it so pleased. Now, however, it was decided that the extra 50% allowance should be subject to external verification, and DST was given the responsibility for the investigation. This meant that claimants would have to open their research management systems to an outside party, the DST. It also required the DST to marshal the necessary expertise to interrogate research plans and records to determine whether 'genuine' R&D was being undertaken.

The outcome of this effort was perhaps predictable: there was a low uptake of applications for the allowance, with the few applications coming from large, very well-organised firms with long-standing skills in R&D management, e.g. SASOL (2010) and Bell Engineering (2010). The experience led DST and Treasury to rethink the legislation, and in due course a further amendment was promulgated, taking effect on 1 December 2012. This amendment extended claims to include software development, but introduced a completely new claims procedure. Companies would now have to obtain pre-approval from DST for R&D projects for which they would wish to claim the enhanced tax relief. Pre-approval is a measure that is in force in Hong Kong, China, Taiwan and Malaysia (Ernst and Young, 2011). It is too soon to tell what the outcome of the procedure will be in South Africa, but past experience suggests that the uptake will remain low.

2.3.2 Policy learning

The above account of the case of the R&D tax incentive is an example of policy learning in practice. Policy learning is the fifth action of the well-functioning innovation system, and was a matter on which the Ministerial Review also expressed its view, agreeing with OECD (2007) that there was a serious knowledge gap regarding the workings of the innovation system that had not been adequately filled by the National Advisory Council on Innovation (NACI). The Committee, noting that the reviews of NACI had gone unheeded, proposed the establishment of a properly capacitated, arms-length agency to be called the 'Office for Research and Innovation Policy' (ORIP) that would provide high-quality policy support to the NCRI, coordinate STI information, conduct monitoring and evaluation, and carry out foresight studies as well.

The Ministerial Review was impelled to offer this recommendation in the light of the two prior reviews of NACI that had not been acted upon, the lack of coordination of STI information, the absence of a policy advisory role for NRF, and the closing down of the S&T policy office in the CSIR. According to the Ministerial Review, STI data sources were scattered and under-utilised, and there were serious gaps in the data being gathered. An additional problem was the mismatch of targets emanating from the Presidency Department for Performance Monitoring and Evaluation and those of line departments. ORIP would address the problem of the information chasm.

2.4 The big picture

The development of a common understanding of the innovation process is necessary and desirable, albeit difficult to achieve in practice. A case in point concerns the expectations that are directed at publicly-funded organisations that in order to survive must engage with the market in the same way that firms do. The on-going debates and unease at the proportion of contract income that science councils earn, and the pressure placed on universities to earn 'third-stream income' attest to the complexity of being both a public and private sector player.

To innovate, to engage in R&D, is to take risk with one's scarce resources, and calls for specific capacities that grow with time. It is a truism that in most cases every large firms grew from something smaller. Obviously, where a large firm splits into a set of smaller but still large firms, this is untrue, but in the main a small firm, if it survives infancy, may become larger, and sometimes big.

In general, as the innovation surveys show, large firms are the main sites of continuous innovation. Some large firms maintain a policy of ensuring that a fixed proportion of their products should have been developed in the last three years. Large firms engage in innovation to stay in business, and will use the most cost-effective means so to do. Where the need for R&D arises they may choose to effect this in-house, by outsourcing the R&D they require, or by searching for existing solutions. Smaller firms do not have the analytic skills and in many cases also lack the absorptive capacity to utilise R&D, and it is here that government may intervene to provide access to R&D services. As Gault (2010) observed, R&D in firms is a rare event. Not all firms can afford to do it; firms are not equally capable; nor can most understand and absorb the results of R&D. That takes specific talent.

Understanding markets is an absolute necessity – staying close to the customer used to be standard advice, but in fast-moving markets this may be insufficient. History abounds with examples where innovators had to create markets or provide market complements in order to sustain their drive for sales and efficiencies of scale. The Model T Ford could only become the success it was because of the complements of a road network and sources of vehicle finance. In consumer electronics, Sony saw the market gap for the Walkman™; Apple had the time and resources to re-engineer the basic MP3™ player to give the world the iPod™, and to follow this with the iPhone™ and iPad™. In South Africa, Heunis created Mxit™ that at its peak relayed 30 billion messages a month, and Shuttleworth thought about a security algorithm for Internet purchasing and came up with Thawte™. Designing a chip to go inside artillery shells ultimately led to DetNet™ electronic detonators. 'White' light emitting diodes invented by Nakamura are now replacing both incandescent and fluorescent lighting; Nakamura began research on gallium nitride semiconductors in 1988 but had to wait until 2005 for a 'company bonus' in recognition of his work. Innovation leadership entails being able to spot innovation potential, deciding how to seize the opportunity, being determined and patient[8]. The DST-CSIR Titanium CoC is an example of an attempt to create a new market, and is a thrust entirely within the CSIR legal mandate under the Scientific Development Act (*Act 46 of 1988*): "to foster, in the national interest and in fields which in its opinion should receive preference, industrial and scientific development".

How does one relate these success stories to the nature of the innovation systems where they arose? This question is virtually impossible to answer. It frustrates and intrigues; it elicits jealousy and fear; protectionism; and even hubris. If innovation is taken to mean the provision of new goods or services to markets, one might do well to study the export-led industrialisation strategy of the Asian Tigers, but in so doing one must take account of the uniqueness of their experience – a combination of early industrialisation, the US protective umbrella, the possibilities of reverse engineering, a workforce initially with restricted rights, but growing levels of skill. A summary of these complex phenomena may lie in a parody of the opening paragraph of Tolstoy's *Anna Karenina*: "all effective innovation systems look the same, the ineffective ones are unique in their shortcomings".

Lundvall speaks to the importance of history, context and path dependence in shaping these behaviours and their eventual culmination in actual performance. Breaking existing constraints thus demands exceptional times and exceptional leadership. Such a view was offered at the recent World Economic Forum (WEF) for Africa meeting in Cape Town, with the General Electric Chief Executive Officer (CEO) for Africa reminding the audience that each African country presented its own unique risks and opportunities (*Business Day,* 2013).

The student of the economics of innovation will look at the eruption of the industrial revolution in England and then Belgium, only later to transform the US and Germany, and Japan. The political and economic institutions in each country interacted with

[8] Albert Einstein laid the basis for today's laser technology in his paper: Einstein, A., 1916. *Strahlungs-emission und -absorption nach der Quantentheorie. Verhandlungen der Deutschen Physikalischen Gesellschaft* ,18, 318–323.

technological change and gave rise to quite different forms of governance. The quest for markets and regional dominance on one side and popular demands for a better life on the other, led to the 'Age of Extremes' that spanned the 'short 20th century' from 1914 to 1989 (Hobsbawm, 1994). Its two World Wars saw the demise of the Ottoman, Austro-Hungarian, British and Soviet Empires, the rise of China and India, the resurgence of Germany and Japan, and the US, briefly the one superpower, but now facing a multipolar world. Smaller countries, notably the Republic of Korea, Finland, Israel, Hong Kong and Singapore emerged to become producers of high technology goods, joining the ranks of the high-income countries. The differing innovation systems of each country played their part in these shifts.

Acemoglu and Robinson (2012) offer a contrarian view of the source of economic growth, using econometric analysis to show that the variables associated with the nature of domestic political and economic institutions better explain the variation than models based on climate, geography, capital, knowledge, and labour. Germany, Japan, and the Asian Tigers have one thing in common, namely having had to recover from the almost complete destruction of their infrastructure through occupation and war. The former two recovered under democratic constitutions imposed by the Allies; the latter progressed under dictatorship or enlightened authoritarian and technocratic leadership. A second commonalty was their commitment to building education and training systems, and their capacity to absorb technology. The recent OECD (2013) Review of innovation policy in the South-East Asian States provides valuable insights into the drivers of innovation showing that specific innovation policy is less important than getting the broad framework conditions right.

Innovation depends to a large extent on workforce skills that are largely determined by public education systems.

The South Africa of 1994 did not face an existential crisis. The country functioned, with gross inequities, but it functioned, some elements doing very well indeed. So we are virtually the equals of Singapore when it comes to financial services, but we lag behind the Philippines when it comes to education. In the final analysis, "Innovation depends to a large extent on workforce skills that are largely determined by public education systems" (OECD, 2013: 109). Innovation system functioning is hampered by its least effective component. It is clear what is holding us back.

2.5 The innovation system approach in South Africa

Governments play an important role in innovation systems, setting innovation policy, ensuring an enabling environment, and intervening directly when the need arises. South Africa's White Paper on S&T not only introduced the idea of the NSI, but also scoped out the attributes that it should meet in addressing national development. The White Paper followed the 1993 IDRC Mission to South Africa that carried out an OECD-style review of the then S&T policy. The Mission took place in the closing days of the security state, and perhaps for fear of any deference to control mechanisms went so far as to advocate high freedom for science by invoking none other than Michael Polanyi's Republic of Science as an appropriate guide for the future.

Mission leadership and the main technical advice for the White Paper came in the person of a former Chair of the OECD Science and Technology Policy Committee so that much of its thinking aligns with the mainstream of OECD thinking of that time. The White Paper offers what might be termed a catholic definition of the national system of innovation "as a set of functioning institutions, organisations and policies which interact constructively in the pursuit of a common set of social and economic goals and objectives" (DACST, 1996: 20). To enable such interaction, the White Paper laid out the government role in policy formulation and regulation, provision of funding to promote research and innovation, ensuring mechanisms for technology transfer, intervening in cases of market failure or direct national need, human resource development and capacity building and the provision of infrastructure. In addition, it argued for the use of foresight and forecasting methods to inform priority setting, and for the system as a whole to be subject to performance measurement to ensure accountability and transparency. These principles were and are consistent with the best practices outlined above.

The White Paper was silent on coordination mechanism for the to-be-transformed innovation system, and for its part the R&D Strategy of 2002 did not address the issue. Instead, through the subsequent New Strategic Management Model of 2004, the coordinating mechanism of the Science Vote was abolished. The rationale for this was that DACST should address cross-cutting issues of S&T without intruding on the turf of sector-specific departments, and would instead provide an overview of what was happening across government by aggregating the S&T budgets of these departments. The R&D Strategy also motivated the transfer of the CSIR from the dti to DST.

It then fell to the OECD Review of 2007 seriously to highlight the potential governance failure that the absence of coordination presented. The matter remained dormant until the new Minister of S&T of the Zuma administration appointed a Ministerial Review Committee (DST, 2012: 3) to advise on:

- The framework conditions to achieve coordination and coherence of the components of the NSI to ensure a functional and effective system that will deliver innovation-driven national economic and social development.
- The appropriate institutional arrangements and structures (existing, or to be established) that will direct the NSI, and will highlight and prioritise future challenges and research needs, and set out a suitable timeframe for addressing them.

The Committee duly gave its view on the state of coordination exhibited by the system, the desired extent thereof, and the mechanisms it considered necessary to achieve this. Where the previous R&D Strategy, Ten-Year Innovation Plan (TYIP) and

OECD Review had either skirted the matter or reported in general terms, the Committee gave serious attention to the issue. Its diagnosis of the state of coordination (DST, 2012: 10) was that

> a common understanding of the role of research and innovation in achieving the priority goals of the country, and the need for more closely coordinated activities to achieve these ends, remain elusive … (There was) … very limited horizontal and vertical coherence and integration of purpose and effort between the various agencies of the NSI.
>
> (So that) … R&D activities appear to be highly fragmented, with the risk or even the reality of duplicated or contradictory effort … (and) the limited level of coherence and coordination (has the effect that) business has been inadequately included in the conception and coordination of the NSI.

After taking evidence, the Committee concluded that:

> … the most pressing matters concern the need for strengthened and coordinated governance at the highest level … dramatically improved resourcing to critical mass directed at a limited number of priority areas, urgent measures to address the broad range of skills needed for the vitality of the system, and the much greater involvement of business in the NSI policy arena.

With this in mind, the Committee recommended the inception of a representative apex body, a Presidential level 'NCRI'. This body would be responsible for prioritisation, agenda setting and highest-level coordination of effort. Such bodies are to be found in many of most successful NSIs around the world – Korea, Japan, and Finland. The second mechanism for coordination would be through the introduction of 'Science Vote 2' in the form of the Research and Innovation Vote that would "function as a macro-coordinating mechanism to ensure that the country's public researchers in all public research-performing institutions (i.e. both HEIs and science councils), are adequately supported to perform their work. The NCRI, in consultation with cognate advisory bodies, should provide the oversight of the broad size and shape of this allocation" (DST, 2012: 17). At the time of writing, the Minister of S&T has declared his intention not to create another statutory body, but rather to convene an annual Summit on STI as a means to bring the various players in the NSI together.

How then does the innovation system perform? More detailed answers to this question are provided in Chapters 3, 4 and 5 below. Here it is useful to offer some views from the outside, namely the assessments of organisations such as the WEF, INSEAD-WIPO and the World Bank. But first a caveat: many of these assessments are based on the subjective impressions of a select group of business sector respondents, rather than from large representative surveys. Investment decisions are of course taken on a mix of hard data and subjectivity, so that the caveat may be more a recognition of reality than an inherent defect.

The twelve-pillar assessment scheme of the WEF Global Competitiveness Index (WEF, 2012) categorises South Africa and China as among 33 efficiency-driven economies, with India in the factor-driven group and Brazil and Russia in transition toward being innovation-driven. The sources of this assessment are Business Leadership South Africa and Business Unity South Africa through the WEF Executive Opinion Survey and other databases of OECD, UNESCO, etc. According to the 'innovation and sophistication factor', South Africa (42) lies midway between Brazil (39) and Chile (45), whilst on basic requirements it stands at 84, as does higher education, while for financial market development it stands at rank 3, behind Singapore (2) and Hong Kong (1).

On the other hand, the INSEAD-WIPO Global Innovation Index (GII) places South Africa at rank 54, above Brazil and below Chile. The various factor scores that place us above our overall rank include 'ease of obtaining credit' (1), securities exchange activity (9) and 'protection of investors' (10), thus confirming the WEF rankings for the financial sector. University-industry linkage has the relatively high rank of 25.

The Knowledge Economy Index (KEI) (World Bank, 2013) places us at rank 67, a decline of 15 places since 2000, largely because of poor rankings on ICT penetration (98) and education (81). 'Innovation' ranks at 44 suggesting that the former two factors, together with poor economic incentives are retarding the innovation system.

What the above assessments point to is that if policies beyond the reach of the DST are out of alignment, the innovation system will not prosper. This is most clearly demonstrated in the WEF results: excellent financial performance; poor general education; low overall rank.

The next chapter provides the reader with an in-depth review of policies that have shaped and impacted the innovation system. It shows that over nearly two decades of incubation the innovation system approach has gradually diffused into the wider policy debate.

Policies, Strategies, Plans and Reviews

3.1 The innovation system in national policy

As argued above, the development and performance of innovation systems is strongly dependent on the overarching context of a country for support, resources and regulation. Its evolution is intimately connected with, and contributes to the political, social and economic fortunes of the environment in which it finds itself. The events of 1990 constituted a watershed moment for the South African system as discussions to dismantle the apartheid machinery and overhaul the entire system intensified. S&T was not spared scrutiny as some of its institutions were regarded as pillars of the apartheid repressive apparatus. There was optimism that the high concentration of R&D within the military institutions would metamorphose into civilian R&D. This chapter considers the way that a selected set of policies dealt with S&T and innovation.

We naturally commence with the 1994 Reconstruction and Development Programme (RDP).

3.1.1 Setting the basis: the RDP

The overarching policy statement of the democratically elected government was the RDP that set out to mobilise the people and the country's resources for the eradication of poverty, and improving health, education and social cohesion as recorded in the *Government Gazette 1954* of 1994. The RDP noted that S&T had an important role to play in the development of all sectors of society but did not use the terminology of the innovation system, and its discussion of economic policies made only a passing reference to innovation in public enterprises. It did, however, propose the restructuring and refocusing of major institutions supporting industrial innovation, such as the Industrial Development Corporation (IDC) and the Small Business Development Corporation. The Office of the RDP, as a Ministry in the Presidency, had a short life, being closed in April 1996 as a result of tensions with the Treasury concerning the control of donor funds at a time of financial stringency. The new economic policy of government was to be the Growth, Employment and Redistribution (GEAR) strategy.

3.1.2 GEAR and innovation

Faced with external pressures and instability of the Rand, and concerns over the commitment to sound macroeconomic policies, government introduced the GEAR strategy to restore confidence and enhance credibility. GEAR was built upon the

strategic vision set out in the RDP by committing government to specific macro targets, and included a phased fiscal deficit reduction plan that was more ambitious than its predecessor (Lewis, 2001:4). GEAR provided an opportunity to improve policy coordination, and amongst other efforts set out to enhance the industrial innovation support programmes. This included retaining the Support Programme for Industrial Innovation (SPII), which had some positive impacts on domestic innovation, as well as the matching grants scheme of the Technology and Human Resources for Industry Programme (THRIP), designed to strengthen the relationship between educational institutions and industry. The technology transfer programme of the Department of Trade and Industry (the dti) that served to oversee and advise on licensing and royalty agreements, was to be converted into an agency dedicated to facilitating access by firms to required technologies. GEAR policy put much emphasis on the development and support for industrial innovation, but did not mention the NSI and STI directly.

3.1.3 AsgiSA and JIPSA

The Accelerated and Shared Growth Initiative for South Africa (AsgiSA) was launched In February 2006, and identified six "binding constraints on growth" that needed to be addressed to achieve shared growth of 6% and the halving of unemployment and poverty by 2014. AsgiSA made no reference to the S&T White Paper, the NSI or any innovation policy whatsoever. It did, however, refer to financial systems innovation. Coupled to AsgiSA was the Joint Initiative for Priority Skills Acquisition (JIPSA) introduced in 2006 to close the skills gap between current and potential employees and employment opportunities. The JIPSA steering committee consisted of the deputy president, key ministers, business leaders, trade unionists, education and training providers, and experts. Its task was to identify urgent skills needs and to develop quick and effective solutions. Solutions included special training programmes, the goal of bringing retirees back to employment, engaging with the South African diaspora, and, where necessary, drawing in new immigrants. It also included mentoring and overseas placement of trainees to fast-track their development. The JIPSA strategy document did not mention the concept of the NSI or STI or innovation but focused on human capital development.

3.1.4 Recognition of innovation through the NGP

The New Growth Path (NGP) launched in 2010 saw innovation as vital to achieving economic growth in South Africa. The NGP stressed that technology policy should allow space for some basic research, but even more importantly should promote myriad, often small and incremental innovations on the shop floor, especially in employment creating activities. Another link of the NGP policy to the NSI, was in targeting the creation of 100 000 new jobs in the knowledge-intensive sectors of ICT, higher education, healthcare, mining-related technologies, pharmaceuticals and biotechnology by 2020. The NGP pointed out the importance of emulation, adaptation and diffusion of existing technologies that would support large-scale employment creation and improved livelihoods. It advocated active industrial policy in which development of knowledge-intensive sectors and green technologies needed new kinds of education and training, greater R&D support, as well as the establishment of learning organisations in enterprises and state agencies (Presidency, 2010). The NGP made no explicit reference to the NSI, but referred to strengthening technological innovation, supporting research, development and entrepreneurship. Coherence, coordination and collaboration as an important strategy to achieve employment, economic growth and quality of life were emphasised as important goals.

The government's acceptance of the NDP as the blueprint for the country over the next 20 years presents a unique opportunity to reposition the NSI by communicating correctly the significance of innovation and why it is important for the nation's future.

3.1.5 The NDP

The National Planning Commission (NPC) was established in 2009 to chart a new path for South Africa that would eliminate poverty and significantly reduce inequality by 2030. Like other national policy documents aimed at socio-economic development, the NDP recommendations are centred on economic effectiveness. Concepts central to the NSI now emerge throughout the document – science and technology innovation, industrial innovation, education and training innovation and social innovation. In some part, this new emphasis is perhaps reflected in the composition of the 26 Commissioners, a third of whom have backgrounds in science, engineering, technology, health and environmental science. This might account for the shift in the fortunes of STI.

The government's acceptance of the NDP as the blueprint for the country over the next 20 years presents a unique opportunity to reposition the NSI by communicating correctly the significance of innovation and why it is important for the nation's future.

The goals of the NDP underscore the World Bank conception of innovation through its emphasis on the need for the NSI to serve the needs of society. The key issue for developing countries is to strike the right balance between using and attracting existing technology and knowledge, and adapting these to the local context, while simultaneously pursuing focused research and development, including that which is regarded as 'frontier technology', in domains where there is local advantage.

The NDP reasons that achievement of the goals of eliminating poverty and reducing inequality will require a far greater commitment to deepening the productive base, whether in agriculture, mining, manufacturing or services. The NDP further stresses that for these goals to be successful, continuous learning and innovation, coupled with substantial R&D and support for commercialisation, are essential.

The plan asserts that South Africa's competitiveness will rely on "national systems of innovation that permeate the culture of business and society". The innovation system should function in a coherent and coordinated manner with broad common objectives aligned to national priorities. The NDP envisages a system of innovation driven by S&T, with higher education and training, public enterprises and private businesses and industries operating in a common framework to address pressing challenges, with special consideration given to dedicated programmes in water, power, marine, space and software engineering in which South Africa is considered to have both comparative and competitive advantage. Although some technologies may not be cost-effective in the short term, South Africa's plans need to take a long-term view and consider the possibility that technology will radically transform infrastructure, mobility and the development of cities, towns and rural areas.

The World Bank conception of innovation through its emphasis on the need for the NSI to serve the needs of society could play an important role for the attainment of NDP targets in the country. The key issue for developing countries is to strike the right balance between using and attracting existing technology and knowledge, and adapting these to the local context, while simultaneously pursuing focused research and development, including that which is regarded as 'frontier technology', in domains where there is local advantage.

In brief, the NDP considers the NSI as a vital means for improving the quality of life and improving economic competitiveness. It emphasises continuous learning, partnerships, networks, coordination and coherence as essential for economic growth. Of utmost importance is collaboration among government, business and industry, research institutions, including science councils and universities, as well as the public at large.

The NDP represents novel thinking about innovation. It adopts and advocates a system-wide view of STI. Any recommendations to re-energise the NSI cannot be seen in isolation from the NDP, and innovation actually becomes a key enabler for many of its elements.

The NDP represents novel thinking about innovation. It gives greater prominence to STI than any of the preceding policy documents and, importantly, adopts and advocates a system-wide view of STI in relation to broader society. It takes the concept out of the sole domain of the DST and considers it to be relevant across government. Any recommendations to re-energise the NSI cannot be seen in isolation from the NDP, and innovation actually becomes a key enabler for many of its elements.

3.2 Specific innovation policy initiatives

The 1996 White Paper on S&T introduced the relatively new concept of a NSI, as well as the importance of 'innovation' as a key driver for both economic growth and social upliftment. The White Paper made a most important statement against which the implementation strategy should be assessed.

> Throughout the White Paper, the theme of innovation, as opposed to S&T itself, has been made central to the determination of policy and strategy. This is a crucial focus – excellence in S&T does not necessarily translate into innovation. The transformation of new ideas into commercial successes, which are so important to the nation's ability to achieve economic growth, employment crea-

> tion and competitiveness, requires that attention be given not only to R&D and the technological factors of innovation, but also the social, institutional and market factors such as adoption, diffusion and transfer. In some cases, these non-R&D costs may account for as much as 60% of the total innovation cost. In the past, policies designed to improve the S&T output of a country have not recognised the importance of non-technological factors to the innovation cycle. As a result, S&T initiatives have often failed to deliver consistently and coherently against promises of economic growth and employment creation.

The White Paper on S&T went further, proposing the development of a number of new studies, reviews and instruments designed to enhance the 'system of innovation' but one should question how far the policies and strategies indeed moved beyond not just a S&T focus, but an R&D focus.

One of the first strategies to be introduced after the White Paper on S&T is on biotechnology, followed by the R&D strategy.

3.2.1 Biotechnology Strategy, 2001

The *2001 National Biotechnology Strategy for South Africa* dedicated a section to how biotechnology innovation proposed a set of biotechnology regional innovation centres (BRICs) and the establishment of a Biotechnology Advisory Committee (BAC). It included roles for anchor investors, incubators and technology platforms. The strategy is currently under review, with a second strategy due in late 2013. The review arose for a number of reasons, including the absorption of the BRICs into the new TIA; failure to form the recommended BAC that was to oversee implementation and act as a coordinator to promote coherence; and despite investment of some R 500 million on platforms and specific projects to launch companies based on locally developed research, there was little evidence of success.

This situation raises the important question – "What have we learnt from this experience and how should DST and TIA incorporate this learning?" It appears that no formal review, with interviews of the BRICs, their beneficiaries, government officials responsible, the broader biotechnology industry and research groups was ever undertaken.

3.2.2 National Research and Development Strategy, 2002

The National R&D Strategy set out to address weaknesses in terms of STI funding, human resources development, the apparent decline of R&D in the private sector, intellectual property leakage, and fragmentation of government's S&T efforts. To achieve these goals, the strategy called for the establishment of five new technology missions – biotechnology, information technology, technology for manufacturing, resource-based technology, and technology for poverty alleviation. These missions were to be advanced by a new body, the Foundation of Technology Innovation, modelled on Finland's TEKES. Although the R&D strategy recognised the crucial need for coordination between government, business, universities and research agencies, it did not provide mechanisms through which this could be addressed. The Department of Trade and Industry initiatives, such as THRIP and SPII, were mentioned as ways to link the public sector with business, but there was no explicit integration with other sub-sets of

the wider innovation system. There was oblique reference to technology innovation and links with universities. Essentially the R&D strategy reads asa strategy for science rather than being pro-innovation. While the strategy claimed to be evidence-based, it used flawed data and did not properly contextualise the lessons that it drew from comparator countries. The underlying ethos of the strategy maintained linear model thinking, rather than advancing the interactive thinking that is believed to characterise innovation systems.

3.2.3 The Nanotechnology Strategy, 2006

The Nanotechnology Strategy sought to position South Africa as a player in this emerging field, claiming that nanotechnology would cut across biotechnology, technology for manufacturing, information technology, natural resources sector exploitation, and by extension could contribute to poverty reduction. A Technology Innovation Network was proposed to support the implementation of the strategy, but as with other initiatives, human resources, infrastructure, and monitoring and evaluation of the initiatives proved to be a challenge.

3.2.4 The Ten-Year Innovation Plan

The Ten-Year Innovation Plan (TYIP) 2008 – 2018 was launched with the aim of transformation towards a knowledge-based economy in which the production and dissemination of knowledge both drove economic benefits and enriched all fields of human endeavour. The focal concern of the plan was to address the government socio-economic mandate, particularly the need to accelerate and sustain economic growth and further contribute to the development of the NSI. The plan also recognised that while the country's S&T was progressing, there was still a huge gap between South Africa and knowledge-driven economies – the WEF of 'innovation driven' economies, such as Korea, Finland, Singapore, Sweden, Germany and the US.

The TYIP, building on the R&D Strategy, referred to the failure to commercialise the results of scientific research, as well as the production of knowledge workers in terms of quality and quantity. The plan is structured around five Grand Challenges designed to stimulate multidisciplinary thinking and develop new technologies. The plan sets out objectives, indicators and targets for where the system should be by 2018. These are stretch targets, which NACI (2012) found to be highly ambitious.

3.3 The NSI as a learning system

3.3.1 SETI and system reviews

Following the White Paper recommendations, the Department of Arts, Culture, Science and Technology (DACST) commissioned reviews of the Science, Engineering and Technology Institutions (SETIs) and the system as a whole. The purpose of the reviews was to take stock of the S&T institutions in terms of human resources, infrastructure, funding and mandates. DACST managed the review process and assembled panels of experts who submitted their reports to the Minister. The ARC received a report highly critical of its staff demographics, but in the main, the reviews of the other SETIs confined themselves to commentary on research excellence. No major transformation followed the tabling of the individual SETI or system-wide reviews.

After the 1997 system-wide review, individual institutions reviews followed for NACI in 2003, the National Research Foundation (NRF) in 2004 and 2010, the MRC, and the CSIR. The NACI 2003 review concluded that NACI should provide the government with well-researched advice on both policy and performance of the NSI, using a group of experienced and active people selected from the many different areas within the system. It also recommended that the NACI Act should be amended so that an independent CEO could be appointed by the board. With the New Strategic Management Model in place, DST and other line departments now took up positions on SETI boards, in theory thereby bringing the SETIs closer to government. This practice lasted some three years and seems since then to have been quietly abandoned or at best, down-scaled.

At present, the responsibility for carrying out reviews of the science councils now rests mainly with their line departments and their individual boards. The system of reviews has become less frequent, and the degree to which the results of the reviews are made publically available in order to ensure transparency, has not been adequately addressed.

3.3.2 National Research and Technology Foresight study, 1999

The National Research and Technology Foresight (NRTF) study of 1995 – 1999 concluded with the release of some 14 panel reports and a synthesis report (DACST, 1999). The foresight used a mix of methodologies – panel discussion, the Delphi process, and the construction of four scenarios. The NRTF envisaged the innovation system as displaying both national and regional characteristics.

The NRTF was a highly innovative process and one of its benefits was to bring a new, young, and more representative group of scientists and technologists into the policy formulation process, and to build considerable stakeholder participation. However, despite the original statement of intent that the NRTF findings would be taken forward by means of an implementation plan, the call for proposals to develop and manage the implementation plan was terminated. While the R&D Strategy claims to have been informed by the NRTF findings, it is in fact difficult to find any such link. What the strategy did explain, however, was that the foresight implementation plan had been terminated through the unavailability of further donor funds. This might be taken to indicate that foresight was not felt to be the core business of the DACST, or that other more pressing demands pushed it aside.

3.3.3 OECD Review

In 2006, the DST commissioned the OECD to conduct a review of South Africa's innovation policy. The OECD Review process entails a country self-assessment followed by in-country fieldwork and subsequent presentation of the country report for response by the responsible authorities. NACI (2006) produced the self-assessment and a four-person review team spent a fortnight interviewing key stakeholders. The impression NACI (2006) created was that 'innovation' is in fact a 'building block' additional to R&D and human capital, in this case driven by government using 'policy, governance and resourcing' in a top-down approach with the role of business and 'public and private users' being the recipients. According to the NACI perspective, the state was

the dominant driver of innovation, which as global experience attests is far from reality. If there was confusion as to what an NSI is expected to do, then this representation only compounded the problem. To use such an organisational model to guide the later focus areas and implementation parameters would indeed be most difficult. The NACI report outlined the 'responsibilities' of the various government departments, the business sector and non-governmental organisations (NGOs) in a compartmentalised view, but little was said of those aspects that require complex and deep interactions between all the participants to generate the supportive eco-system for innovation to thrive. In particular, it considered that DST should assume direct management responsibility for S&T, as detailed in terms of policy formulation, funding, performance and international relations.

The review team duly carried out their work and tabled their findings to a large stakeholder meeting at The Innovation Hub in Gauteng. The review arrived at a number of quite critical findings that were later endorsed by the Ministerial Review Committee. The following observations are worth repeating (OECD, 2007):

- There seemed to be only a limited horizontal coherence and integration between agencies in the NSI, and no cabinet-level coordinating body had yet been successful in devising and monitoring national level strategies for innovation, and marshalling the resources needed for these.
- NACI's mandate was hamstrung by the fact that it reported to the DST and thus had no structural location that would afford it the authority needed for effective coordination of a national system.
- Business was insufficiently involved in building the NSI.
- The concept of a NSI has as yet gained limited currency, both in the extent to which it was understood as something wider than the sum of traditional R&D activities, and in the extent to which it had been absorbed into the strategies of key actors (including government departments and higher education institutions).
- The notion of innovation – in all its dimensions, including technical, economic and social – was poorly understood, especially on the demand side.

One might have expected these findings to have become the source of a very active debate across all the actors in the NSI. Instead, nothing transpired, and the subsequent TYIP appears to have taken no account whatsoever of the OECD views.

3.3.4 Ministerial Review Committee on the STI landscape in South Africa

The most recent appraisal of the NSI is the Ministerial Review Committee report on the STI landscape in South Africa that was gazetted in May 2012. This report provides an overview of innovation policy from 1997 to 2007. Although the review was narrowed to this period, it naturally considered policy discussions from the dawn of democracy to 2010 when the Committee was appointed.

The Ministerial Review Committee regarded innovation as the capacity to generate, acquire and apply knowledge driven by R&D, as well as the forms of learning and adaptation that might be market-led or socially driven. The report further indicated that innovation is to advance economic and social purposes. To them, innovation included the search for frontier technologies fundamentally uncertain, highly contextual and path dependent, but it is at the heart of moving the country from its present mix of resource and efficiency-driven economic activity to one that is driven by the generation and application of knowledge.

The Ministerial Committee further found that there are inadequate resource flows in the NSI, both in quantity and quality, between its actors and in the system as a whole, whether this is for formal R&D or VC for start-ups and innovative enterprises. Adequate knowledge infrastructure is a crucial condition for a well-functioning NSI. This refers to the set of universities, vocational colleges and state laboratories with equipment for research and to the provision of utilities, such as reliable energy supply, communications and transport, and especially ICTs, such as broadband and computing power. The report noted that the earlier National Research and Technology Audit and its later NACI-commissioned update, concluded that the public research system was seriously under-capitalised, and that inputs of around R700 million at current prices would be needed annually over six to seven years for its renewal, around double what is currently being invested.

In their critique of the Ministerial Review Committee report, Walwyn and Hagendijk (2012) commented that resolving the apparently low profile of innovation policy within the Cabinet, the weakness of the DST in government, and the general lack of an innovation culture within the state and society, would demand strategies such as policy cohesion with other government initiatives (such as the NDP). This would call for the enunciation of a clear message of benefit; securing external funding sources in addition to National Treasury; and establishing binding alliances across and especially beyond government, that is, with industry and with civil society organisations. New structures might be of some help in achieving these strategies. In reviewing the recommendations of the report, however, they felt that many of these matters did not achieve sufficient prominence. The governance recommendations did address many of the deficiencies of integration, but there was still a strong emphasis on the R&D element without the necessary balance on other important issues. Walwyn and Hagendijk (2012) were also critical of what they felt was a long, but un-prioritised list of recommendations. However, one could argue that this approach had some merit as it led to rapid implementation of at least some of the recommendations, which has in fact happened, e.g. review of TIA and of cyber-infrastructure; review of physical infrastructure and sectoral innovation funds.

3.4 Other government initiatives

3.4.1 Department of Trade and Industry perspectives

The R&D strategy (2002) pointed out that venture capital stimulation and fiscal incentives to encourage and enhance private sector participation were the responsibility of the dti and its agencies, the IDC and the Small Enterprise Development Agency (SEDA). The main objectives of the dti are to facilitate transformation of the economy through promoting industrial development, investment, competitiveness, employment creation and broad-based economic participation. Technology-oriented supply measures promoted by the dti include the SPII, Technology Venture Capital (TVC), THRIP, SEDA and the SEDA Technology Programme (STP).

Through the Industrial Policy Action Plan (IPAP) of 2007, the dti identified priority sectors based on substantial growth and employment potential. IPAP 2 2011/12 – 2013/14 made reference to technology innovation, specifically noting the DST and NRF strategies that set the overarching framework for technological interventions, particularly on the research side. IPAP 2 proposed to increase the focus of efforts in support for the commercialisation of processes and product innovations and new technologies.

The Strategic Plan for 2012 to 2016 of the dti maintains that despite the existing programmes and various initiatives to support small, medium and micro enterprises (SMMEs), this sector has not experienced substantial growth. SMMEs still face challenges of access to financing, the cost of finance and accessing technical support in general. While there are a few success stories, the lack of adequate data, as well as inconsistent monitoring and evaluation, make it difficult to assess progress.

3.4.2 Human capital development

The Human Resources Development Strategy for South Africa: A Nation at Work for a Better Life was adopted in 2001. The mission of the strategy was to maximise the capabilities and the potential of the people of South Africa, through the acquisition of knowledge and skills, to work productively and competitively in order to achieve quality of life for all. In 2009, the DHET revised and renamed the strategy as the Human Resources Development Strategy for South Africa 2010 – 2030 (HRD-SA).

The central concern of the HRD-SA is to accelerate the development of skills to match supply and demand. It argues that economic competitiveness is measured not only by the aggregate skills of a country's workforce, but more importantly by the flexibility and capacity of the workforce to adjust speedily to rapid changes in technology, production, trade, and work organisation.

The HRD-SA maintains that the conventional definitions of human resources development (HRD) generally tend to focus solely on strategies that are aimed at using skills development and supply to promote economic growth. While the promotion of economic growth is a pre-eminent objective for HRD in South Africa, it certainly does not constitute the sole objective of our development agenda. HRD-SA is based on the National Skills Development Strategy (NSDS) 2005 – 2010 (including the Scarce Skills List 2007); the Basic Education Strategic Plans (early childhood development, schooling, adult education); the Further Education and Training (FET) Strategic Framework; the Higher Education (HE) Strategic Framework; Immigration Policy; and the HRD Strategy for the Public Sector.

As to the link between the HRD-SA and STI policies, one of the HRD-SA aims is to ensure that South Africa is ranked in the top 10% of comparable countries on the various technology and innovation indices. The HRD-SA strategy aims to improve technological and innovation capability and outcomes by increasing the number of skilled personnel in areas of science, engineering and technology, and improving performance in teaching, research, innovation and the commercial application of high-level science, engineering and technology knowledge.

Another DHET initiative is the National Skills Development Strategy III also launched in 2009 to increase access to high-quality and relevant education and training and skills development opportunities, including workplace learning and experience, to enable effective participation in the economy and society, and reduce inequalities. The strategy noted that there was currently no institutional mechanism that provided credible information and analysis with regard to the supply and demand for skills. While there are a number of disparate information databases and research initiatives, there is no standardised framework for determining skills supply, shortages and vacancies, and there is no integrated information system for skills supply and demand across government. The NSDS III sees its task to promote occupational directed research and innovation, and improve technological and innovation capability.

3.5 Presidential programme of action reviews

The starting point for the review was the twin challenges of 1994: developing policy and legislation in line with the democratic constitution; and virtually simultaneous institutional transformation. As the first Premier of Gauteng Province put it, 'we build the aeroplane, while we fly it'. Second, the government had to deal with the legacy of apartheid within South Africa, whilst at the same time facing new challenges of integrating the country in a rapidly changing global environment. The Presidency assessment of 2004 Towards a Ten-Year Review made no reference to the NSI *per se,* with technology and industrial innovation seen as critical to achieving economic growth.

The Fifteen-Year Review of 2009 took stock of progress of the government programme of action, identified shortcomings and challenges, and how to improve development efforts. In looking towards the future, the review identified broad strategic thrusts rather than detailed programmes. The review praised government for introducing the TYIP. The explicit reference to the TYIP might be taken as a sign of the burgeoning importance that S&T was being given by the Zuma administration.

3.6 Concluding remarks

This chapter assessed whether policy for STI as key contributors has received broad recognition. It has been shown that macro-economic policy showed an incremental awareness and recognition of the role that STI play in addressing the critical challenges of the country. In the RDP and GEAR policy documents, it is clear that R&D, technology development and the concept of innovation were treated quite separately. Even "Towards a Ten-Year Review of Government Programmes" interpreted the concepts as isolated. But the Fifteen-Year Review swung around to endorsing the TYIP.

Although the concept of the NSI was advocated in 1996, it was only toward 2009 that the concept began to be more generally accepted, as evidenced in the 2009 National Human Resource Strategy, National Skills Development Strategy III and to a lesser extent, the dti strategic plan for 2012 – 2014. Other departments such as Health, Basic Education, Energy, Water and Environment do not provide readily accessible data to demonstrate their role in and link with the NSI. Although there were some intergovernmental departmental meetings, for example the annual ministerial meeting of the DHET and the DST, there is not much evidence to suggest that the

inter-ministerial coordination and collaboration relating to the building of a NSI was taking place. The Ministerial Review Committee concluded that there was a limited level of coherence and coordination among cognate government departments, with R&D efforts being highly fragmented. Business, both established and emerging, was largely excluded in the conception and coordination of the NSI. The NDP observed that S&T, the education system, government entities, and private industries should create a common overarching framework to address the country's pressing challenges.

What is evident, however, is that the TYIP, unlike the NDP, appears to have wide constituency support – this might be recognition of the importance of STI, or conversely could reflect just how unimportant STI issues are in the wider political arguments that are now paralysing the administration. The very prominence of the TYIP in the Fifteen-Year Review, IPAP, NGP and NDP could variously be due to real commitment, the serendipitous appointment of the Director-General of DST as the convenor of the Forum of South African Director-Generals (FOSAD) Economic Sectors and Employment Cluster, or simply the low political stakes attached to issues of research and innovation. Whatever the reason, the prominence should be exploited to the full.

In summary, it is not unreasonable to claim that the conceptualisation of an innovation system and governance have been inadequate from the outset.

Moreover, the governance structure centred on DACST-DST, whose later New Strategic Management Model was found to be largely beyond the power of DST to implement. Once the even weak coordinating function of the Science Vote was terminated, line departments simply related to their PROs as they deemed appropriate. In more than one case, this saw the steady erosion of research infrastructure as baseline budget increases fell in real terms. This goes some way toward explaining why line department policies and strategies might have paid lip service to 'innovation' without seeing their behaviour as impacting on the NSI as a whole. The OECD Review comment that there was a lack of understanding of the broader concept of an innovation system rings true since there was no cross-cutting and authoritative source communicating a unified vision across government, let alone to business.

Quantitative Evidence: Inputs, Outputs and Outcomes

4.1 Introduction

The system of innovation is a complex organism that relies on numerous direct and indirect inputs as its various component actors, institutions and constituencies go about their activities. A wide range of indicators is used to depict and assess the performance of a NSI. South Africa has a well-established national statistics system, but this does not mean that the system is complete.

Key input data needed to provide comprehensive STI information cover the full spectrum of education and training statistics, information on the institutional actors in the NSI, R&D, and innovation activities. Among these, the state of the pipeline of learners completing school with high achievements in science and mathematics is a critical component. Another often neglected pipeline is the supply of technical skills. Ultimately, successful innovation systems stand or fall on the quality of their school and technical education systems. An additional important input indicator is R&D expenditure. Not only are there gaps, but as is true for all systems, there are occasional changes in methodology that make time series comparisons inappropriate and difficult.

Output measures include research publications, number of patents, number of trademarks and the technology balance of payments.

The South African school system features in the NDP as in the previous reviews as a major constraint to a vibrant NSI.

In terms of performance, there is a high achieving core and a large periphery of under-performing schools.

4.2 The skills pipeline

4.2.1 Human capital: school level

This analysis will start with an assessment of the school level. By law, the school system is now non-racial, with nominally open access. In practice, the school system continues to reproduce class divisions, and these follow racial cleavages. The school system is bifurcated with a high achieving core, and a large periphery of under-performing schools. In the main, the core consists of high fee-paying private schools, the more modest fee-paying ex-model C schools, and a clutch of well-performing schools in the black community. There has been significant expansion in the number of high fee-paying schools.

The school curriculum has seen considerable reforms; the most important being the attempt to replace what was viewed as teacher-centred rote learning with learner-centred outcomes-based education. From 2008, with the abolition of the three-level Senior Certificate (higher, standard and lower grade), mathematical literacy or mathematics were made compulsory subjects in the National Senior Certificate (NSC). (The 1994, ANC Policy for Education and Training did in fact call for both mathematics and a science subject to be compulsory throughout the years of schooling. Thus far it is only the mathematics requirement that has become national policy.)

There has been a large injection of funds into the teaching profession to raise certification levels. By 2010, over 67% of teachers had a four-year teaching qualification (increased from 25% in 1998).

South Africa spends 6% of GDP on education, the 38th highest in the world.

Learner participation in school falls off sharply after Grade 10, reflecting government policy of compulsory schooling to age 15 and the point where learners may enter the labour market at age 16.

In parallel, the teaching profession has enjoyed large injections of public funds to raise certification levels, to the extent that by 2010, over 67% of teachers had a four-year teaching qualification (admittedly of highly variable quality)up from 25% in 1998 (CEPD, 2011).

These various inputs equate to spending 6% of GDP on education that places us at 38th highest in the world, well above the average. On a purchasing power measure, our teachers are paid at rates among the highest in the Commonwealth.

In terms of participation in schooling, the sharp fall off in enrolment after Grade 10 reflects the point when most learners reach age 16 and may enter the labour market (Table 1). Furthermore, compulsory schooling is only to age 15.

Table 1: Enrolment ratios by grade for 2011

Grade	Enrolment ratio
General Education phase gross enrolment ratio	90%
Grade 9 net enrolment ratio	96.5%
Grade 10 net enrolment ratio	100.3%
Grade 11 net enrolment ratio	81.9%
Grade 12 net enrolment ratio	56.9%

Source: DBE, 2011.

It is obvious that sound practice in general education lays the basis for further education and beyond. For an assessment of the general education phase, one may turn to Trends in International Mathematics and Science Studies (TIMSS) in which South Africa has participated since 1995. Even though the TIMSS test items do not entail a perfect content match with our curriculum, they do provide a reasonable means for benchmarking and the measurement of progress. Table 2 presents our TIMSS achievements in the international context since 1999.

Table 2: TIMSS scores (Grade 9), 1999, 2003 and 2011

	Mathematics score	Physical science score
1999		
South Africa	275	243
International average	487	488
2003		
South Africa	285	244
International average	467	474
2011		
South Africa	352	332
International average	467	477

Source: TIMSS.

Performance on international tests reveals that while the TIMSS score has increased since 2003, it is still much lower than international levels.

The data show that the international average has remained static, that the South African scores are way below average but that the scores have increased sharply. It must of course be noted that in most countries the test is taken in Grade 8, whereas our learners take the test in Grade 9. Nonetheless, the upward move offers encouragement – in the view of TIMSS, the increase of 60 points for both mathematics and physical science is equivalent to a one-and-a-half grade improvement. The average score of the lowest quintile also rose strongly, so that overall disparity between the lowest and highest quintiles decreased. Inter-provincial variation declined, with students in the former homeland schools showing a greater increase than their counterparts in other schools.

Of concern is that even the best-resourced schools only perform at the international average and. South Africa is ranked in the bottom three of 45 countries that participated in the TIMSS survey.

What is worrying, however, is that students in the best-resourced schools performed only at the international average level, and that South Africa is still ranked among the bottom three countries of the 45 that participated in the assessment. Reddy (2013) explains that the under-performance may be a mix of curriculum and test mismatch, but that teacher qualification is also a factor; 60% of South African mathematics teachers have a degree, and the corresponding figure for science teachers is 53%, whereas, the international averages for participating countries were 87% and 90% respectively.

The next level to consider is the Senior Certificate. Table 3 presents the Department of Basic Education's (DBE) attainment targets, along with the number of 'passes' at the 30% level. In 2012, some 511 000 candidates of the 'born free' generation, the survivors of the 1 319 000 Grade 1 class of 2001 sat the NSC examination.

Table 3: Targets and number of passes (000s) for mathematics and physical science, 2009 – 2012

	2009		2010		2011		2012	
	Target	Pass	Target	Pass	Target	Pass	Target	Pass
Mathematics	125	133	136	125	147	104	158	122
Physical science	120	81	130	98	140	96	150	110

Source: DBE, 2011; DBE, 2012.

The first cohort took the NSC in 2008: allowing three years for this educational innovation to bed down, one must observe that the pass for physical science was and is way below target; that for mathematics is also lower than target, but not consistently so. In the view of the DBE, the performance of males and females in mathematics and physical science has improved. In mathematics, the female pass rate rose from 42.4% in 2009 to 49.2% in 2012; males from 50.2% in 2009 to 59.7% in 2012. In physical science, the female rate increased from 34.3% in 2009 to 58.9% in 2012; and for males from 39.5% in 2009 to 64% in 2012 (DBE, 2013). In 2012, the pass rate at 40% or greater in mathematics stood at 35.7% (80 716 candidates) and in physical science at 39.1% (70 076 candidates). These statistics suggest greater selectivity on the part of schools and candidates; the number of candidates is down, but the 'quality' of the pass rate is up. The impact evaluation of the Dinaledi Schools Programme (World Bank, 2010b) attributed only slight improvements in former African schools, but little or none in former House of Assembly schools. The Dinaledi Programme was implemented patchily and has not made the difference its proposers had envisaged.

No like-for-like comparison can be made with the old higher grade subjects, but there is the suggestion that the pass bands of the new subjects are one level below those of the old higher grade. If so, one might compare the 2012 results with those of 2007 by adding together the number of candidates with E or better in standard grade and those with F or better in higher grade for the subjects in question.

It is clear that the poor state of school education limits the potential of tertiary education. Such matters cannot fall outside the discussion of a NSI as the future ability to compete in a global knowledge-based world is steadily being eroded.

South Africa still uses the school completion examination to determine university matriculation, hence the new term 'Bachelor Pass' to replace the previous Matriculation Exemption. In 2012, a total of 136 047 candidates attained a Bachelor Pass; in 2007, the number acquiring Matriculation Exemption was 89 838. It is too soon to tell how these students will fare in higher education.

It is clear that the poor state of school education limits the potential of tertiary education. Such matters cannot fall outside the discussion of a NSI as the future ability to compete in a global knowledge-based world is steadily being eroded.

4.2.2 Human capital: higher education level

Logically the next area for consideration must be higher education. Accordingly, Table 4 provides enrolment and graduation data for the period 2007 – 2011 by subject area.

Table 4: Higher education full-time equivalent (FTE) enrolments and graduates (all levels), 2007 – 2011

Year	2007		2008		2009		2010*		2011	
*CESM Category	Enrol	Grad	Enrol	Grad	Enrol	Grad	Enrol	Grad	Enrol	Grad
Agriculture	13 465	2 271	13 007	2 335	13 247	2 444	14 514	2 580	16 915	3 029
Computer science	32 587	4 252	34 467	4 368	35 209	4 508	38 075	4 756	36 891	5 144
Engineering	59 909	8 381	62 961	9 003	66 827	9 782	71172	10 200	77 152	11 084
Health sciences	46 193	9 432	49 868	10 422	52 439	11 226	50 615	11 202	51 469	11 773
Life and physical science	29 166	5 293	29 563	5 595	32 109	5 735	46 815	8 593	46 846	9 011
Mathematics	14 175	2 047	16 191	2 427	17 345	2411	15 384	2 036	21 359	2 436
STEM Totals	**195 495**	**31 676**	**206 057**	**34 150**	**217 176**	**36 106**	**236 575**	**39 367**	**250 632**	**42 477**
Grand Totals	760 889	126 618	799 490	133 241	837 779	144 854	892 936	153 325	938 200	160 625
% STEM	**25.7**	**25**	**25.8**	**25.6**	**25.9**	**24.9**	**26.5**	**25.7**	**26.7**	**26.4**

Source: http://www.dhet.gov.za/Structure/Universities/ManagementandInformationSystems/Graduates/tabid/471/Default.aspx.
*: The Classification of Education Subject Matter altered in 2010 with major changes to health, life and physical science categories.

At the higher education level, the proportion of science, technology, engineering and mathematics (STEM) enrolments and graduates (all levels) has remained steady at approximately 25% over the 2007 to 2011 period.

It is evident that the overall proportion of STEM enrolments and graduates (all levels) is steady over the 2007 to 2011 period. Enrolments have grown by 23%, but unevenly across the categories, with health up by 11%, engineering up by 28%, mathematics by 50% and life/physical science by 60%. What the above table does not speak to is the representation of 'African' students in the graduate output (Table 5).

Table 5: Higher education FTE graduates (all levels), Africans, 2007 – 2011

CESM Category	Graduates
Agriculture	2 140
Computer science	3 671
Engineering	6 500
Health sciences	6 259
Life and physical science	4 710
Mathematics	1 476
Total	24 756
% STEM	**58.3**

Source: HEMIS.

There has been significant growth in the proportion of African students (including those from Africa) who now comprise 58.3% of STEM graduates.

'African', *viz*. South African students who are black African, plus students from elsewhere in Africa, comprise 58.3% of STEM graduates. This appears to be a significant indicator of progress toward equity. Up to 1990, Africans were in effect excluded from engineering; today they comprise 59% of new graduates. But there are two dimensions that must not be overlooked, namely access and progression, and these tell a rather different story.

Access to higher education still reflects the historical legacy of apartheid. In 2009, participation of students designated as white was 56.9%, Indian 44.9%, coloured 14.8% and African 13.3%.

Data from the Council for Higher Education (CHE) on higher education participation in the 20 – 24-year age band show that in 2009, this stood at 56.9% for whites; Indians 44.9%; coloureds 14.8% and Africans 13.3%. This clearly reflects the inherited financial and, indeed, social capital of the four groups. In the apartheid era, whites enjoyed a standard of living comparable with Western Europe, much as did and does the elite in South America.

Overall progression rates are problematic: of the 120 000 students who enrolled in 2000, 50% dropped out and only 11% graduated in three years.

Regarding the progression rate, Letseka and Maile (2008) show that of the 120 000 students who enrolled in 2000, half dropped out, and only 13 200 graduated in three years. More than two-thirds of the African and coloured dropouts came from poor backgrounds. This finding is consistent with that reported by the Balintulo Committee on the National Student Financial Aid Scheme (DHET, 2010). For Balintulo the issue was class, no longer race. For higher education, the issue must be to ask whether indeed they are adequately responding to the demands that the new 'majority classroom'[9] presents to academia.

An overarching concern must be that engineering enrolments as indicated in Table 4 above have barely kept pace with enrolment growth, and health sciences appear to have contracted: both are critical for the realisation of developmental goals. It is also useful to have insight into the wider distribution across fields: through to Honours level, business science, education and law make up nearly two-thirds of all graduates (Table 6).

Table 6: Graduates by selected qualification and selected fields, HEMIS 2011

	3 yr	4 yr	Honours	Masters R	Masters C	PhD	Total
Agriculture	307	998	336	179	93	85	1 998
Architecture	617	691	501	167	167	13	2 156
Business Comm	14 295	5 701	5 151	724	1 724	129	27 724
Comp science	979	714	680	167	53	42	2 635
Education	228	5 498	6 382	356	215	152	12 831

[9]This is educator John Volmink's descriptor.

Engineering	297	4 458	554	612	256	120	6 297
	3 yr	**4 yr**	**Honours**	**Masters R**	**Masters C**	**PhD**	**Total**
Health	793	5 029	465	570	599	155	7 611
Law	721	3 420	222	292	328	34	5 017
Life sciences	2 073	300	1 043	460	74	217	4 167
Physical	1 531	478	965	430	84	176	3 664
Mathematics	1 198	133	398	105	30	41	1 905
Social science	2 420	1 520	1 086	338	227	99	5 690
TOTAL B*TYPE*	**2 545**	**28 940**	**17 783**	**4 400**	**3 850**	**1 263**	**81 695**

In 2011, a total of 1 576 doctoral degrees was awarded. Approximately 25% of these were awarded to foreign students from other African countries. Many of these exit the country upon graduation, leaving around 75% available to seek employment, although some of the foreign doctoral graduates will undertake postdoctoral fellowships that will retain their expertise in the country. The trend line for PhD production (Figure 2) suggests that by 2018, in the order of 1 200 STEM doctorates will be awarded, of which a quarter would be to foreign students, far below the target of the TYIP.

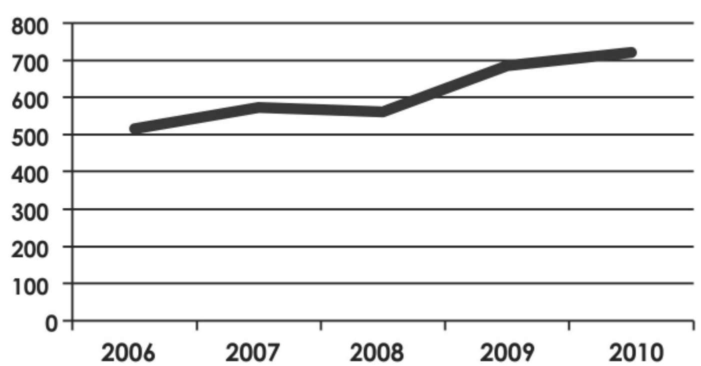


Figure 2: STEM PhD production, 2006 – 2010

There were about 17 000 permanent instruction and research staff members at universities in 2011. Of these, 35% had doctoral degrees compared with the NDP target of 70%.

Staff levels have not kept pace with the growth in student enrolment and the number of 'science workers' in general has declined since 2004.

At present, roughly 35% of university instruction and research staff hold doctoral degrees, with the NDP now setting a target of 70% by 2030. According to HEMIS, there were some 17 000 permanent instruction and research staff in 2011, at least half of whom will retire by 2030. Raising the qualification level of staff is a worthwhile goal that may be driven by legislation and changes in employment conditions. The question arises as to whether the desire to raise qualification level will be market-led, or be driven more actively, and will it be accompanied by an expansion of higher education staffing? Staff levels have not kept pace with the growth in student enrolment and would have to be expanded to produce a dramatic increase in PhD graduates.

Technical and vocational education has been seriously neglected in policy frameworks; a total of 13 500 artisans graduated in 1985 compared with 2 548 in 2004.

Finally, there is the often neglected area of technical and vocational education. This sector has seen considerable change since the 1980s when the state utilities and private sector maintained extensive apprentice and upgrading programmes. With the privatisation and corporatisation of the utilities, and the growth in services, the demand for technicians fell and these training schemes declined from 13 500 artisans graduating in 1985 to 2 548 in 2004. Organised labour, responding to past discriminatory practice, successfully lobbied for a new system that would ensure skills portability. Following the Australian model, this led to the introduction of a Skills Development Levy and its use for certified training under the Sector Education and Training Authorities (SETAs), with the South African Qualification Authority (SAQA) as guarantor of standards. In parallel, the 152 technical colleges were re-organised into 50 further education and training (FET) colleges with a new qualification structure, the National Certificate (Vocational).

Table 7: National Certificate (vocational) enrolments (all years of study) by field, 2010

Field	Enrolments
Office administration	25 922
Marketing	7 632
Finance, economics and accounting	13 306
Management	8 298
Building & civil construction	10 842
Engineering & related design	18 794
Electrical infrastructure & construction	24 050
Information technology & computer science	11 059
Primary agriculture	2 354
Hospitality	7 061
Tourism	7 638
Safety in society	5 409
Mechatronics	1 200
Education & development	1 124
Total	**144 689**

Source: Cosser *et al.* (2011).

The challenge now is to attract working-age persons to upgrade their skills, as opposed to the FET colleges acting as conduits for school leavers.

The FET colleges now resort under the DHET. In the process, critical skills were lost, with experienced staff being offered retrenchment packages. Enrolments have fallen by a quarter over the last decade and the age and race profile of staff and students has changed significantly. Cosser *et al.* (2011) explain that the task now is to attract working-age persons to upgrade

There has also been a shift from engineering fields to service-related fields.

their skills rather than the colleges acting as way stations for school leavers with no other prospects. No other education sector has seen such radical changes. Table 7 shows that half of all enrolments are in service-related fields; while the previous emphasis of technical colleges was on engineering.

Having addressed the pipeline of skills that can serve the needs of the research and innovation system, the next matter is to examine the financial and personnel inputs to the system.

4.3 The inputs to R&D

The inputs to R&D are summarised in Table 8 by means of the composite indicator, the ratio of GERD (gross expenditure on R&D) to GDP.

Table 8: GERD:GDP, 1991/92 – 2009/10

1991/92	1993/94	1995/96	1997/98	1999/00	2001/02	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
0.84	0.61	N.S.	0.60	N.S.	0.73	0.79	0.85	0.90	0.93	0.92	0.92*	0.87*

Sources: OECD (2011); * HSRC (2013).
Note: NS – no survey.

The 1991/92 R&D Survey found GERD:GDP to be 1.04%, but GDP was subsequently revised upward (once the homelands were re-incorporated) so that the official GERD:GDP for 1991/92 is now 0.84%. Adjusting and rebasing GDP is, of course, normal practice. This rebasing makes the reduction in GERD: GDP look less severe than the previously calculated drop of 43 percentage points that was declared to be a consequence of the termination of military R&D projects. It must also be noted that over the period 1991 to 1999, the performance of the survey fell to four different parties with consequent instability. However, the research of Batchelor and Dunne (1998) shows that the reduction in state military R&D between 1991 and 1993 accounted for eight percentage points in the decline of GERD, much less than the 43 points alluded to by the R&D Strategy. The more likely explanation is that the drop in GDP was a survey artefact. Even so, the drop has acquired mythical status.

The GERD:GDP ratio hovers around the 0.87 level, well below the target of 1.0.

Since 2002, the Human Sciences Research Council (HSRC) has performed the survey on behalf of DST. GERD:GDP appears to have settled around a median value of 0.87%, below the 1% target that was set for 2008. Over the period 1991/92 to 2009/10, real GERD rose by 190%, at a compound annual growth rate (CAGR) of 4%.

The next matter for consideration is R&D expenditure by sector (Table 9).

Table 9: R&D expenditure by sector (%), 2001/02 – 2009/10

	2001/02	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Business/ NPO	54.6	57.6	58.0	59.9	57.2	58.9	59.7	54.1
Government	20.1	21.9	20.9	20.8	22.8	21.7	20.4	21.6
Higher education	25.3	20.5	21.1	19.3	20.0	19.4	19.9	24.3

Source: HSRC (2013).

In 2009/10, R&D expenditure was: business (including state-owned entities) 54.1%; government, 21.6%; and higher education, 24.3%.

Table 9 shows that the business sector, at around 58% of GERD, is the main performer of R&D, with higher education and government (science councils, PROs) each accounting for 21%. This distribution is similar to that of France, Germany and Eastern Europe. The business sector includes state-owned entities, and if these are excluded from business expenditure on R&D (BERD), the business share would fall to around 40%, making our business share similar to that of Brazil or Argentina. Back in 1989/90, the business share was 37%, rising to 47% in 1991/92. The assertion of the R&D Strategy that business was not contributing to R&D is not supported by the data.

There has been a steady increase in foreign funds for R&D. Of this, 60% (R 1.5 billion) goes to the business sector.

DST's contribution to the system has increased from R 1.149 billion (current Rands) in 2005 to R3.450 billion in 2009.

The sources of funds for R&D are presented in HSRC (2013) and our comments will be restricted to three observations. The first is the R1.1 billion drop in funding from government to business over the period 2008/09 to 2009/10 that is certainly due to the termination of the Pebble-bed Modular Reactor (PBMR) programme. The reason for this drop was not addressed by HSRC (2013). The second is the steady rise in foreign funds for R&D – it would be useful to know more about the use to which these funds are applied, the more so as 60% (R1.5 billion) goes to the business sector. Is this mainly for clinical trials or does the funding go toward more production-oriented research? The third is that transfers from DST into the system rose from R1.149 billion (current Rands) in 2005 to R3.430 billion in 2009, entailing an annual compound growth rate of 130%. This is a steep increase, arising from support to the Centres of Excellence (CoEs), the South African Research Chairs Initiative (SARChI), the PBMR Human Capital Programme, the Joule Electric Vehicle, and KAT/SKA.

The proportion of R&D expenditure by main categories is basic research 26.5%; applied research 31.4% and experimental development 42.1%. This new shift towards basic research is a direct result of the termination of the PBMR project. As is typically the case, the universities are the main site for basic research.

Expenditure by field of science shows five main clusters: engineering, applied science and technology 30.2%; natural sci-

The number of FTE researchers in the higher education sector has barely changed from 1991/92 to 2009/10, hovering around 3 600. In the business sector, FTE researchers peaked at 6 663 in 2007/08 and have declined since.

ences 24.5%; health sciences 16.7%; ICT 15.6%; social sciences and humanities 13.0%. These summary statements conceal wide variation: almost all ICT research is in the private sector that, in turn, does almost no research in social sciences and humanities; research in social sciences and humanities is concentrated in higher education institutions where it makes up 34% of all R&D expenditure (HSRC, 2013). Labour (including student costs) is the single largest item of expenditure at 45.3% of GERD, followed by other running costs at 41.9%. The time series of the availability of FTE researchers is provided in Table 10.

Table 10: Full-time equivalent (FTE) researchers, by sector (1991/92 – 2009/10)

	1991/92	2001/02	2003/04*	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10
Business/ NPO	3 395	3 149	4 411	5 300	5 896	6 111	6 663	6 379	6 247
Government	2 428	2 134	2 342	2 040	1 974	2 768	3 057	3 052	2 932
Higher education	3 631	3 424	3 374	3 508	3 555	3 658	3 672	3 643	3 672
Total	9 454	8 707	10 127	10 848	11 425	12 537	13 392	13 074	12 851
Students	2 353	5 475	5 960	6 833	5 680	5 833	6 035	6 310	6 942
Grand Total	**11 007**	**14 182**	**16 087**	**17 681**	**17 105**	**18 370**	**19 427**	**19 384**	**19 793**

Source: HSRC (2013). Note: 2003/04 student FTE adjusted.

The FTE doctoral students have tripled in 17 years, but the number obtaining doctorates has only doubled.

These data offer a number of important messages:

- The FTE researchers in higher education has barely changed over seven years.The decline in business expenditure is immediately evident in the sharp decline in FTE researchers since the peak in 2007/08.
- The FTE of doctoral and postdoctoral students has tripled in 17 years; but the number obtaining doctorates has only
- doubled.
- The researcher FTE has only increased at CAGR 2%, while GERD increased at CAGR 4%. Since staff costs make up around half of GERD, this points to considerable salary inflation.
- Using the number of researchers as a proxy for size the science council sector has not seen appreciable growth.

The FTE for technicians has remained static.

Table 11 offers insight into the FTE for technicians that is equally disturbing: the FTE for technicans has remained absolutely static over the 18-year period. This may reflect the emergence of ICT and clinical trials as major fields where conventional technicians are not required, or a case of hard-pressed research managers simply making do without. Further research is needed to determine the underlying cause.

Table 11: Full-time equivalent (FTE) researchers and technicians, by sector

	1991/2		2009/10	
Sector staff	Researcher	Technician	Researcher	Technician
Business	3 395	2 907	6 247	3 685
Government/ Science councils	2 428	1 810	2 932	1 535
Higher education	3 631	289	3 672	580
Total	**9 454**	**5 006**	**12 851**	**5 820**

Source: DNE (1993) and HSRC (2013).

It is now instructive to compare South Africa's GERD per FTE researcher with that for the OECD member states combined. Over 2004 to 2007, the median expenditure in PPP$ (year 2000) per FTE researcher was $187 500 in South Africa compared with $174 500 across OECD. South Africa's expenditure is actually higher. This suggests that there is no shortage of funds, but there is a shortage of researchers. This is illustrated by the fact that from 1992 to 2009 the total number of FTE researchers rose by a mere 38%, at a compound growth rate of 2%. GERD, on the other hand, rose at a compound rate of close to 4.0%.

In terms of demographics, the R&D Survey of 2001/02 set out to determine the race, age and gender profile of R&D personnel but found many respondents could not provide detailed headcount information by race, age and gender. As a result, the data set represented a significant undercount. This undercount notwithstanding, the survey found that the proportion of white male researchers was 38%. The age profile of researchers was similar across all sectors except higher education, whose peak age was ten years older.

In 1994, the then science council staff with graduate qualifications were predominantly white (LHA Consultants, 1994), with only 5% of the 3 123 graduates being black. According to the 2009/10 R&D Survey (HSRC, 2013), the graduate research personnel in the science councils stands at 3 756, of whom 1 820 are white. The message in these data is that significant demographic transformation has occurred in the science councils, where black research staff are now in the majority, comprising 51.5% of the total.

This section considered the restricted world of R&D through the lens of the *Frascati Manual*. Reducing the act of R&D to a set of indicators, conveys the impression that R&D is a commodity, and inadvertently plays into the notion that R&D is something that all actors in the innovation system are equally able to contribute to, or work with. The experience of many decades shows that this is simply untrue. What appears to be true is that R&D is inherently 'leaky' so that spillages will always occur, as for example is the case of encryption technology used in pre-payment meters and electronic detonators for open-cast mining, both of which had origins in the military R&D of the 1980s.

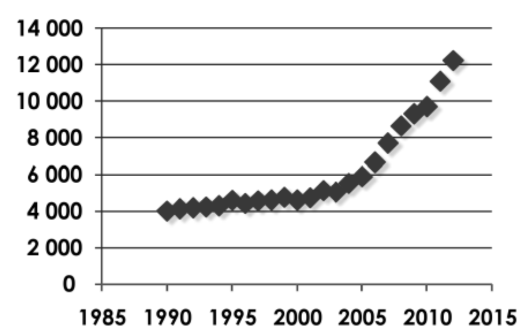
From this follows the question: if R&D results are readily available from the higher education and PRO sectors, why do firms not take these up? The reason for this apparent failure is tied to economic considerations and what might be termed the cognitive capability of firms. Arnold and Bell (2001) provide a clear explanation of the capacity of firms to absorb new knowledge that is strongly dependent on their high-level skills reservoir, especially the presence of a sufficient corps of engineers. And even where capacity to absorb new knowledge is in place, this capacity will only swing into action if the knowledge is perceived to have relevance and have the prospect of adding value.

4.4 Research output

The conventional measure of research outputs comes in the form of bibliometric analysis of research publications. Such analysis relies on the availability of bibliographic databases, the best known of which are the subscription-based Thomson-Reuters Web of Science (WoS) and Elsevier Scopus. The use of the WoS databases as a means of determining research productivity and impact remains an area of debate, and in response to negative criticism, and to keep up with its competitors, the Web of Science has broadened its coverage by field, language and geography, and now also includes books and book chapters. The underlying philosophy for the selection of publications follows a Pareto principle: a core of publications will host the most important contributions. The WoS is used to obtain insights into the research products arising from the NSI.

SA's publication output is not confined to journals indexed in the WoS. It is estimated that the WoS accounts for only 60% of South Africa's article output.

It should be pointed out that SA's publication output is not confined to journals indexed in the WoS. The DHET Funding Framework (established in 1987 and revised in 2003) includes an additional list of South African journals (n = 232) that are not indexed in the Web of Science but which do qualify for subsidy purposes. This means that any analysis that only takes the WoS as point of references, underestimate the total article output of South African scientists and scholars. Because of the fact that many scholars in the Humanities and Social Sciencs publish predominantly in local SA journals, this underestimate is even higher for



Source: Web of Science.

Figure 3: Total publication count, 1990 – 2012

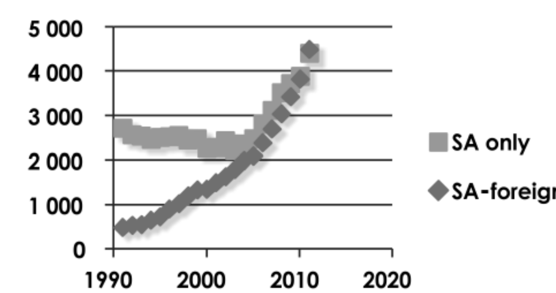
these fields. CREST (Stellenbosch University) estimates that approximately 40% of SA's article output appears in local journals and that the articles published in the Web of Science constitutes 60%. Finally, besides the uneven distribution of fields of sciences in these different indexes and lists, there is also a huge differentiation in the institutional publication practices of SA universities. Some universities (such as UCT, WITS and UKZN publish more than 80% of their total articles output in the Web of Science, whereas others (such as UNISA) publish less than 20% of their output in the WoS.

Figure 3 displays the count of all publication types in the Science Citation Index (SCI) Expanded, Social Science Citation Index (SSCI) and Arts & Humanities Citation Index (A&HCI) that include a South African address over the period 1990 to 2012.

Despite no appreciable increase in the FTE researchers, the publication count has tripled.

The curious aspect of these data is that despite no appreciable increase in the FTE researchers in higher education over the period, the publication count has increased nearly threefold, with a significant rise taking place from 2003 onward. What then is driving the increase? (Kahn, 2011; Pouris and Pouris, 2011) Part of the answer comes from analysis of the trend (Figure 4) in the number of articles co-authored with foreign researchers. This shows that the count of publications with foreign co-authors rose from 15% of the total to 50.5% by 2011, serving as an unexpected measure of the openness of our research and innovation system, but also perhaps on its dependency on foreign assistance.

The publication count with foreign co-authors has risen from 15% of the total (in 1990) to above 50% in 2011.



Source: Yuh-Shan Ho, private communication.

Figure 4: Article count, South Africa only and South Africa-foreign, 1990 – 2011

South Africa's share of world total publications has fallen from 0.42% to 0.36% over the period 1995 to 2009 reflecting the increased contribution of countries such as Brazil, India and China.

Confirmation of the importance of co-authorship comes by adjusting for fractional counts. Such datasets are laborious to compute so the data of the US National Science Foundation (NSF) *Science and Engineering Indicators* (Table 11) were used. NSF restricts publication counts to research areas on the WoS databases that it regards as 'Science and Engineering.' Table

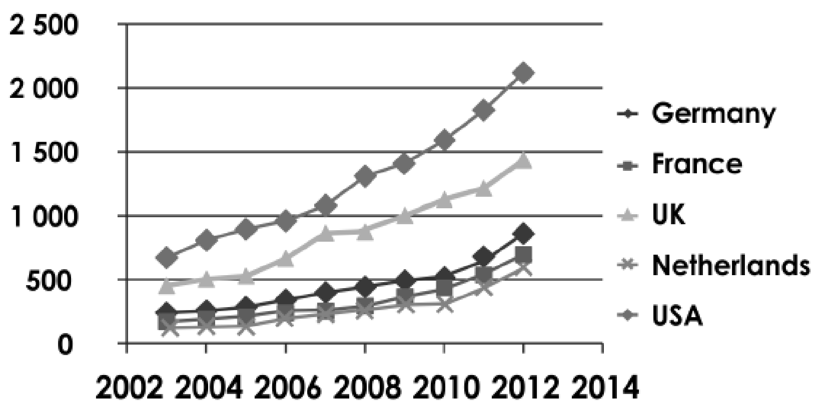
Table 12: Fractional publication counts, South Africa, world, world share, 1995 – 2009

	1995	1999	2003	2007	2009
World	564 645	610 203	661 753	785 586	788 347
South Africa	2 351	2 303	2 205	2 808	2 864
World Share %	0.42	0.38	0.33	0.36	0.36

Source: NSF 2012, Appendix 5.26

12 displays fractional counts for South Africa and the World, as well as our share of the total.

Major research collaborating countries are the United States, followed by the United Kingdom, and then some way behind, a cluster comprising France, Germany and the Netherlands, All at similar levels.



Source: Web of Science.
Figure 5: Co-authored articles by country, 2003 – 2012

When adjusted for share of authorship, the rise dissipates; our real share of the world total has fallen from 0.42% to 0.36%. Figure 5 shows openness as measured by co-authorship with our five major research collaborating countries.

A full statistical analysis is required to determine accurately the relative strengths of the drivers of the increase in publication counts.

Four research areas (infectious diseases; public environmental and occupational health; immunology; and virology) have shown dramatic increases in publication counts.

4.5 Research focus and concentration

The WoS offers a ready means to analyse research. It is instructive to investigate the research focus at the transition to democracy (1990 – 1994) and the situation once the new dispensation had taken form, over the period 2004 – 2008. Over this time, the number of article counts indexed to the WoS, which includes SCI, SSCI and A&HCI databases, increased from 20 909 to 34 463. The inbuilt query facility of the WoS allows disaggregation according to 'research areas', a useful category, but one that is inevitably subjective in that the indexing team must make decisions as to which category best fits an article and

a journal. To investigate shifts in focus one may tabulate the count by research area for the two periods. From this, it is immediately apparent that four research areas have shown a dramatic increase in their counts: infectious diseases; public environmental and occupational health; immunology; and virology, where the ratio of counts between the latter and earlier periods stands at 8.4, 3.5, 5.4 and 6.7, respectively. What is more significant is to compare the relative share (also known as 'activity') of these research areas across the two periods. This yields a second set of ratios: 5.1, 2.1, 3.3 and 4.1, respectively, adding further evidence for the new importance of these research areas. At the same time, general and internal medicine that had received the most counts in 1990 – 1994, fell to 5th position, but most tellingly its ratios were now much lower, falling from 0.7 to 0.4 respectively. Surgery, 9th in 1990 – 1994, fell to 32nd with the ratio declining from 0.8 to 0.5. There has been a clear swing away from research in 'clinical medicine' toward infectious diseases.

The swing away from clinical medicine to infectious diseases took place at the very time that government policy in the area of HIV/AIDS was uncertain as to focus; this shift cannot be ascribed to a drive from government to address the specific retroviral epidemic. While government had elected to introduce an Essential National Health Research Agenda with an emphasis on primary health care, this had yet to translate into a deliberate policy to channel funds towards research on HIV/AIDS (and tuberculosis). On the other hand, the decline in research on clinical medicine appears to have a source in policy, as a consequence of the downscaling of provincial support for research in the academic teaching hospitals, whose funding was a provincial competence. The shift toward research on infectious disease came more from the 'Republic of Science' than from the side of the state, especially as funding became available from international donors, such as the Bill and Melinda Gates Foundation, the United States PEPFAR initiative, and the pharmaceutical industry's multi-country clinical trials.

The universities are the major producers of research, followed by the science councils, then the national facilities, with industry falling far behind.

The universities, as is generally the case, are the main site of production of publicly available research publications. The second largest site is the science councils, the major producers over 2009/11 being CSIR (784), MRC (366), ARC (308) and HSRC (208). The MRC count excludes MRC units at universities; the ARC count is approximate since the ARC institutes publish using their own addresses. The third concentration resides among the National Facilities (SAAO, Hart-RAO, iThemba, HMO) that collectively contributed another 900 papers. Industry falls far behind, with SASOL (107) and Aurum Health (50) the leaders.

4.6 Citation of research and career incentives

Few topics in the academic community elicit quite as much emotion as the use of publication citation and impact data to influence decisions regarding research career advancement. The most recent, and high-profile objection to the use of journal impact factors for the assessment of individual scientists or, by extension, research group prowess is the *Declaration on Research Assessment* (DORA), which arose from a meeting of prominent cell biology researchers in San Francisco in December 2012. By May 2013, the declaration had attracted the signatures of 150 leading scientists and 75 research organisations, including the American Association for the Advancement of Science (AAAS). In short, DORA objects to the use of impact factors as "a surrogate measure of the quality of individual research articles, to assess an individual scientist's contributions, or in hiring, promotion, or funding decisions" (Alberts, 2013: 787).

The DORA position does not mean that citation counts are irrelevant; the issue is how that information is used. With this in mind, some aspects of publishing behaviour in South Africa are considered.

A total of 7 714 articles whose authors stated at least one South African address were indexed to the Web of Science in 2010, and up to the date of writing, elicited 45 303 citations.

A total of 7 714 articles whose authors stated at least one South African address was indexed in the WoS in 2010, and up to the date of writing elicited 45 303 citations. Of the ten most highly cited articles, nine were in infectious diseases; one in astrophysics. For the next ten, eight were in infectious diseases, one in high-energy physics, and one looked at lizard behaviour as an indicator of climate change. Citations averaged 1.96 per article, per year. In the previous section, reference was made to the importance of foreign co-authorship in the production of scientific publications. One may now investigate the citation rate for South Africa and other countries (Table 13).

Table 13: Citation counts, articles only, 2010.

Countries	Article Count	Citation count	Annual rate
SA only	7 714	45 303	1.96
SA-USA	1 251	20 254	5.40
SA-England	838	13 574	5.40
SA-Germany	453	7 577	5.57
SA-France	374	7 684	6.85

Source: Web of Science.

Another view as to the effect of co-publication is obtained by extracting articles that do not involve co-authorship with our seven major research collaborating countries: USA, England, Germany, France, the Netherlands, Italy and Belgium. This reduces the article count to 5 246, and a citation count of 16 545, or 1.05 a year, half the rate with all countries included. The message is clear:

South African authors enjoy higher citation rates when they co-author with a foreign author.

South African authors enjoy higher citation rates when they co-author articles with a foreign partner (this is in line with most bibliometric work on the relationship between co-authorship and citation visibility).

In 1987, the former Department of Education introduced a subsidy for research outputs, updated in 2003. The subsidy is paid to the HEIs for a journal article published in a journal that is indexed in the WoS, the IBSS or the Department of Education's list of South African journals. (It is also payable for books, book chapters and conference proceedings that meet set criteria.) A publication unit in 2011 would earn approximately R120 000 for the HEI concerned. Some universities share a portion of this subsidy with their staff who have produced the publications through the mechanism of a research account, and proceeds may be used to fund recognised research activities. Others retain the entire subsidy in general university funds, while some offer a direct taxable inducement to their staff.

4.7 Innovation outputs

The codified and publicly available output measures of innovation include patents (Table 14), trademarks, registered designs, copyrights and plant cultivars. By their very nature, disclosure agreements that protect business secrets are confidential and thus restricted for distribution. Much intangible capital is protected through this mechanism.

Table 14: South African patents, 1997 – 2011

Year	Resident	Rank	Non-Resident	Rank	Abroad	Rank
1997	355	38	6 917	15	599	22
1998	200	50	7 190	14	657	22
1999	138	55	3 002	26	666	23
2000	895	32	2 400	30	626	27
2001	966	30	5 427	19	687	27
2002	983	29	5 617	16	684	27
2003	922	32	5 303	16	628	29
2004	956	30	5 833	16	854	28
2005	1 003	33	6 001	16	1 106	27
2006	866	35	6 739	16	1 006	29
2007	915	33	7 402	16	1 167	29

Year	Resident	Rank	Non-Resident	Rank	Abroad	Rank
2008	860	32	7 081	15	1 239	29
2009	822	37	5 913	16	1 141	31
2010	821	38	5 562	17	1 175	32
2011	656	38	6 589	16	1 105	31

Source: http://www.wipo.int/ipstats/en/statistics/country_profile/countries/za.html.
Note: Non-resident refers to a filing in South Africa by a foreign-registered entity; Abroad refers to a filing abroad by a South African entity.

Table 14 gives the number of South African patents for the period since South Africa's accession to the Patent Cooperation Treaty (PCT). Before commenting on these trends a second set of patent data for the period prior to PCT accession is provided (Table 15).

Table 15: South African patents, 1988 – 1995

	1988	1989	1990	1991	1992	1993	1994	1995
Non-resident	4 905	4 842	4 943	4 654	4 423	4 282	4 968	5 842
Resident	4 829	5 134	1 093	1 023	888	904	935	883
Total	9 734	9 976	6 036	5 677	5 311	5 186	5 903	6 725

Source: as Table 14.

These data show a discontinuity between 1989 and 1990 that requires explanation. Inquiries to the community of patent attorneys[10] yielded information that prior to 1990, the patent count included provisional and complete patent applications for which complete specifications were filed; from 1990 onward, the count only included complete applications. Again, this points to the problem of unreliable data. The 'real' level of patenting in South Africa would appear to be far higher than the official data specify.

The trend shows a strong upward movement even whilst slipping in international rank, largely because of the sharp rises occurring among the Asian Tigers and China. Table 17 presents applications by field of technology, and shows the dominance of civil engineering, materials and chemical engineering.

Table 16: Patent applications by field of technology, 1997 – 2011

Field of Technology	Share
Civil engineering	7.16
Materials, metallurgy	6.79
Chemical engineering	6.47
Basic materials chemistry	6.15
Medical technology	5.48
Handling	5.04
Other special machines	4.54

[10] Confidential correspondence.

Field of Technology	Share
Furniture, games	4.50
Transport	3.85
Electrical machinery, apparatus, energy	3.57
Others	46.45

Source: as Table 14.

There are some salutary lessons from Malaysia. Key lessons are government investment in high quality education, especially mathematics and science, and focused support of industry.

In the 1970s, South Africa was far ahead of Malaysia in terms of GDP/capita and scientific output. Today, Malaysia's GDP/capita is 50% greater than South Africa's and its exports comprise among the highest proportion of high technology products worldwide. To increase local participation in the ICT industry, the Malaysian government has invested considerably in high-quality education, especially in mathematics[11] and science, and for nearly five decades has supported the work of MIMOS Berhad[12] that has pursued applied research in ICT since 1985. Table 17 compares the PCT applications for 2012 of Malaysia and South Africa, showing the top ten applicants and the world rank by patenting activity of those organisations.

Table 17: Top 10 PCT applicants, number, rank, for Malaysia and South Africa, 2012

Malaysia	PCT	Rank	S A	PCT	Rank
Mimos Berhad	146	120	Sasol Technology	13	1 437
Universiti Sains Malaysia	39	520	CSIR	10	1 796
Universiti Putra Malaysia	15	1 266	Stellenbosch University Sa Sugarcane Research Institute	9	1 976
Petroliam Nasional Berhad	8	2 202	University of the Witwatersrand	9	1 976
Malaysian Palm Oil Board	7	2 480	Ael Mining Services Ltd	8	2 202
Iq Group Sdn Bhd	4	4 050	Discovery Holdings Ltd	7	2 480
Universiti Malaya	4	4 050	Detnet SA (Pty) Ltd	5	3 321
Widetech Manufacturing Sdn Bhd	4	4 050	Agricultural and Industrial Mechanisation Group Ltd	4	4 050
Institute Of Technology Petronas Sdn Bhd	3	5 206	North-West University	4	4 050
Lembaga Getah Malaysia	3	5 206	University of Cape Town	4	4 050

Source: http://www.wipo.int/ipstats/en/statistics/country_profile/countries/my.html.

As an aside, the increasing trend in Malaysia's patenting is remarkably similar to South Africa, with a strong non-resident involvement in patent applications. There are of course some major differences: Malaysia's fields of technology are strong-

[11] Malaysia ranks 26th in TIMSS 2011 with grade 8 average of 440; South Africa scored 352.
[12] 'Berhad' means 'Limited' in Malay.

ly oriented toward high technology; and patenting activity is highly concentrated in a few entities, whereas South Africa's PCT applications show low levels of concentration and high spread across the economy. The rapid advance of MIMOS offers a salutary lesson. Another lesson comes by recalling that up to the late 1980s, South Africa was ahead of Korea in gaining awards from the US Patent and Trademark Office. In the next 20 years however, the situation reversed, with Korea surging ahead as its consumer electronics industry burgeoned. South Africa, by contrast, allowed its high-technology military industries to decline so that the share of high-technology exports declined. Over the period 1988 – 2008, South Africa inventors received 2 232 awards from USPTO; Norway some 3 300, while Koreans obtained 57 625 as its electronics industry entered new high-technology markets that forced it to patent its goods on offer. South Africa on the other hand continued to export commodities and services, neither of which called for patent protection.

Next to be considered is trademarks (Table 18) that show considerable growth for both resident and non-resident entities, with the former outpacing the latter, to the extent that resident applicants rank 22nd worldwide.

Table 18: Trademark applications, 1970 – 2010

	Resident	Non-resident	Abroad
1997	11 218	9 118	2 152
1998	14 599	9 001	2 029
1999	14 153	9 785	2 208
2000	13 509	12 169	3 680
2001	12 959	8 942	2 888
2002	12 535	7 832	3 022
2003	14 676	8 092	4 106
2004	14 982	8 844	4 278
2005	16 985	10 850	4 416
2006	20 017	11 778	6 089
2007	17 080	17 921	5 877
2008	16 032	13 875	6 000
2009	16 134	10 487	5 886
2010	18 040	12 509	5 720
2011	19 522	13 962	5 641

Source: As Table 13.

The final item of codified intellectual property that was considered is plant cultivars (Table 19). The registration of plant

In terms of the registration of plant cultivars, South Africa is amongst the 15 most prolific countries globally.

cultivars is a form of intellectual property (IP) that is generally neglected in the innovation studies literature, which is surprising given their obvious economic importance. Then again, plant cultivars take up to 20 years to develop so their registration does not capture media attention, and their economic impact accrues slowly over time. The record of registrations with the Union of Plant Varieties places South Africa among the 15 most prolific in the world; the country has lost some ground, but retains standing as an important source of plant cultivars[13]. Part of the downward shift is a result of additional countries joining the Union of Plant Varieties to comply with the World Trade Organisation (WTO) TRIPS Agreement and having their data included in its statistics, so that the volume of registered plant cultivars has grown quite strongly in recent years.

Table 19: Registration of plant cultivars

Year	2003	2004	2005	2006	2007	2008	2009	2010	2011
Resident issue	69	79	63	50	76	155	71	92	116
Non-resident issue	124	198	107	85	149	160	102	185	181
Total issued	193	277	170	135	225	315	173	277	297
In force	1 887	1 870	1 882	1 866	1 950	2 116	2 250	2 318	2 425
World	61 478	64 276	66 915	70 810	76 511	81 595	86 484	90 344	94 413
%	3.1	2.9	2.8	2.6	2.5	2.6	2.6	2.6	2.6

Source: www.wipo.int.

4.8 Technology balance of payments

Information on the technology balance of payments (TBP) from abroad, and receipts for South African technology abroad, is only available from 1995 onward. Our discussion will concentrate on the most recent data (Table 20).

Table 20: Technology payments and receipts, 2000 – 2009

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Payments	245	330	442	614	887	1 071	1 280	1 591	1 662	1 643
Receipts	40	21	19	26	37	45	46	53	53	48
Gap	205	309	425	588	850	1 026	1 234	1 538	1 609	1 595

Source: World Bank, OECD.

The data appear to show that receipts are very low compared with other industrialised countries, and that there is a large gap between payments and receipts, an issue that has led to negative concerns expressed by NACI[14] and the DST.[15]

[13] The ARC Institute for Tropical and Sub-tropical Crops developed the world's first seedless lemon 'Eureka.' For further information on plant cultivars see *ARC Annual Reports*.
[14] http://d2zmx6mlqh7g3a.cloudfront.net/cdn/farfuture/B9FlzfdepysmYskmNeBub-bPztQBlndQpMgl_HBHMiY/mtime:1287481409/files/docs/101014naci_0.pdf.
[15] http://www.info.gov.za/speeches/2007/07021414451001.htm.

The receipts for South African technology abroad are very low when compared with those of other industrialised countries, which is puzzling given the large expansion in trading abroad.

The reality is that the gap between payments and receipts is not large by world standards nor in relation to GERD (65%), or GDP (0.4%). South Africa is in the same position as Portugal, Italy, Mexico and Norway. But the data do raise some interesting questions. For example, given the fact of the massive expansion of trading abroad, why are receipts so low and static? And second, why the steep rise from 2001 onward? Is the increase in outflows because of royalties paid on pharmaceuticals, or yet another consequence of the Automotive Industries Development Programme that pulls in components for assembly 'under licence' in the plants of Uitenhage, Silverton and Durban? The gap in payments does not matter if the imported technology is put to good use, as in the case of the AIDP the jobs multiplier may be invoked. The gap in receipts may matter (and this applies to the payments as well) if it arises through illegal transfer pricing[16] that would deny tax income to the fiscus.

4.9 Concluding remarks

The inputs to R&D point to a system that is moving to embrace the potential of all its people. The demographics of the science council sector have shifted dramatically toward increased 'African' participation, even when bearing in mind that 'African' includes many staff from north of the Limpopo River, a fact of life that is true across the economy and society as a whole. In turn, this supply-side failure pushes up the cost of labour, so that the growth in GERD is strongly driven by salary inflation.

The innovation outputs – patents, trademarks, plant cultivars – reveal the following:

- South Africa's high relative USPTO standing in the 1980s has fallen; as a commodities exporter its profile is now similar to that of Norway, not Korea.
- Domestic patenting shows a volume pattern similar to Malaysia, but is spread among many institutions rather than being highly concentrated in the universities as in Malaysia.
- Our country continues to excel in the registration of plant cultivars.
- The technology balance of payments gap is not large by world standards.

It is useful to note at this point that patents and trademarks are only a good proxy for innovation if the patents are exploited and put to use.

In summary, the data suggest that the in-novation system continues to display a certain robustness, but like the greater economy is not growing as fast as it should. All things being equal, the stretch targets for human resources laid down in the TYIP will be unattainable, and if these are unattainable, so too will be the stretch targets for GERD: GDP, research publications and PhD production. Growth requires people – their nurturing, retention and recruitment, from all communities, worldwide.

[16] http://www.oecd.org/tax/transfer-pricing/50526258.pdf.

These measures represent some of the many indicators commonly used and cited in the Report. It is acceptable to assess the status of S&T in South Africa in terms of PhD numbers, publication counts, citations, patents, etc. but there is a need to go beyond these measures. The outputs need to be considered in terms of their relevance to the NSI goals. The views of employers on the quality of knowledge workers and graduates produced by our education system need to be assessed. South Africa needs to develop capability to measure the value of the investment in innovation-related processes and the returns. Finally, and perhaps most importantly, the country needs to have indicators that relate to the imperatives of the NDP.

Chapter 5

The Evolving Research and Innovation System

5.1 A map of the landscape

The chapter enquires into the characteristics of, and the interactions among the major research and innovation actors, including the private sector, PROs, HEIs (including new initiatives such as CoEs, SARChI and CoCs), science parks and intermediaries. What is termed research and innovation stand or fall according to the extent that they involve mutually beneficial interaction among their various actors in the NSI, regional systems of innovation, sectoral systems of innovation, and internationally.

The concept of innovation needs to be an overarching one. Government has a key role to play in both the policy and regulatory level in establishing an ecosystem that stimulates and supports innovation. It should have a leadership role in communicating the intent to support innovation, particularly within the private sector.

The 2012 Ministerial Review grappled with the problem of identifying the locus of innovation activity. Was this to be found in the 'science and technology system' of the IDRC Review, or through the combined activity of the 'higher education system and innovation system' as the NDP now proposes? This uncertainty points to some enduring confusion. If the policy trajectory is to move from a science push system toward one led by interactions and demand, as embodied in the innovation systems approach, then the NDP conception needs further work, lest it might entail a step sideways. The concept of innovation needs to be an overarching one, which ensures that comprehensive value chains are cultivated, not just in government circles and its institutions, but in the country as a whole. Clearly government has a key role to play in both the policy and regulatory level in establishing an ecosystem in the country that stimulates and supports innovation, and to ensure that the regulatory framework does not inhibit such development. It should also have a leadership role in communicating the intent to support innovation, particularly within the private sector, which is so important in successful implementation. This can only be achieved by creating this required interactive and collaborative environment.

While the argument has been developed that research and innovation are quite different things, it should come as no surprise to find global attempts at finding a way to recognise the difference as, for example, in the European Commission rebranding of its Directorate-General Research as 'Research and Innovation'. In the UK, the quest for synergy involved the merger of the Department for Business, Enterprise and Regulatory Reform and Department for Innovation, Universities and Skills into a super ministry, the Department for Business Innovation and Skills. The Ministerial Review sought synergy by introducing the idea of the 'research and innovation system', and to provide overall agenda setting and prioritisation, recommended the establishment of a NCRI that would be supported by an Office for Research and Innovation Policy (ORIP). It is in this spirit that a 'research and innovation' concept map has been developed, which is shown as Figure 5.

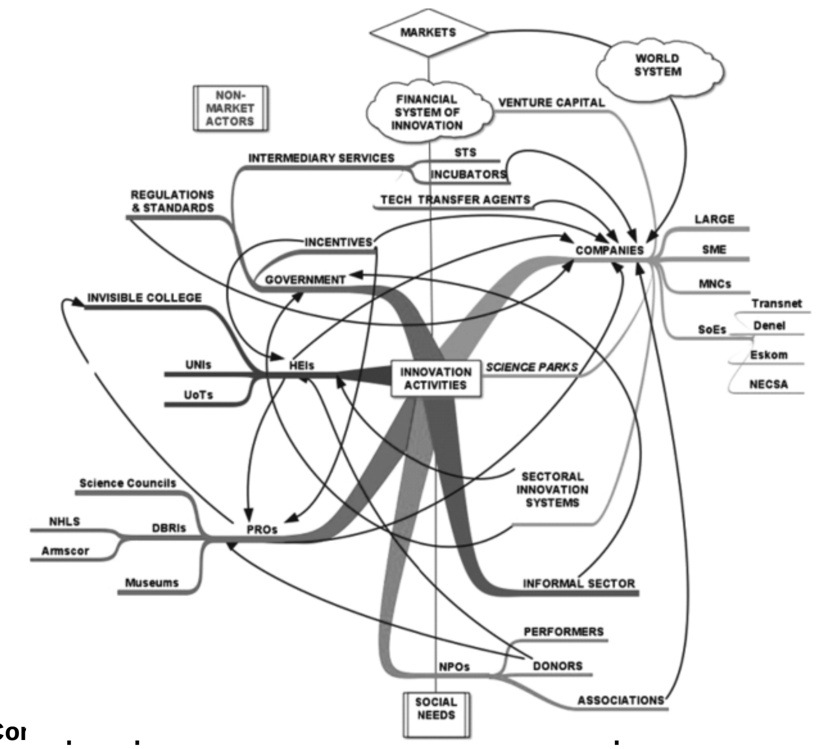


Figure 5: Co[illegible]
Source: Kahn MJ, 2012.

The choice of a concept map to show the interactions among the actors is quite deliberate and stands apart from the many schemas depicting the working of innovation systems, including the chain-link model of Kline and Rosenberg (1986), OECD (1997), Arnold and Kuhlmann (2001), and Meyer-Stamer (2005) to mention but four. In our view, these models, while elegant, convey a restricted picture of the complex interactions that underpin innovation activity. The concept map that is offered here was constructed with a software engine that readily allows for linkages to be incorporated into the graphic. Naturally, to avoid ending up with something that resembles cooked spaghetti, one has to limit the number of interactions that are included.

The map serves the purpose of highlighting complexity and provides a means to visualise the interdependency of the system. The concept map is structured with six main arms: PROs, HEIs, companies, NGOs, government (the five of the R&D Survey) plus the informal sector. The non-market actors are placed on the left and are those mainly concerned with research and services (PROs), and research and teaching (HEIs).

On the right of the concept map are the actors that introduce innovations into the marketplace that sometimes perform R&D or have the capacity to absorb R&D find-

The South African research and innovation system comprises actors and institutions typical of a mature innovation system; it is the linkages and interactions that are weak.

ings. Earlier, the non-equilibrium nature of the innovation process as the firm seeks out information and learns, has been pointed out. The multiplicity of links into the companies' arm attests to the subtleties of the company operating environment. Making sense of this is the responsibility of management; it is not easy.

The concept map conveys the important message that the South African research and innovation system comprises actors and institutions typical of a mature innovation system.

What the concept map cannot do (unless one employs animation tools such as Gapminder™) is to convey the historic depth of the research and innovation landscape and the way that it shapes and is shaped by, political, economic and social relations. All innovation systems exhibit high levels of inertia, respond to incentives, and are able to meld these to suit their own ends. In that sense they exhibit evolutionary behaviour as they adjust to changing circumstances. It is thus to be expected that with changing circumstances, role definitions and mandates may become inappropriate or stretched.

5.2 Key actors in the NSI

5.2.1 Science councils

A case in point concerns the demand on the science councils (Schedule 3 bodies) to earn contract income, as the Public Finance Management Act (*Act 1 of 1999*) permits and their respective acts encourage. The enabling legislation for each science council creates a juristic person that may enter into contracts and is in control of the physical assets of the organisation. The issue of mandate creep is partly a matter for the board of each science councils, and partly a matter of legislative definitions.

DST, in its annual report to Parliament on government expenditures on scientific and technological activities (STAs), notes that in real terms core support for the public research institutes (PRIs) is falling, with the consequence that PRIs would seek other sources of income that could "inadvertently result in the erosion of capacity or less focus on government objectives" (DST, 2011: 14).

The extent to which the major R&D performing science councils supplement the Parliamentary grant with 'other income' is illustrated in Table 21 that shows the grant ranging from 32% (CSIR) to 68% (ARC) of total income. This does not necessarily imply

Table 21: Science council expenditure (current Rands, millions)

Council	Year	Total	Grant	Grant %	R&D (2009/10)	R&D % of revenue
ARC	2010/11	871	590	68	772	89
CSIR	2010/11	1 731	550	32	1 501	87
Geosciences	2009/10	205	133	65	91	44
HSRC	2010/11	341	148	43	192	56
Mintek	2010/11	337	129	38	347	103
MRC	2010/11	553	260	47	382	69
Totals		4 038	1 810		3 285	

Sources: Annual Reports; HSRC, 2013.

loss of control of government influence on science councils that derive less than 50% of their income from the Parliamentary grant, since the balance of 'other income' invariably includes significant contract work for government departments. The data cannot be used to interrogate mandate creep or otherwise. Table 21 also includes data on R&D expenditure by each science council, and here too some comment is warranted. The compilation of R&D expenditure is done according to the guidelines of the *Frascati Manual*, which is at pains to distinguish R&D from "other scientific and technological activities" that while important, do not count as R&D. So in the case of the Council for Geosciences, mapping does not count as R&D; for the HSRC, routine surveys should also not be counted; soil-testing by ARC is a service, and not R&D. In general therefore, R&D expenditure must be less than the total revenue of a science council. The value for Mintek is thus an anomaly that requires explanation.

The six science councils have succeeded in leveraging R1.8b of Parliamentary funding into R3.3b of R&D.

What is clear, however, is that the six science councils succeed in leveraging the R1.8 billlion of Parliamentary funding into around R3.3 billion of R&D. They achieve this through meeting the needs of their constituencies and through active marketing. The CSIR, for example, has been highly successful in joining various research projects funded under the EU Framework 7 Programme; the ARC has entered into a long-term contract to support the Department of Rural Development and Land Reform; the HSRC is working with the Department of Health on the National Health Insurance project. At face value, the science councils deliver. It is always possible for them to deliver more; that requires clear signals from political leadership and the wherewithal for delivery.

Exactly what benefit arises from this work cannot be determined from these crude figures. The HSRC has done important work on nosocomial causes of HIV transmission; the CSIR supports the South African National Defence Force in a range of secret projects; and the ARC regularly introduces new cereal and fruit cultivars into the multi-billion Rand agribusiness sector, thereby enhancing our food security. In order to demonstrate scientific and technological achievement and societal benefit, if not merely value for money, careful *post hoc* evaluations are necessary. The culture of performance measurement mooted in the S&T White Paper remains weak, with output and impact evaluations few and far between, and this despite the operations of the Ministry for Performance Monitoring and Evaluation.

Nevertheless, this much is clear, the science councils have all established strong brands that earn them a unique position with the media. A statement issued by a science council draws notice mostly in an uncritical manner suggesting one of two things: that the science councils are ‘trusted’ parties that are sources of objective and reliable information, or that the media lack the necessary expertise adequately to interrogate the information that is being released. This innocuous comment points to what may in fact be a serious shortcoming in the innovation system, namely the extent of, and manner of science communication with the public.

5.2.2 The business sector

In commenting on the changing role of business under the new political and economic order it is necessary to return to the situation of 1990. At that time, close to 10% of manufacturing industry workers were engaged in arms production. The economy was operating in import substitution mode, with the export of commodities serving as its window into the world and the source of foreign exchange for technology imports, with these often purchased at inflated prices. The dominance of Anglo American Corporation on the JSE was beginning to decline, and South Africa, among the first signatories to the 1948 General Agreement on Trade and Tariffs, was moving toward membership of the incipient WTO. Four major forces then came into play: portfolio investment by international fund managers; takeovers of listed companies; and the evolution of the IDC and the Public Investment Corporation as significant minority shareholders. More than ever the JSE was open to business.

Faced with the opportunities to trade on world markets and uncertainties at home, leading firms extended their international footprints, giving rise to listings on foreign bourses, joint ventures, acquisitions and market capture. In the process, South African Breweries became SABMiller, the second largest brewer in the world; and Standard Bank expanded into Africa, Latin America and Asia. Other companies with large international footprints include Nandos, MTN, Sappi, Sasol, Remgro, Naspers, Old Mutual, SASOL, ABSA, Aveng, Shoprite, Barloworld, Bell Engineering, Steinhoff and Grindrod. They compete in global markets and produce innovations as needed. One must of course not forget the mining base, exemplified in the transmutation of Gencor into Billiton and then its acquisition by Australian BHP to become BHP Billiton, a firm even larger than Anglo American. Many of these firms now derive half of their revenue globally. For this reason, the South African economy is rated ‘open’, since exports plus imports amount to 70% of the value of GDP.

In South Africa, things moved slowly as the economy continued its slide toward the services sector, with mining and agriculture[17] shedding jobs. The job-shedding arose for a variety of reasons – in mining through the exhaustion of high-yield ore bodies; in agriculture because of previous forced migration of farm workers, shifts in the choice of viable crops, and unintended consequences of policy. Some industrial sectors waned – textiles, armaments, leather goods, and foundries suffered, while others grew – automotive, financial services, tourism. The previous comparative advantage of state-owned coal mines and steel works, and agricultural marketing boards gave way to global prices through the import parity pricing mechanism. This gave certainty to manufacturers but would seem to have raised their input costs. Faced with these changed circumstances, companies such as Reunert, that had been major arms manufacturers, had to re-invent themselves; others such as Aspen, Bidvest, Eureka, Altech, Mediclinic, Discovery, Dimension Data and Datatec grew national and then international footprints.

Inward foreign direct investment (FDI) was sluggish[18], and generally confined to takeovers rather than the introduction of new technologies, the exceptions being the significant investments into motor vehicle assembly lines. Exports remained dominated by commodities, with automotive components being a new growth area, but one whose net effect on the balance of payments remains disputed. The mid-2000s commodities boom prior to the 2008 financial crisis culminated in a missed opportunity as infrastructure bottlenecks rendered the country unable to ramp up its exports to meet the demands of China for coal and iron ore. The late-2000s claimed another casualty as Eskom, once among the world’s three lowest cost electricity producers, fell victim to a mix of flawed planning, disruption of its supply chains, electricity theft and equipment failures. These factors created the perfect storm of 2008 when the grid all but collapsed, mines were forced to close, and rolling blackouts followed. In order to build the cash reserves needed to pay for the cost of new generating capacity, Eskom has since raised the cost of electricity threefold[19]. Low-cost electricity was virtually the last comparative advantage that the country had retained, and this was now lost.

Average GDP growth remained around 3%, way below the level needed to bring about significant improvement in the quality of life. The Gini coefficient was calculated to be as high as 0.70, though once social transfers were added back, it fell to 0.59 or the same level when the restructuring began (Bosch *et al.*, 2010).

This example suggests dynamism on the part of large firms. As measured by the methodology of the OECD/Eurostat *Oslo Manual*, such firms do indeed rate themselves to be highly innovative. However, like their Latin American (and Danish) peers they tend to introduce incremental and adaptive innovations, rather than radical or disruptive innovations. This means that their innovations do not show up in patents or royalty payments, but are evidenced in new or increased market share and profits. Given the enormous role of the services sector, it is not surprising to learn that 25% of

[17] Jobs in agriculture declined from 1.8 million in the 1970s to 0.75 million in the late 2000s.
[18] Inward FDI averaged $4.5 billion over 2005 to 2010.
[19] Over 2008-2012 NERSA approved annual rises of 27%, 30%, 26%, 26% and 16%.

Large firms rate themselves as innovative. However, they tend to introduce incremental and adaptive innovations, rather than radical or disruptive innovations, so that the innovations do not show up in patents.

business R&D occurs in the services sector; that to an extent explains the vibrancy of financial services and retail in selling Brand South Africa abroad. One simply cannot stay ahead without investing in skills and research, be this market research, the modelling of customer behaviour, or reverse engineering of point of sale systems.

What is urgently needed is a set of company case studies that will probe the various strategies that companies have employed as they absorb information, develop their knowledge base, and introduce innovations. This is critical to get a better understanding of exactly what is happening, and why.

5.2.3 The higher education sector

With the mergers completed, higher education policy has concentrated on the next set of issues – continuing to push access, equity and redress measures but, increasingly, imperatives that relate to quality and efficiency. The mechanisms for access, equity and redress fell to the Department of Education and its successor, the Department of Higher Education and Training (DHET), taking form through reforms of the student loan scheme, reinstatement of bursaries in areas of skills shortage, re-consideration of language policy, support to the humanities, and remodelling the funding formula to level the playing field across the HEIs.

As a consequence of the negotiations that culminated in the agreed structure of the 1994 administration, the DST has no direct responsibility for the education system. By law however, each HEI enjoys considerable autonomy and DST has thus been able to work directly with HEIs and partner organisations to build capacity through three major programmes, the SARChI, the CoEs and CoCs.

CoEs are organised both as single site and decentralised entities that build on and extend capacity in well-established and prestigious research areas. At present there are ten CoEs that cover ornithology, catalysis, tree health biotechnology, theoretical physics, strong materials, climate and earth systems science, invasion biology, epidemiological modelling, and biomedical tuberculosis research. Top-ranked researchers lead these centres, some of which have pedigrees going back decades (e.g. Forestry and Agricultural Biotechnology Institute; Percy Fitzpatrick African Institute of Ornithology). The choice of centres shows a strong match with pressing social and environmental issues facing the country and the present needs of industry (hydrocarbon synthesis; pulp and paper). There is also a 'blue sky' element in the designation of two CoEs for new materials and physics.

The CoE annual reports are readily available[20] and the programme was subject to external evaluation in 2009 and 2013. The outcome was a highly favourable report on the programme while expressing concerns at its financial viability and the problem it might face from competition with SARChI, whose funding was longer term and more generous. Another issue the evaluation raised was that in most instances, 'African' CoE students came from elsewhere in Africa.

The SARChI was established in 2006 as a direct result of Presidential concerns that the universities were not producing sufficient numbers of highly skilled scientists and engineers. The Ministers of S&T and Public Enterprises were tasked to analyse the situation and propose solutions.

Table 22. SARChI awardees, 2013

Tier 1 holders	99
Tier 2 holders	22
Recruited from South African universities	93
Recruited from industry and abroad	28
Female	24
Male	97
Black (African, Indian, coloured)	39
White	82

Part of the answer came in the form of the SARChI, closely modelled on the Canadian research chairs programme. It was conceptualised with the support of National Treasury to set the initial target of 210 research chairs by 2010. As of March 2013, some 157 chairs have been awarded, with 93 research chairs[21] in operation across 21 HEIs. Table 22 displays the demographics of the awardees. SARChI is one of the most important interventions in the HEIs that, like many other interventions must recognise reality and compete with other needs. One notes that SARChI is not a 'new blood' programme, since 93 of 121 (77%) holders were existing HEI staff. White and male dominance reflects the present reservoir of high-level skills that is being called upon to build future generations of researchers drawn from all communities. Once more the label 'African' is misleading since as of 13 June 2013 at least eight staff among the 124 chairs in post were born elsewhere in Africa[22].

DST/NRF have extended the research chair initiative by drawing in private sector support in the form of the FirstRand Group Research and Development Chairs that focus on improving primary level numeracy and literacy, and secondary level mathematics.

5.2.4 The 'innovation chasm' & 'big science'

One of the ways that the DST seeks to address what it sees as the 'innovation chasm' is through the mechanism of CoCs. The Department of Trade and Industry has its own

[20] www.nrf.ac.za/coes.php?fdid=&tab=reports_list&sub=Reports%20and%20Publications.
[21] http://hicd.nrf.ac.za/?q=sarchi-overview.
[22] Private communication.

means of mitigating the market failures in its domain of influence, through some 30 or more industry incubators. CoCs have been instituted in many countries, sometimes as networks (ETH, Switzerland), as projects within academic departments as at KTH in Sweden, or industry-led CoCs, as for example Kplus, Kind and Knet in Austria and Cooperative Research Centres in Australia.

The DST, having identified research-commercialisation market failure has now set up the government-led CoCs initiative. The Hydrogen South Africa (HySA) strategy argued that South Africa's position as the holder of the bulk of world reserves of platinum, coupled with expertise in catalysis, should allow us to become a world leader in fuel cell technology. Accordingly HySA now involves three CoCs for infrastructure, catalysts and systems respectively, drawing in universities, the CSIR and the platinum industry. Similar thinking underlies the development at the CSIR of the CoC for exploiting titanium. South Africa is also a leading producer of titanium dioxide and now a refiner of titanium. The CSIR has developed a novel technology for continuous production of titanium powder. This is the feedstock for a sintering process that may allow for the rapid production of lower cost airframe components. This CoC brings a range of aerospace capabilities into play, including established players such as the CSIR (the composite airframe OVID turbo-prop trainer) and Denel (Rooivalk helicopter gunship). This expertise has long spilt over to the private sector, where for example, Aerosud is now producing airframe components for Airbus, while the former Omnipless, now owned by UK Cobham, produces compact air-borne radar sets. The nucleus of a future aerospace industry is taking shape, with DST effectively the angel investor.

The CoC strategy blends into a wider, but unstated strategy, to support 'big science' in areas of comparative advantage as evidenced over the years in support for SALT and the successful bid for the SKA. The investments in the PBMR and the Joule Electric Vehicle are cases where the government has sought to pick winners.

5.2.5 Knowledge infrastructure

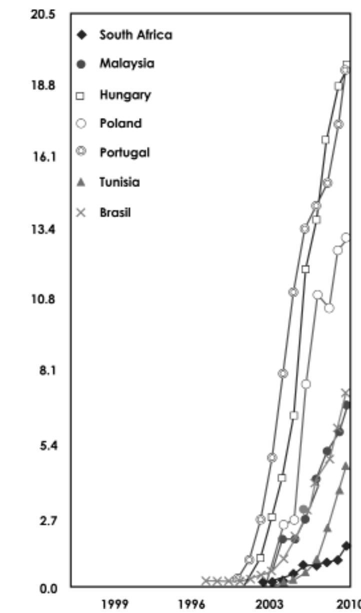
What is broadly referred to as knowledge infrastructure refers to the institutions and utilities that support the broad needs of research and innovation enterprises. HEIs and science councils are part of this, so are the national facilities, transport, power, and telecommunications utilities, data-processing centres and science parks. NACI commissioned an audit of research infrastructure in 2006 that identified serious shortcomings, and the Ministerial Review added its voice to the concern. DST is currently preparing a research infrastructure roadmap.

To date, progress on cyber-infrastructure includes the establishment of the Centre for High Performance Computing, the South African National Research Network that is implemented and managed by the CSIR Meraka Institute and the South African Very Large Database initiative.

This effort is laudable but does not mean that affordable high-speed broadband is readily available to all parties active in research and innovation. Figure 6 provides the evidence that when it comes to broadband, South Africa remains a laggard by comparison with comparator middle-income countries and the lower rank EU countries.

Low broadband not only retards development but also influences perceptions regarding South Africa's development potential.

Low broadband penetration not only retards development, but also influences perceptions regarding our development potential. Appropriately therefore the NDP has made broadband availability one of its key objectives. It is surprising to find a senior organ of government belatedly identifying the starkly obvious. The fact that the NPC, with the former Minister of Finance as its head, recognises that broadband availability is an obstacle to progress, suggests that changing this situation demands a political rather than an economic solution.



Source: Indexmundi.com.

Figure 6: Fixed broadband Internet subscribers/100

S&T parks, like special economic zones, have been successful in various places around the world, and thereby attract the attention of policymakers. It is tempting to assume that transplanting a regulatory framework to a greenfield will automatically produce a silicon valley or silicon glen. The greatest danger would be to plough scarce resources into infrastructure in the hope that research entrepreneurs will rush in to set up shop. Segal (2008:17) suggests that the establishment of a S&T park depends on timing and has a prospect of success when government, higher education and business have reached agreement on the vision and strategy associated with a specific economic and social objective.

The Stellenbosch Technopark is a good example of a S&T park that was established to meet a specific need, namely as a light industrial park for the SMEs that were to be drawn to meet the needs of the 1980s ballistic missile facility, with its command centre at Grabouw and launch facility near Arniston on the east coast. Stellenbosch Municipality owns the Technopark, where a number of high-technology medium-sized and small companies are in operation, including Sunspace, EMSS, the Institute for Mine Seismology, EOH and Reunert Radar. These companies display varying types and extent of linkage with SU and the larger innovation system (Kahn, 2013), ranging from strong to non-existent. One is in the park simply for its good location; Reunert was an original anchor tenant; Sunspace is a spin-out from the university and had strong links to the missile programme.

By contrast, The Innovation Hub, a subsidiary of the Gauteng Economic Development Agency was founded in 2001 to act as a magnet to draw high-technology companies toward the Hub by virtue of its strategic location adjacent to the CSIR and nearby University of Pretoria. Arguably, the Sappi Technology Centre is the most visible tenant in the Hub that hosts more than a score of small and start-up S&T services companies. Thus far, The Innovation Hub track record shows modest achievement. Two developments include the Vaal University of Technology Science Park at the defunct Vista University site in Southern Gauteng, and the eMonti Science and Technology Park (East London) that will focus on aquaculture and water technologies, renewable energy and plant-based technologies.

Drawing tenants and new entrepreneurs to remote sites requires careful appraisal of the incentive regime that will be needed. International lessons abound: tax holidays are often effective; reduction of tariffs, relaxation of laws regarding hiring and firing of staff, preferential access to land, and rapid supply of bridging finance and land have all worked in different settings.

5.2.6 Regional systems of innovation

The NSI includes a number of regional systems. A valuable contribution was made to the understanding of the status of these systems through the Cooperation Framework on Innovation Systems between Finland and South Africa (COFISA), a bilateral programme that took place over 2006 – 2010. Finland, a small country with a homogeneous culture, has extensive experience and success with the implementation of its NSI, especially in building regional capabilities. The thrust of COFISA (2010) was to build on:

> … particular strengths and opportunities of the local economy, because for any particular area, the ability to be competitive in all business environments and all areas of the value chain is very difficult. A certain strategic focus and a process of making choices of where and how resources should be invested are therefore necessary. In this way, the local milieu of actors, organisations and institutions can be developed and relevant competence areas pushed forward intensively. Regions must thus establish the capability to identify, nurture and exploit their assets; and engage in collaborative processes for socio-economic growth and development. In this way the regions and consequently the NSI will be able to ensure an effective response to the global knowledge economy.

COFISA worked with the Gauteng, Western Cape and Eastern Cape Provincial Governments, and it was immediately found that there were important differences in the local exposure to the innovation systems approach and little was in place to facilitate such a discussion. This experience emphasised the criticality of implementation steps and that one should not assume that a national policy is automatically driven by diffusion into the regions. Most evident was the absence of mechanisms to encourage collaboration and interaction that once started resulted in promising behaviours that were perhaps not sustained after the end of the COFISA programme.

In practice, however, there was a dearth of spatial economic data and innovation system activity on a sub-national level. Lorentzen (2009) published a 'first cut' on *The Geography of Innovation in South Africa* that focused on how well the productive and knowledge-based activities are integrated in the country's provinces and how relevant is geographic proximity between firms and other knowledge users or producers. Countries are not closed systems and thus interactions with foreign sources of knowledge are increasing, but nevertheless, the local and national networks remain important, and one needs to determine when regional, as opposed to national, systems are more appropriate. Lorentzen (2009) showed that in French manufacturing, for example, having a highly skilled force and productive universities, did not make a difference unless they were part of a system, and there was a significant relationship between the actors in a region. He also noted that for R&D-intensive and small firms, spill over of knowledge have limited geographical reach, which is why proximity matters. Essentially, South Africa was a 'latecomer country', whose skewed development played a major role in compounding policies aiming at normalising the status across the sub-regions.

Although availability of data was difficult, and the proxy of R&D spend, and patents produced were used to classify knowledge generation, Lorentzen (2009) concluded that the correspondence of knowledge generation with the key regional sectoral economic indicators was largely absent in most parts of the country, except for some sectors in Gauteng, the Western Cape and possibly KwaZulu-Natal. In terms of the utilisation of knowledge, he found that although the Western Cape is not the most important producer of knowledge, it is perhaps the most effective user. He further suggested that geographic proximity did not appear to play a major role, except in the Western Cape. The telemetry sectoral system of innovation, the sectoral systems associated with agriculture, and possibly even financial services are all highly concentred by geography.

There is an embryonic regional innovation system in South Africa. These 'bottom-up' initiatives need to be harmonised and incorporated into the NSI. Regional systems are key building blocks of the national system.

Overall, the regional innovation initiatives of DST have relatively low profiles. The COFISA experience shows that driving regional activity requires a larger staff complement to ensure consistent linkages, facilitation and involvement to achieve the required levels of collaboration. While a number of provinces have become active in the debate, with embryonic regional innovation system thinking taking off, it is notable that the Ministerial Review gave no attention to this groundswell of activity. The concern is that provincial innovation initiatives are not presented as part of a national system.

International experience has shown that there are often higher abilities to innovate in industry clusters due to the concentration of complementary competences, specialised service providers and enhanced technology and market knowledge. Such clusters often link to local tertiary education institutions and develop relevant research capabilities.

The DST has initiated a programme to stimulate Regional Innovation Forums in the various provinces. Some have built on the interactions started by COFISA, and others are new initiatives. Progress has been slow but some uptake is clear.

In order to take matters further, the DST has decided to focus on the Eastern Cape as its primary pilot and is collaborating with the Provincial Government, who has created "INNOVATE Eastern Cape'. This is an innovation coordination initiative that has been set up by the Eastern Cape Provincial Government under the aegis of the Department of Economic Development, Environmental Affairs and Tourism (DEDEAT). Its main function is to drive the development of the Provincial Systems of Innovation through structured and coherent processes aligning them to the developmental priorities of the Eastern Cape Province, as outlined in the Provincial Growth and Development Plan, as well as supporting documents. The Eastern Cape Regional Innovation Forum is coordinated by the Nelson Mandela Metropolitan University.

In other provinces, the innovation initiatives take different forms. For example, Gauteng has approved a Gauteng Innovation Strategy (2010). They have adopted a broader approach and have strongly included social innovation and open innovation in their strategy.

To date, the DST has supported the formation of Regional Innovation Forums with variable success. However, this aspect has essentially been under-resourced and never was 'mainstream'. In revitalising the NSI, therefore, a robust regional innovation strategy will need to be developed and a suitable administrative model and funding defined. Such a structure will be key to engaging and interacting with the various role players and should have neutrality to be able to facilitate across the spectrum of actors.

5.3 Key elements of a successful NSI

Four elements are identified as critical to a successful NSI.

5.3.1 Governance

The NSI has not had an adequate level and structure of governance from the outset. Initially the structure focused only on S&T, and later the New Strategic Management Model was largely dysfunctional. The OECD review (2007) made many pertinent observations, one of which was that there was a lack of understanding of the broader concept of innovation. This is explicable as there was no cross-cutting and authoritative voice communicating a unified vision across government, and to other actors. The NSI was essentially 'pilotless'. This critique was mirrored in the Ministerial Review Report.

In the White Paper (1996), it was recommended that a Minister's Committee on Science and Technology (MCST) be created, together with an advisory body, *viz*. NACI.

It is noted immediately that the MCST was directed to S&T and not innovation, which is already a worrying indicator for governance of a NSI. This committee did operate for some years but then fell away. In 2004, the New Strategic Management Model (NSMM) was established, with DST being the coordinator of this governance structure. The Ministerial Review describes in some detail the activities of this NSMM, but comments that "DST, largely as a result of the NSMM organisational model set up in 2004, has not been in a position to create a coherent, truly systemic policy framework to promote and coordinate the NSI, and has been obliged instead to throw its energies into activities that it seems to have undertaken in the manner of a 'line department', rather than a system-wide facilitator".

In summary, it is fair to say that the NSI has not had an adequate level of governance from the outset. Initially the structure only focused on S&T, and later, the NSMM was largely dysfunctional. This goes far in explaining why most of the policies and strategies from other line departments may have mentioned 'innovation' as an important concept, but made no specific efforts to see their activities as an integral part of the NSI. The OECD's comment on the lack of understanding of the broader concept of innovation is explicable as there was no cross-cutting and authoritative source communicating a unified vision across government, and to the other actors. In reality, the NSI can be described as 'pilotless', and in turn did not develop or evolve as the country moved over the last 17 years. What is more concerning is the lack of response to the comments of OECD which, if considered, could have re-invigorated the NSI much earlier.

The Ministerial Review has made some specific proposals regarding new models for the governance of the NSI in the form of a National Council Research and Innovation (NCRI), which have merit. Given the reluctance of the DST to establish another statutory body in the form of NCRI, it will be important to find an alternative governance structure that could provide the direction that is needed. Certainly, the inclusion of business is important and given the emerging Provincial innovation strategies mentioned earlier, their learning will be a key input into national innovation strategies and linkages should be encouraged.

As an alternative to the establishment of NCRI, DST convened a STI Summit in July 2013, which is proposed as an annual gathering with high-level ministerial support and participation from the research sector and business and industry.

At the time of writing, uncertainty still surrounds the fate of the Ministerial Review-proposed ORIP. Given the reluctance to establish a new entity, as mentioned above, a solution is to amend the NACI Act to transform NACI into a unit within DST, allowing it to become responsible for coordinating policy advice and for generating and commissioning research and analysis. This dual role implies that the 'new' unit replacing both NACI and ORIP would assist in identifying gaps within the NSI and direct research to address the gaps. The policy advisory work currently undertaken by NACI could be given to the Academy of Science of South Africa (ASSAf), an independent body, whose mandate is to provide evidence-based advice on matters related to national challenges in general, including innovation. The Academy will have to devise a strategy to draw more systematically from a larger pool of expertise to ensure that it is inclusive and to address critical factors such as business participation, age, gender and racial imperatives, all while maintaining its principle of excellence.

5.3.2 Interactions among NSI actors

Collaboration, sharing and interaction are key characteristics of an innovating country.

Collaboration, sharing and interaction are key characteristics of an innovating country. Most of the case studies reveal that even when the research offers commercial potential, the success rate is limited by factors linked to the interrelationships between the participants in the process. Whether this breakdown results from a lack of entrepreneurial or business skills, internal competition as opposed to collaboration, or misalignment with markets, if these aspects are not understood and improvements made, the NSI will struggle to achieve the goals originally set.

It is important to consider the hidden aspect of the interrelationships and interactions necessary between all the elements that make for effective functioning of the innovation system. The measurement of innovation impact remains difficult, but without it, one is left with input factors and can obtain a distorted

image of the reality and success rate of the system. Impact assessment of research and innovation remains a contested field (Delanghe and Muldur, 2007; Simmonds *et al*., 2010; Teirlinck, 2011), the more so when applied to basic research that most often only yields long-term benefit.

As an interesting example, Stanford University has completed a study entitled *Stanford University's Economic Impact via Innovation and Entrepreneurship* that indicates that since the 1930s, companies formed by Stanford entrepreneurs have generated global revenues of $ 2. 7 trillion, and have created 5.4 million jobs. Further key findings include:

- 29% of respondents (Stanford alumni) reported being entrepreneurs who founded an organisation (for profit or non-profit).
- 32% of alumni described themselves as an investor, early employee of a board member in a start-up at some point in their careers.
- 25% of faculty respondents (some of whom were also alumni) reported founding or incorporating a firm at some point in their careers.
- Among survey respondents who became entrepreneurs in the past decade, 55% reported choosing to study at Stanford because of its entrepreneurial environment.

While Stanford may be an exception, it shows how an institution renowned for outstanding research can also play a major role in its host system of innovation by stimulating entrepreneurial flair among its students. The question that is posed by this example is whether South Africa, can learn that it is only by working together, collaborating, sharing and interacting that the country will ever move forward as an innovating country.

There have been too few in-depth studies and reviews of the project and programmes supported by the many instruments that have been initiated by government to enable the innovation system.

What then is our evidence for 'interactive learning' in South Africa as part of our NSI? Generally, there have been too few open in-depth studies and reviews of the project and programmes supported by the many instruments that have been initiated by government to enable the innovation system. Such studies are often seen as an 'audit' where the emphasis seems to be on finding problems, instead of being aimed at generating 'learning and improvements'. Does South Africa have a culture of regular evaluations of each of the programmes and interventions, to ascertain positive features and areas where improvements should be possible? It is important to differentiate such review reports from the regular organisational annual reports written to meet their statutory requirements. The real facts in a review process often come from interviewing the beneficiaries who can give a unique perspective. In such studies, the relationship issues between the various participants form a key part of the learning. Such reports should be presented and discussed in open forums. In this regard, the processes used by Finland in relation to their bilateral programmes would be a good example, where international and totally objective reviewers are brought in to provide the most benefit.

In the present study, a search for such reports in the public domain proved difficult and indications were given that no such reviews, as above, had been done. This becomes even more important as a number of programmes were absorbed into the TIA, without open assessment of their previous outputs and value to the NSI, which is problematic.

The importance of such studies is highlighted by Kruss (2006), who reviewed case studies of selected projects with special emphasis on “network alignment that analyses links that are present or absent within and between networks in production, innovation and knowledge systems”. Highlighting her conclusions from three Innovation Fund case studies, Kruss suggested that even though the intellectual capacity and degrees of entrepreneurial capability existed, spin-offs from our universities are extremely complex. Many of the reasons for failure could be attributed to inadequate relationships and misalignments in value chains. She concluded that “The depth and extent of network alignment within and between the subsystems of the national technological system and industrial subsectors in South Africa are not yet able to support knowledge intensification adequately”. Adding, “Stronger, wider and deeper complementarities and overarching linkages within firms, within government and universities, and between government agencies, universities and firms, could support the achievement of shared developmental goals more effectively”.

It is felt that the value of such studies is under-appreciated while this type of learning is core to providing optimised offerings to support the NSI. Most of the case studies reveal that even when the research offers commercial potential, the success rate is limited by factors linked to the interrelationships between the participants in the process. Whether this breakdown results from a lack of entrepreneurial or business skills, internal competition as opposed to collaboration, or misalignment with markets, if these aspects are not understood and improvements made, the NSI will struggle to achieve the goals originally set.

Mobility, expressed as ‘brain circulation’, is a vital aspect of innovation activity. Laws and regulations that needlessly impede these flows are counter-productive.

5.3.3 Openness to the world

One of the most important characteristics of innovation systems is their openness to new ideas, new people, and new organisations. The US is still reaping the benefit of the thousands of intellectuals, scientists and engineers who fled Europe during the interwar years and settled there. Pre-1994, South Africa encouraged immigration from Europe; as evidenced above, post-1994 South Africa is benefitting from soft immigration policy toward scientists and engineers from elsewhere in Africa. Mobility expressed as ‘brain circulation’ is a vital aspect of innovation activity. Laws and regulations that needlessly impede these flows are counter-productive.

The DST Europe-South Africa S&T ESASTAP initiative has played an important role in promoting mobility of researchers. In relation to the size of its research system, South Africa is the single most active third-country participant in the EU Framework 7 Programme. As the bibliographic record confirms, the research system is now open to the world.

Insofar as higher education and research are concerned, South Africa has a special relationship with Africa. As already noted, there are a large number of students and staff from Africa active in the institutions of the innovation system. Between 7 to 8% of university students are from sub-Saharan Africa (SSA), making our country the higher education hub of the continent. African scholars occupy leadership positions as research chairs, research managers and analysts in the public and private sectors. The DST provides critical support to AU S&T flagship projects, and plays a leading role in promoting innovation policy development through the New Partnership for Africa’s Development (NEPAD) S&T Desk and the African STI Indicators Initiative. South Africa performs the associated role of an African interlocutor with the EU for S&T development, and has also served as a test site for new approaches, such as the EU-funded Innovation for Poverty Alleviation project.

South Africa has active S&T bi-lateral agreements with Brazil, Russia, India and China, as well as for specific industrial R&D projects that fall outside the immediate scope of the bilateral agreements, as for example previous Russian interest in the PBMR, the Denel-Brazilian Air Force co-development of the A-Darter missile, the Fujian University-Cedara mushroom project, and mobility grants for scientists to travel to India as part of the IBSA S&T agreement.

Merely gaining the award of the SKA is a significant achievement; building the 60-dish MeerKAT precursor will stretch our capabilities and capacities yet further. Exactly how this effort will build local manufacturing R&D and innovation outputs remains to be seen. The experience of Chile in relation to the spill over that may arise from its hosting the European Southern Observatory in the Atacama Desert (Feder, 2012) will be particularly instructive and deserves close study.

There is a new emphasis on demand-side policies giving rise to the need understand how these policies will benefit South Africa and how should they should be implemented.

5.3.4 Demand-driven

Given the importance of the interactions within a functioning NSI, Georghiou (2007) described an increasing convergence of innovation and industrial policy. In particular, he focused on the transition from 'technological forecasting' to 'innovation forecasting' applied to both 'content' and structural' issues. In the latter case, specific mention was made of the French *Futuris* programme, which was industry-led and focused on the reorientation of their NSI. The foresight process, as was also used by the COFISA programme, has the effect of building up networks and "wiring up the innovation system" (Martin and Johnson, 1999).

Innovation policy is also being reoriented to reflect the realities of 'open innovation' (Aho *et al*., 2006, Georghiou, 2007). This has resulted in a new emphasis on demand-side policies, "broadly speaking the use of instruments such as public procurement and regulation to pull-through innovations but also encompassing measures such as clusters and platforms which seek to bring together demand and supply. In some ways, these measures may be seen as new industrial policy as well as new innovation policy, but in this case an industrial policy which is fully compatible with the principles of competition". These demand-side measures are equally applicable to developing or emerging economies.

Applying these methods in a number of developing and transition economies, Georghiou (2007) noted that an important issue was the system capacity for strategic development. Deficiencies that exist may include:

- lack of conducive integrated policy and institutional framework;
- under-developed technology and innovation promotion planning capabilities;
- short-term thinking and reactive mode action;
- implementation failures on strategies;
- system linkage failures and poor coordination;
- disconnection of application of new technologies from socio-economic problems;
- scientific institutions with strong and inflexible disciplinary focus;
- low technology and innovation intensity in industry.

Resource deficiencies may include:

- lack of funding for technology acquisition and diffusion;
- lack of human capital and increasing human resources crisis (brain drain, demography);
- absence of adequate equipment and infrastructure.

5.4 Strengths and weaknesses of the NSI

A number of local and international assessments of the NSI reveal some causes for concern, both in terms of interpretation of data, the message that is conveyed and our international competitiveness.

The South African Innovation Survey (2008) paints a positive picture, showing South Africa to have a higher percentage of 'innovation activity' than countries such as Denmark, Sweden and the United Kingdom. However, of this activity, only 27.3% had successful innovations. The indication that South African companies are highly innovative does not appear to have translated into growth in the relevant sectors. International benchmarking studies reveal some major shortcomings and causes for concern.

The INSEAD/WIPO Global Competitiveness Index (GII) was launched in 2007 with "metrics and approaches to better capture the richness of innovation in society and go beyond the traditional measures of innovation as the number of research articles and the level of R&D expenditure". Specifically, the indicators used were divided into those affecting the inputs to innovation, and those reflecting the outputs. Two indicators derived, were the GII, as the average of the input and output scores, and the Innovation Effectiveness Index (IEI), as the ratio of the output and input scores. Table 23 displays the GII.

Table 23: Global Innovation Index, South Africa

	GII Score	Rank	Income	Rank	Region	Rank
Overall	37, 4	54	Upper middle	12	sub-Saharan Africa	2
Input factors	46, 4	45	Upper middle	5	sub-Saharan Africa	1
Output factors	28, 5	73	Upper middle	23	sub-Saharan Africa	3

While South Africa is the top sub-Saharan (SSA) country in terms of the inputs to the innovation system, and 5th out of 40 upper-middle income countries, the situation is radically different for outputs. Here, South Africa slips to 73rd overall, 23rd amongst the upper-middle income countries and down to 3rd in SSA.

In terms of the IEI, which is the ratio of output to input scores, South Africa is ranked 22nd in SSA (out of 31 countries) and 116th out of 141 countries, highlighting a deficiency in the NSI. The reason lies in the very low score achieved for knowledge diffusion (106th position).

In terms of the Innovation Efficiency Index (IEI), which is the ratio of output to input scores, South Africa is ranked 22nd in SSA (out of 31 countries) and 116th out of 141 countries, highlighting a deficiency in the NSI. The reason lies in the very low score achieved for knowledge diffusion (106th position).

In the WEF Global Competitiveness Report 2012-2013, South Africa is ranked 52nd out of 144 countries and has remained close to this position for some years. South Africa is ranked as an 'efficiency-driven economy'.

A key contributor to an NSI is entrepreneurship. In the 2012 report, the score for early-stage entrepreneurship fell from 2011 to 2012 and was well below the average for an efficiency-driven economy. It is as a result, inter alia, *of poor infrastructure, burdensome regulatory hurdles and lack of finance.*

Knowledge diffusion is a composite of technology, royalty receipts, high-technology exports, outward foreign direct investment (FDI), and ICT services exports, all of which reflect our dependence on commodities. It is regarded as one of the most important aspects of a NSI, especially in developing countries.

World Economic Forum – The Global Competiveness Report 2012 – 2013: South Africa is ranked 52nd out of 144 countries and has remained close to this position for some years. South Africa is ranked as an 'efficiency-driven economy'. Factors which demonstrated high competitiveness are Financial Market Development (rated 3), Market Size (rated 25) and Goods Market Efficiency (rated 32). At the negative end, the Health and Primary Education (rated 132) and Labour Market Efficiency (rated 113) are most obvious. Under the Higher Education and Training pillar, it is noteworthy that South Africa is rated 143 for the "quality of mathematics and science education" and 140 for the "quality of the education system".

In the categories for the innovation-driven economy, South Africa has a number of positive measures, but certain others stand out, e.g. Nature of Competitive Advantage (rated 107), Value Chain Breadth (rated 106), Government Procurement of Advanced Technology Products (rated 105) and Availability of Scientists and Engineers (rated 122).

The report lists the 'most problematic factors for doing business' in South Africa, with the top five being:

- Inadequately educated workforce
- Restrictive labour practices
- Inefficient government bureaucracy
- Inadequate supply of infrastructure
- Corruption

Such aspects, although not directly part of the NSI, are all important factors in the ecosystem. Thus the influence is inseparable. Likewise, the NDP has specific actions needed to improve these factors, and again reinforces the inextricable linkages between this plan and the NSI.

The result is that South Africa is classified as an underperformer based on the GII and GDP.

Global Entrepreneurship Monitor (GEM) Survey: A key contributor to an NSI is entrepreneurship. In the 2012 report, the score for early-stage entrepreneurship fell from 2011 to 2012 and was well below the average for an efficiency-driven economy. It is

as a result, *inter alia*, of poor infrastructure, burdensome regulatory hurdles and lack of finance.

While international benchmarking studies are useful and illuminating, they do not reflect deeply enough on the critical relationship issues and success factors. They are thus useful but insufficient to address the further development of an NSI. What is missing is interactive learning as part of our NSI. There have been too few open in-depth studies and reviews of the projects and programmes supported by the many instruments that have been initiated by government to enable the innovation system. Such studies are often seen as an audit where the emphasis seems to be on finding deficiencies, instead of being aimed at generating learning and improvements. There is also a need to review case studies of selected projects with special emphasis on issues that determined success or failure. The value of such studies is underestimated since they are central to providing guidance in support of the NSI.

South Africa has also benefited from participation in the OECD Review processes and has become exposed to international trends. The OECD Review made a number of significant recommendations that should have been taken into account through extensive debate in the NSI with all the actors, but again this critical opportunity was largely missed, but should be regained.

There is a critical element that is missing in all the debates and findings of committees, including the most recent Ministerial Review Committee report, and that is the lack of good evidence of the performance of the various instruments that have been established to serve the NSI. The key question is how to develop a new strategy without a properly considered history? To date, there has been a very limited amount of what is considered direct learning from the experience. There is also a need to have a dedicated institution that would serve as a national archive for such NSI historic data for learning purposes.

Were there regular evaluations of each of these programmes, and the associated completed projects, to ascertain positive features and areas where improvements should be possible?

Much effort in South Africa is expended on the various S&T and innovation surveys which allow international benchmarking, but these indicators do not reflect deeply enough on the critical relationship issues and success factors. Thus, while useful, such studies are insufficient to foster the further development of a NSI.

Toward 2030

6.1 Reflection

This appraisal of the state of our NSI considers the period from 1994 to the 2030 endpoint of the NDP. It is noted that the country is now halfway through this period.

The countries of Western Europe, Japan, and the Asian Tigers were able significantly to raise their living standards in a generation; Singapore is another example of this rapid change. Other countries such as Malaysia will take perhaps two generations to reach high-income status.

Democratic South Africa, while in a weakened economic state, did not start from the same level of destruction as did the above-mentioned countries, though the damage to our psyche is perhaps comparable. The long process of nation building enunciated in Archbishop Tutu's metaphor of the 'Rainbow Nation' has begun a process in which there are inevitable winners and losers. Business, the PROs, HEIs, NGOs and other actors have had to make sense of the new conditions and seek the wherewithal to survive and prosper. New state structures have been put in place and the face of government has changed completely.

South Africa may sometimes appear to muddle along, but we should remember that we are trying to manage an innovation system. It may be relatively easy to track the inputs to the system, and to log the codifiable outputs, but ensuring specific outcomes, determining impacts, and ascribing these to specific actions, may be difficult. Other than during the fog of war, governments are not very good at driving specific innovation outcomes. The country must assume that all its people do their best, and if that is indeed the case, then it would have to agree that the innovation system actors – from government through to NGOs – have done reasonably well. The criticism made here is in the spirit of continuous improvement.

One of the most insightful comments of the OECD Review was in noting "the striking achievement of South Africa ... to defy the extremely poor framework conditions facing the innovation system in the early 1990s' (OECD, 2007: 4)". Unlike other countries that underwent massive political and social restructuring, the innovation system did not collapse. Indeed, most institutions showed continuity of activity whereby the capability built over many years remained in place and was able to serve both existing interests and new priorities. This was precisely what the Constitution intended to happen. The country has done quite well.

The broad features of the innovation system landscape are thus relatively unchanged from those pre-1994 – the set of science councils is barely altered; the leading universities of then are the leading universities of now. Business looks somewhat different, with the dominance of the few giving way to the emergence of new actors. The balance of forces nationally and internationally is radically different: government must deal with many constituencies with varying degrees of leverage and influence; the international order has shifted from the bipolar Cold War era, to the short unipolar dominance of the US, and now, at least economically, to the multipolar world with the Peoples' Republic of China as the second largest economy, to Japan in third position. South Africa, still the dominant economy in Africa, has gained a seat in the BRICS bloc as the 'Gateway to Africa,' a delicate role that will be contested by players such as Nigeria and Egypt, if and when they achieve stability. The facts of demography, being the smallest of the BRICS, are simply not in our favour. It is time to recognise that our dependence on minerals amounts to our own special version of the resource curse that encourages the postponement of addressing our underlying challenges.

To prosper and develop, South Africa needs to think as smartly as did the Asian Tigers, who recognised that their main resource was their people. This is what the NDP sets out to do. But it does so without being propelled by a national crisis so encompassing that it forces strong alignment toward the pains of restructuring. The country is perhaps too complacent, with the *status quo*.

The agenda of science, what one might very loosely term its compact with society, has shifted from one that provided technology for the warfare state to one providing social science for the welfare state, with the freedom to pursue 'own research' being maintained over the transition. The 'big science' strategic projects of the 1970-1990 period – armaments and nuclear weapons – have given way to a new set of big science projects – the PBMR, SALT, MeerKAT, and now, SKA. Science has risen to the challenges of tuberculosis, HIV and to a lesser extent, malaria, and with dignity and flair has built world-class capability in work on infectious diseases. This is 'own science' at its best. South African scientists have continued to garner international recognition. Again, the country has done quite well.

Business has also performed reasonably, less so in terms of job creation, but certainly in creating and capturing new markets. Brand South Africa is ubiquitous and growing its international reputation by the day.

The innovation system is open to the world, and open to all South Africans, with the recently published Forbes List of young African entrepreneurs[23] including Sizwe Nzima (Iyeza Express), Stanley Uys (Medical Diagnostech), Ludwick Marishane (Headboy Industries), Rapelang Rabana, (co-founder Yeigo Communications) and Justin Stan-

[23] http://www.iol.co.za/capetimes/cape-tops-young-entrepreneurs-list-1.1531405#.UbwzbPahlXc.

ford (4Di Group). What these five have in common is the recognition of health needs and ICT potential. Their talent and recognition suggests there may be greater vitality in the system than the Global Entrepreneurship Monitor (GEM) found.

And the featuring of Lodox™ on the TV series Grey's Anatomy story[24] serves as a positive counterpoint to the disappointment associated with Hoodia. One should take note however, of the length of time it took for Lodox to gain a foothold in medical imaging, from its origins in the 1980s to counter-diamond smuggling to the present when low-intensity x-ray scanning is in high demand. The Industrial Development Corporation (IDC) is a major shareholder in Lodox Systems, pointing to the combination of attributes that has been fulfilled: a clear need, technology that might meet that need, the skills base to develop the technology, the financial backing to make it happen. This is a great example of a product associated with the resource curse, evolving into a tool for curative medicine. For the moment this is a niche market, but it does show a way forward, much as DetNet and EMSS have.

This is the type of intervention that governments are best equipped to do. It involves careful appraisal of a public need, emphasising the demand-driven aspect of a successful innovation system, and then the marshalling of the necessary resources within the appropriate regulatory framework to allow it to happen.

6.2 Key findings and recommendations

As a consequence of the analysis given in the body of the Report, it is important to highlight some of the key findings of this review and to provide recommendations aimed at improving the ability of the NSI to deliver on its promises and potential.

As a starting point, there was a focus on definitions and it was concluded that there is a lack of a shared understanding of the concepts of innovation and a system of innovation. The definition favoured by the DST is the one given in the *Oslo Manual* and is shared by the SADC, AU and EU. In this Report the broadening of the definition to consider a more recent World Bank (2010a) understanding, particularly appropriate for developing countries is recommended. It places emphasis on the dissemination of technologies that are new to a given society and that innovation should benefit society.

The need to create a common understanding of innovation and the NSI applicable to South Africa is essential before the interrogation of the role of the NSI in the NDP is made. The 'linear model of innovation' has become entrenched in our thinking and continues to dominate policy formulation. It is responsible for concluding that an increased investment in basic and applied research will necessarily lead to innovative products and services in the marketplace, and where this does not happen, has given rise to the concept of an 'innovation chasm', which has also become an entrenched idea.

An alternative view given in Chapter 5 places emphasis on the linkages and interactions within the system, and also emphasises that these are complex, and often

[24] http://lodox.com/2013/06/from-good-to-grey-a-south-african-story/.

reciprocal in nature. A concept map of the STI landscape has been produced (Figure 5) that provides a means of visualising the interdependency and complexity of the system. The conclusion is that the South African research and innovation system comprises actors and institutions typical of a mature innovation system; it is the linkages and interactions that are weak.

The NDP represents novel thinking about innovation. It gives greater prominence to STI than any of the preceding policy documents and, importantly, adopts and advocates a system-wide view of STI in relation to broader society. It takes the concept out of the sole domain of the DST and considers it to be relevant across government. In brief, the NDP considers the NSI as a vital means for improving the quality of life and improving economic competitiveness. It emphasises continuous learning, partnerships, networks, coordination and coherence as essential for economic growth. Of utmost importance is collaboration among government, business and industry, research institutions, including science councils and universities, as well as the public at large.

Any recommendations to re-energise the NSI cannot be seen in isolation from the NDP, and innovation actually becomes a key enabler for many of its elements. The government's acceptance of the NDP as the blueprint for the country over the next 20 years presents a unique opportunity to reposition the NSI by communicating correctly the significance of innovation and why it is important for the nation's future.

The goals of the NDP underscore the World Bank conception of innovation through its emphasis on the need for the NSI to serve the needs of society. The key issue for developing countries is to strike the right balance between using and attracting existing technology and knowledge, and adapting these to the local context, while simultaneously pursuing focused research and development, including that which is regarded as 'frontier technology', in domains where there is local advantage.

Government has an important role to play in fostering a climate in which innovation will flourish. There are five actions that governments can typically take to contribute towards a well-functioning innovation system. These are:

1. *Setting the framework conditions*: macro-economic stability; regulation; mechanisms for prioritisation, agenda setting and coordination; maintenance of a standards regime; protection of intellectual property rights; direct and indirect funding incentives.
2. *Ensuring the supply and mobility of knowledge workers*: human resource development; immigration law; networking mechanisms.
3. *Promoting knowledge exchange*: mechanisms for knowledge exchange and technology transfer including codified and tacit knowledge, and mobility.
4. *Providing knowledge infrastructure*: public research organisations; provision of scientific and technological services; provision of research and communication infrastructure.
5. *Engaging in policy learning:* measurement, monitoring and evaluation; impact assessment; foresight study; utilising evidence-based decision-making; consensus conferencing.

Inputs considered in the Report are human capital inputs, both at the school and higher education level, and financial inputs in terms of GERD, as well as R&D expenditure.

The South African school system features in the NDP as in the previous reviews as a major constraint to a vibrant NSI. In terms of performance, there is a high-achieving core and a large periphery of underperforming schools. Performance on international tests reveals that while the TIMSS score has increased since 2003, it is still much lower than international levels. More concerning is that even the best-resourced schools only perform at the international average, and furthermore, that South Africa is ranked in the bottom three of 45 countries that participated in the survey. Learner participation in school falls off sharply after Grade 10, reflecting government policy of compulsory schooling to age 15 and the point where learners may enter the labour market at age 16.

South Africa spends 6% of GDP on education, the 38th highest in the world. There has been a large injection of funds into the teaching profession to raise certification levels. By 2010, over 67% of teachers had a four-year teaching qualification (increased from 25% in 1998). Yet teacher qualifications are still below international norms; only 60% of South African mathematics teachers have degrees (international average is 87%) and only 53% of South African science teachers have degrees (international average is 90%).

It is clear that the poor state of school education limits the potential of tertiary education. Such matters cannot fall outside the discussion of a NSI as the future ability to compete in a global knowledge-based world is steadily being eroded.

At the higher education level, the proportion of STEM enrolments and graduates (all levels) has remained steady at approximately 25% over the 2007 to 2011 period. There has been significant growth in the proportion of African students (including those from Africa) who now comprise 58.3% of STEM graduates.

Access to higher education still reflects the historical legacy of apartheid. In 2009, students' participation designated as 'white' was 56.9%, 'Indian' 44.9%, 'coloured' 14.8% and 'African' 13.3%. Overall progression rates are problematic: of the 120 000 students who enrolled in 2000, 50% dropped out and only 11% graduated in three years.

There were about 17 000 permanent staff members at universities in 2011. Of these, 35% had doctoral degrees compared with the NDP target of 70% (for 2030). Staff levels have not kept pace with the growth in student enrolment and the number of 'science workers' in general has declined since 2004.

Technical and vocational education has been seriously neglected in policy frameworks; a total of 13 500 artisans graduated in 1985 compared with 2 548 in 2004. There has also been a shift from engineering fields to service-related fields. The challenge now is to attract working-age persons to upgrade their skills, as opposed to the FET colleges acting as conduits for school leavers.

Universities have played a crucial role in developing resources but the outputs are more supply-driven rather than demand-driven. This has resulted in the production of a pool of human resources not adequately matched to the requirements of the NSI. The higher education sector would need to conduct a foresight study to determine the current and future skills required by business and society to inform their curricula, and teaching and learning. The universities of technology have an important task in linking technology development and diffusion and supply the required human resources with requisite skills for industry and private business such as SMEs.

Turning to financial inputs, the GERD:GDP ratio hovers around the 0.87 level, well below the target of 1.0. In 2009/10, R&D expenditure was: business (including state-owned entities) 54.1%; government, 21.6%; and higher education, 24.3%. This profile is similar to that of France, Germany and Eastern Europe. If state-owned entities are excluded, then the business sector proportion drops to 40%, producing a profile similar to that of Brazil and Argentina. There has been a steady increase in foreign funds for R&D. Of this, 60% (R 1.5 billion) goes to the business sector.

The DST's contribution to the system has increased from R 1.149 billion (current Rands) in 2005 to R3.430 billion in 2009, an annual compound growth rate of 130%.

The number of FTE researchers in the higher education sector has barely changed from 1991/92 to 2009/10, hovering around 3 600. In the business sector, FTE researchers peaked at 6 663 in 2007/08 and declined since. The FTE doctoral students have tripled in 17 years, but the number obtaining doctorates has only doubled. The FTE for technicians has remained static.

In terms of research outputs, the publication count has increased nearly three-fold over the period 1990 to 2012. Since 2003, there has been a sharp increase of 140%. This trend has occurred despite the fact that there has been no appreciable increase in FTE researchers.

The publication count with foreign co-authors has risen from 15% of the total (in 1990) to above 50% in 2011. South Africa's share of world total publications has fallen from 0.42% to 0.36% over the period 1995 to 2009, reflecting the dramatically increased contribution of countries such as Brazil, India and China. Major research collaborating countries are the US, followed by the UK, and then some way behind, a cluster comprising France, Germany and the Netherlands, all at similar levels.

Four research areas (infectious diseases; public environmental and occupational health; immunology; and virology) have shown dramatic increases in publication counts. There has been a swing away from research in clinical medicine to infectious diseases, with the decline in clinical medicine being attributed to the downscaling of provincial support for research in academic teaching hospitals i.e. directly related to this area of government intervention. The increase in research in infectious diseases research, on the other hand, cannot be attributed to government policy as the shift took place at the time of the government's HIV/AIDS causation debacle; it is rather related to the availability of funding from international donors.

The universities are the major producers of research, followed by the science councils, then the national facilities, with industry falling far behind.

There is a problem of reliable data when considering innovation outputs, implying that the real level of patenting is probably higher than the statistics show. The number of South African patents registered has increased over time, despite a slippage in international rankings, due to a relatively greater increase in the Far East and China. The fields of civil engineering, materials and chemical engineering are dominant in patents registered.

There are some salutary lessons from Malaysia. In the 1970s, South Africa was far ahead of Malaysia in terms of GDP/capita and scientific output. Today, Malaysia's GDP/capita is 50% greater than South Africa's and its exports comprise amongst the highest proportion of high technology products globally. Key lessons are government investment in high-quality education, especially mathematics and science, and focused support of industry.

The receipts for South African technology abroad are very low when compared with those of other industrialised countries, which is puzzling given the large expansion in trading abroad. There is also a large gap between payments for technology from abroad and receipts. The technology balance of payments gap is not significant if the imported technology is put to good use and creates jobs, as is the case with the Automotive Industries Development Programme (AIDP). However, the gap may be significant if it denies tax income to the fiscus.

In terms of the registration of plant cultivars, South Africa is amongst the 15 most prolific countries globally. These measures represent some of the many indicators commonly used and cited in the Report. It is acceptable to assess the status of S&T in South Africa in terms of PhD numbers, publication counts, citations, patents, etc. but there is a need to go beyond these measures. The outputs need to be considered in terms of their relevance to the NSI goals. The views of employers on the quality of knowledge workers and graduates produced by our education system need to be assessed. There is a need to measure the value of the investment in innovation-related processes and the returns. Finally, and perhaps most importantly, the country needs to have indicators that relate to the imperatives of the NDP.

Four key elements of a successful NSI were listed. They are:

Governance
The NSI has not had an adequate level and structure of governance from the outset. Initially the structure focused only on S&T, and later the New Strategic Management Model was largely dysfunctional. The OECD Review (2007) made many pertinent observations, one of which was that there was a lack of understanding of the broader concept of innovation. This is explicable as there was no cross-cutting and authoritative voice communicating a unified vision across government, and to other actors. The NSI was essentially 'pilotless'. This critique was mirrored in the Ministerial Review report. In response to the Ministerial Review report recommendations on NCRI, DST organised a STI Summit attended by the Deputy President and representatives of other ministries responsible for sub-sets of the NSI, and research and business leaders.

Interactions between NSI actors
Collaboration, sharing and interaction are key characteristics of an innovating country. Most of the case studies reveal that even when the research offers commercial potential, the success rate is limited by factors linked to the interrelationships between the participants in the process. Whether this breakdown results from a lack of entrepreneurial or business skills, internal competition as opposed to collaboration, or misalignment with markets, if these aspects are not understood and improvements made, the NSI will struggle to achieve the goals originally set.

Openness to the world
Mobility, expressed as 'brain circulation', is a vital aspect of innovation activity. Laws and regulations that needlessly impede these flows are counter-productive.

Demand-driven
There is a new emphasis on demand-side policies giving rise to the need to understand how these policies will benefit South Africa and how they should be implemented.

Turning to the strengths and weaknesses of the NSI, a number of local and international assessments of the NSI reveal some causes for concern, both in terms of interpretation of data, the message that is conveyed and our international competitiveness. The South African Innovation Survey (2008) paints a positive picture, showing South Africa to have a higher percentage of 'innovation activity' than countries such as Denmark, Sweden and the United Kingdom. However, of this activity, only 27.3% had successful innovations. The indication that South African companies are highly innovative does not appear to have translated into growth in the relevant sectors. International benchmarking studies reveal some major shortcomings and causes for concern.

It is important to restate the findings of the Global Competeveness Report 2012 – 2013 which ranked South Africa 52nd out of 144 countries and has remained close to this position for some years. South Africa is ranked as an 'efficiency-driven economy'. Factors which demonstrated high competitiveness are Financial Market Development (rated 3), Market Size (rated 25) and Goods Market Efficiency (rated 32). At the negative end, the Health and Primary Education (rated 132) and Labour Market Efficiency (rated 113) are most obvious. Under the Higher Education and Training pillar, it is noteworthy that South Africa is rated 143 for the "Quality of Mathematics and Science Education" and 140 for the "Quality of the Education System".
In the categories for the Innovation-driven Economy, South Africa has a number of positive measures, but certain others stand out, e.g. Nature of Competitive Advantage (rated 107), Value Chain Breadth (rated 106), Government Procurement of Advanced Technology Products (rated 105) and Availability of Scientists and Engineers (rated 122). The report lists the "most problematic factors for doing business" in South Africa, with the top five being:

- Inadequately educated workforce
- Restrictive labour practices
- Inefficient government bureaucracy
- Inadequate supply of infrastructure
- Corruption

Such aspects, although not directly part of the NSI, are all important factors in the eco-system. Thus the influence is inseparable. Likewise, the NDP has specific actions needed to improve these factors and again reinforces the inextricable linkages between this plan and the NSI. The result is that South Africa is classified as an underperformer based on the GII and GDP.

While international benchmarking studies are useful and illuminating, they do not reflect deeply enough on the critical relationship issues and success factors. They are thus useful, but insufficient to address the further development of an NSI. What is missing is interactive learning as part of our NSI. There have been too few open in-depth studies and reviews of the projects and programmes supported by the many instruments that have been initiated by government to enable the innovation system. Such studies are often seen as an audit where the emphasis seems to be on finding deficiencies, instead of being aimed at generating learning and improvements. There is also a need to review case studies of selected projects with special emphasis on issues that determined success or failure. The value of such studies is underestimated since they are central to providing guidance in support of the NSI.

South Africa has also benefited from participation in the OECD Review processes and has become exposed to international trends. The OECD Review made a number of significant recommendations that should have been taken into account through extensive debate in the NSI with all the actors, but again this critical opportunity was largely missed, but should be regained.

There is a critical element that is missing in all the debates and findings of committees, including the most recent Ministerial Review Committee report, and that is the lack of good evidence of the performance of the various instruments that have been established to serve the NSI. This relates back to Lundvall's description of an NSI that stresses interactive learning. The key question is how to develop a new strategy without a properly considered history? To date, there has been a very limited amount of what is considered direct learning from the experience. There is also a need to have a dedicated institution that would serve as a national archive for such NSI historic data for learning purpose.

Each and every review of the NSI has identified the poor engagement with private sector business as one of the serious failings in implementing the NSI model. This is particularly true of the SME. The Ministerial Review report recommended "systemic efforts to bring business and government together" and that government departments involved in research and innovation should employ staff with business skills to improve communication. Likewise, the previous OECD report in 2007 had also highlighted the same deficiency but made no specific recommendations.

In order to gain a full perspective of the actors in the NSI, their alignment with national priorities and the extent of active innovation value chains, much information needs to be gathered and summarised to understand where the gaps in the processes are and how these can be improved.

Discussions with key industry sectors will provide information on needs and future requirements for technology transfer, research and development priorities, and human resource development. These needs can be discussed with the relevant actors in universities, agencies and public research labs to build connections, based on what are considered to be appropriate responses locally or through international acquisition.

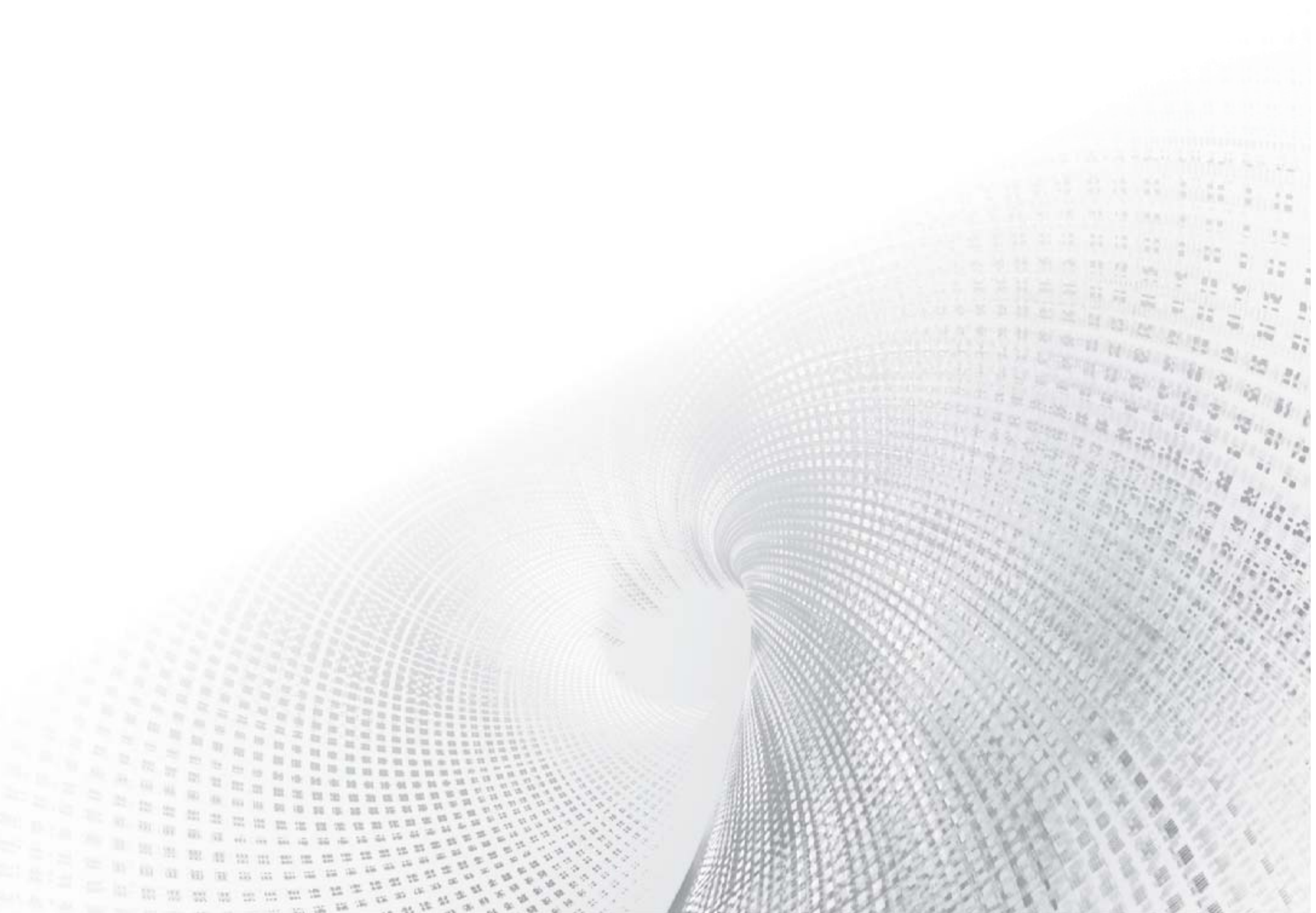
There is an embryonic regional innovation system in South Africa. Various regions and provinces have started to define their own approaches to innovation strategies. These 'bottom-up' initiatives need to be harmonised and incorporated into the NSI. Regional systems are key building blocks of the national system.

The presence of clusters, e.g. the wine industry in the Western Cape, is most likely to be regional. International experience has shown that there are often higher abilities to innovate in industry clusters due to the concentration of complementary competences, specialised services providers and enhanced technology and market knowledge. Such clusters often link to local tertiary education institutions and develop relevant research capabilities.

To date, DST has supported the formation of Regional Innovation Forums, with variable success. However, this aspect has essentially been under-resourced and was never 'mainstream'. In re-vitalising the NSI, therefore, a robust regional innovation strategy will need to be developed and a suitable administrative model and funding defined. Such a structure will be a key to engaging and interacting with the various role players and should have neutrality to be able to facilitate across the spectrum of actors.
In conclusion, based on the key findings summarised above, a set of recommended actions for reinvigorating the NSI is made as follows:

1. The major message is simple: everything possible must be done to open the skills pipeline and ensure that quality emerges from it.
2. Regular studies of linkages among the NSI actors need to be undertaken to determine what improvements are needed for the system. There is a need for a careful review of the positioning and expectations of outputs of all the actors and institutions in terms of their optimum roles in serving the local system of innovation.
3. Mechanisms need to be put in place to enhance the selection and use of technology and knowledge that is globally available, in order to develop the capacity to utilise these for the most pressing social and economic needs.
4. A comprehensive and fully inclusive communications strategy for the NSI and its role in the NDP should be developed and implemented.
5. There is a need to integrate education and local research systems into the NSI approach to get the alignment, focus, societal support and the enhanced cohesive energy to meet the country's needs.
6. There is a need for coherent opportunities for 'lifelong learning' as the speed of change in technology and knowledge is so rapid that individuals need assistance to stay abreast.

7. There is a need to develop an augmented new set of output indicators that go beyond the traditional measures that will facilitate determination of the value of investment and link to the goals of the NDP.
8. Scoping studies of priority sectors (e.g. those identified in the NDP, the IPAP of the dti, etc.) and, in particular, the knowledge-based sectors, such as ICT, biotechnology, pharmaceuticals and health, should be carried out to identify large and small business contributors and the related industry associations in each case.
9. Reviews must be conducted of policies and instruments to determine their effectiveness and to suggest enhancements or changes that should be made. The reviews should be placed in the public domain to canvas further input and formulation of recommendations.
10. In re-establishing the NSI, Regional Innovation Forums should be supported and strengthened. An assessment should be carried out, by region, of the regional determinants and the active linkages.



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