Towards a Next-Generation Science, Technology and Innovation White Paper for South Africa

NATIONAL ADVISORY COUNCIL ON INNOVATION

Performance Analysis

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Executive Summary

This Performance Analysis contributes to the formulation of the intended White Paper on Science, Technology and Innovation (STI). It should be read in conjunction with the separate Situational Analysis.
The Performance Analysis seeks to:

> Conduct analysis of the performance of the NSI since 1994, paying special attention to framework conditions such as policies (including the National Research and Development Strategy (NRDS) and the Ten-Year Innovation Plan (TYIP)), policy initiatives and incentives, knowledge linkages, the development and retention of knowledge workers, legacy issues (class, race, gender, exclusion, inequalities, etc.), effectiveness, impact and outcomes of policy implementation (including any unintended consequences). The concepts of "innovation", a "national system of innovation", and "science and technology for development" from the 1996 White Paper should be reviewed. A clear sense should be provided of what worked, what should be carried forward into the new White Paper and decadal plan, and what should be stopped. Strengths and weaknesses should be identified.

A high-level methodology is used which seeks to address the task through two interrelated lenses: one quantitative, and the second a qualitative approach that surfaces the theory of change (ToC) implicit in the policy and implementation instruments that have been deployed to shape the National System of Innovation (NSI). Where possible, these policy instruments are evaluated against their own stated objectives, indicators and targets.

In the main, the study draws upon secondary sources. By its very nature, such a task conducted over a short time period will not draw upon extensive primary research. However, discussions were also held with expert peers, and stakeholders, Department of Science and Technology (DST) officials, the National Advisory Council on Innovation (NACI) Council, NACI Task Team and NACI Secretariat, the White Paper Reference Group, and the community of practice of innovation studies practitioners. In addition, quantitative data have been generated specifically for the analysis, especially the analysis of the R&D Strategy and the TYIP. Expert judgement is declared in the work and evaluative comment is supported by confirmatory evidence.

Two important understandings guide the analysis, first that innovation involves a wide range of activities, including R&D, with constructive interactions among the various sectors and actors essential to the innovation process. Secondly, the contemporary definition of innovation is followed, as explicated in the 2005 Organization for Economic Cooperation and Development (OECD) *Oslo Manual*.

The analysis commences with a depiction of South Africa's current reality arguing that structural features of the pre-1994 period remain, especially the dominance of the minerals-energy-financial services sectors, and the essentially extractive nature of the economy. The economy is now more open but there are high barriers to entry for new players into the domestic economy, and inequality and underemployment remain high. The decline in manufacturing and the growth of the services sector, largely driven by short-lived public sector expansion, have placed a premium on post-school qualifications.

The next section examines the assumptions that guided the formulation of the national system of innovation as set out in the White Paper. It is argued that the White Paper definition of innovation is narrower than the technological, product and process (TPP) approach that was in vogue at that time. Instead, it accords a privileged role to basic and applied research whereas TPP focuses on technological innovation. On the other hand, its intent is broader with a stress on socio-economic development. This amounted to the declaration of a new contract between science and society in place of that of the apartheid years which can be described as a combination of 'own' science and science in the service of the State. In its own terms, the White Paper sets out to combine science and technology (S&T) for competitiveness alongside S&T for all.

The starting point for the quantitative assessment is to examine funding for innovation activities. This is followed by a discussion of the talent dimension, after which system outputs are assessed in detail.

Innovation is found to be primarily incremental and adaptive, a feature common to emerging economies. Patenting activity has increased marginally, especially through new entrants such as higher education and foreign companies. Plant cultivar registrations remain a core strength, but there is a worrying reduction in absolute volume. From 2007/08, Gross Expenditure on R&D (GERD) to Gross Domestic Product (GDP) ratio declined and now stands at 0,73%. The decline was not primarily due to the migration of industrial R&D abroad. Within GERD, there is a clear shift toward basic research, a decline in manufacturing-oriented research, with health and social science research expenditure rising sharply.

In the state sector, there have been strong gains in the representivity of the highly skilled workforce, but the total researcher complement has remained static, pointing to a replacement, rather than a growth strategy.

Regarding scientific outputs, the high-level appraisal is that whole count, and fractional counts have risen alongside increased international co-authorship. The most cited papers are strongly clustered in astronomy/astrophysics and infectious diseases, reflecting mega science involvement and attempts to address the HIV/AIDS and TB burden of disease. Except for bibliometric analysis of co-authorship, system linkages enjoy little coverage in the research literature. Data on student and staff mobility are generally unavailable. A brief comparative analysis of South African S&T within the five BRICS countries (Brazil, Russia, India, China and South Africa) suggests that the country is holding its own.

The quantitative evidence speaks of a system under construction and finding its way, with pockets of excellence alongside areas of lower prominence. Competitive science has been maintained and built, and the shift toward socially relevant research suggests that this goal of the White Paper is being addressed.

As to innovation more broadly, there is growth in university patent awards and trademarking, and plant cultivar registrations remain at high levels. The number of degrees awarded to African students has shown a phenomenal increase, and significant demographic shifts are occurring, though output is still short of employment equity goals.

The historic debt of South Africa to its Southern African Development Community (SADC) hinterland is being repaid many times over through the training of students and academics in South Africa's excellent universities. The qualitative assessment enquires into the ToC that informs the various instruments that have been deployed since 1994, beginning with White Paper implementation which saw the introduction of a range of policy processes and instruments, as well as new organizations and organizational enhancements involving considerable policy experimentation and learning. In a narrow sense, and in agreement with the NACI review, these represent the fulfilment of the White Paper goals. The next consideration is the system intelligence capacity in which significant gaps have been noted, especially insofar as external evaluation and follow through are concerned.

As to the matter of 'system steerage,' it is argued that the R&D Strategy represents a linear model approach to innovation that perpetuates supply side rather than demand-side thinking. This thinking is embedded in the subsequent TYIP and is replicated in the approaches of the NACI and Technology Innovation Agency

(TIA). By implication, this is soft on steerage. Implementation of the R&D Strategy is most apparent in the rearrangement of the organizational landscape, the introduction of new incentives for research, and the provision of R&D infrastructure. As to innovation outputs, it is difficult to attribute changes in such to the Strategy that was not accompanied by a blueprint, perhaps reflecting the distributed, autonomous and self-organizing nature of the innovation system.

Turning next to the TYIP, attainment of its stretch targets was always going to be a challenge, and has been patchy with successes in space science and technology and participating in climate change science.
On system learning, the recommendations of the OECD Review of 2007 were not adopted, as were the sentinel recommendations of the 2012 Ministerial Review. Nonetheless, certain recommendations have a varying extent of implementation, especially institutional and infrastructural matters and the sectoral innovation programme.

In terms of its ToC, a number of aspects of the R&D Strategy 'worked' as did those attributed to the TYIP. These include the organizational changes involving the Council for Scientific and Industrial Research (CSIR), National Research Foundation (NRF), TIA, National Intellectual Property Management Office (NIPMO), South African Agency for Science and Technology Advancement (SAASTA), and South African National Space Agency (SANSA).

Other organizational innovations include the South African National Research Network (SANReN) rollout, the Microscopy Centre at Nelson Mandela Metropolitan University (NMMU), university centres of excellence and centres of competence, a pilot plant to produce a foot and mouth disease vaccine. It also includes facilities such as the University of Cape Town's (UCT) Institute of Infectious Disease and Molecular Medicine (IIDMM), the Doris Duke Medical Research Institute (DDMRI) at the University of KwaZulu-Natal (UKZN), the Wits Reproductive Health and HIV Institute, the Southern African Large Telescope (SALT), and the Karoo Array Telescope (KAT-7), now known as MeerKAT.

The qualitative assessment further emphasizes the dearth of external evaluation studies. Alongside this is the considerable resource of science advice that resides within the broad science community and that is available on call to government.

The thread linking White Paper, R&D Strategy and TYIP is the translation of R&D into commercializable products through a linear model of innovation. This success has been much less in evidence than intended, despite the R&D Tax incentive and the Intellectual Property from Publicly Financed Research and Development (IPPFRD) Act. On the other hand, the research base provided through Flagship science has prospered in the form of palaeontology, astronomy, mathematics and theoretical physics projects. Health science has prospered with very strong international links to governmental and multilateral donors and philanthropies.

The White Paper set out a social contract that promoted science excellence and science and technology for all. In the event the resulting policy mix was largely focused on excellence through instruments that largely support 'own science.' Strong support was given to the mega-science projects for commercial and scientific-cultural reasons.
If sustaining curiosity led research was the overarching goal of the White Paper, then the policy mix was appropriate to that end. On the other hand, if the NSI goals were innovation, economic growth and reduction in unemployment, then both the public and private sectors were less than successful.

What then is the summative view? Is the NSI glass half full or half empty? The answer is that the glass is

perhaps half full, but there exists a clear and present danger that the contents of the glass may stagnate. This is to be situated in the context of an economy that has pockets of wealth in a sea of poverty, and that is underperforming against a host of measures. The NSI must reflect the milieu in which it functions.
The contract between science and society is largely a continuation of the pre-1994 accommodation, even as the National Development Plan (NDP) calls for a new social contract. Without this, the goal of coordination will remain illusory with linear model thinking continuing to inform policy.

The performance analysis debunks the claim that the research for the social sciences and humanities is underfunded, and the social sciences and humanities revealed comparative advantage (RCA) is high, though of moderate impact. A vibrant social entrepreneurship sector is taking form, but the NSI is too small to meet many urgent tasks, is losing institutional memory and capacity, and rare exceptions aside, much research is individual rather than group focused and sub-optimal in size. Urgent steps are needed to enhance science, technology, engineering and mathematics (STEM) education, and immigration regulations must be amended for the recruitment and retention of the highly skilled.

System learning must become more nimble, with careful attention given both to *ex-ante* regulatory impact analysis and *post hoc* impact evaluation.

In closing, one returns to the future. The Anthropocene era and the 4th Industrial Revolution will impact decisively on the meaning of work, leisure, and longevity in ways that are difficult to appreciate and comprehend. In other words, we don’t know what we don’t know and, without foresight capacity, we shall not know.

1. Introduction

This Performance Analysis contributes to the formulation of the intended White Paper on Science, Technology and Innovation (STI). As detailed in the Terms of Reference (b), its specific task is to:

(a) Critically engage with the 2016 White Paper Review.

(b) Conduct analysis of the performance of the NSI since 1994, paying special attention to framework conditions such as policies (including the National Research and Development Strategy (NRDS) and the Ten-Year Innovation Plan (TYIP)), policy initiatives and incentives, knowledge linkages, the development and retention of knowledge workers, legacy issues (class, race, gender, exclusion, inequalities, etc.), effectiveness, impact and outcomes of policy implementation (including any unintended consequences). The concepts of "innovation", a "national system of innovation", and "science and technology for development" from the 1996 White Paper should be reviewed. A clear sense should be provided of what worked, what should be carried forward into the new White Paper and decadal plan, and what should be stopped. Strengths and weaknesses should be identified.

(c) Conduct a situational analysis of the contemporary conjuncture, identifying local and global trends that influence society, the productive sector, and the conduct of STI, taking into consideration BRICS, the International Panel on Climate Change, the Sustainable Development Goals, the African Union Agenda 2063, and the National Development Plan Vision 2030, among others. Techno-economic trajectories and socio-technical transition literatures should also be covered.

(d) Use (primarily) existing data, information and knowledge. If they consider it vital, the experts may negotiate with the NACI Secretariat about the possibility of commissioning other essential primary research.

(e) Draw on and take into consideration the recommendations of the White Paper, the research and technology foresight exercise done in the 1990s, NRDS, the 2007 Organisation of Economic Cooperation and Development Review of the NSI, the TYIP, the Ministerial Review Committee on the STI Landscape in South Africa, current foresight studies, the Institutional Landscape Review currently under way, and other relevant studies and assessments of the system.

(f) Conduct a broad range of stakeholder and role player workshops.

Essentially, the Performance Analysis must answer three questions as contemplated above, namely, what worked, what should be carried forward, and what should be stopped. As with all policy analysis, the problem of bounded rationality is recognized. This means that there are limits to the amount and quality of information available to an investigator, that an investigator cannot fully process and evaluate all information sources, and that there are natural time constraints.

Two viewpoints guide the analysis, firstly that innovation involves a range of activities, including information exchange, reverse engineering, constructing prototypes, organizational learning, protection of intellectual property, R&D, study tours, acquisition of new technologies, and staff training. Learning from others, and by doing, using, and interacting are all essential to the process. Secondly, the contemporary definition of innovation is wider than that of the White Paper and involves the introduction of new or significantly improved products, processes and organizational changes into a market or organization.[1] This definition allows for both technological and non-technological changes, and does not favour R&D *per se.*

1 OECD 2005. *Oslo Manual*, 3rd Edition. Paris, OECD.

Providing the required answers is no small task, and an appropriate high-level methodology is therefore utilized. This is structured through two interrelated lenses. The first lens provides a comparative performance assessment using quantitative sources; the second lens follows a qualitative approach to surface the ToC implicit in the various policy and implementation instruments that have been deployed to shape the NSI since 1994. ToC is premised on the understanding that 'social change processes are complex and unpredictable, that different perspectives exist on what needs to change and why, and that a full analysis of the context of a change intervention and of the assumptions underlying its design are crucial to enhance its chance of success' (Van Es et al., 2015: 13).

Where possible the policy instruments that were designed to shape the new NSI are evaluated against their own stated objectives, indicators and targets.

In the main the study draws upon secondary sources, both quantitative and qualitative, and queries relevant databases such as bibliographic and intellectual property repositories. Discussions were held with expert peers, and stakeholders, DST officials, the NACI Council, NACI Task Team and NACI Secretariat, the White Paper Reference Group, and the community of practice of innovation studies practitioners. The investigators might be characterized as expert insider/outsiders who have worked in the system, as well as studied it as external independent analyst. Where appropriate, expert judgement is declared in the work, and evaluative comment is supported with confirmatory evidence.

A task of this nature, conducted over a short time period, will by its very nature not draw upon extensive primary research. Even so, various elements of quantitative data have been generated specifically for the analysis. In addition the analysis of the two key policy instruments, the R&D Strategy and the TYIP, represents a first such study.

The Performance Analysis is to be read as a standalone document. Its structure is as follows. After the Introduction, Chapter 2.0 provides a sketch of the current reality. Then follows 'Science and Technology for All,' a critical discussion of the goals of the White Paper. The next two chapters address the question 'What worked?' with Chapter 4.0 presenting the quantitative analysis, comparing metrics for finance, personnel, outputs and linkages of the system over a two-decade period. Chapter 5.0 takes the qualitative view, surfacing the ToC implicit in the major policy instruments and then analyses system intelligence, steerage, and learning. This leads to the critique of Chapter 6.0 that provides the synthetic overview and probes deeper into the reasons why the system has assumed its present shape. Suggestions are offered as to what should be carried forward, and what should be stopped.

2. Current Reality

Before commencing on the quantitative assessment, it is necessary first to situate the work in the current reality of South Africa. Without belabouring the point, post-apartheid South Africa retains characteristics of the pre-1994 period, notably the extractive nature of its political and economic institutions (Acemoglu and Robinson, 2012).

Extractive institutions serve the interests of small interest groups that appropriate power and wealth. Apartheid is a classic case of extractive behaviours.

The 1996 Constitution set out to build an inclusive society, but the country is merely one generation into that project. The data presented in Table 1 provides insights into this current reality.

Table 1: Socio-Economic-Environmental indicators, 2015

GDP ($PPP) billion (Rank)	723 (31)
Population (million) (Rank)	54 (26)
Population living in absolute poverty (million)	10.2
Human Development Index (HDI) (Rank)	0.67 (123)
Life expectancy at birth, years	63.1
Gender development index (Group)	0.948(3)
Household access to potable water %	93
Household access to electricity %	66.9
Employment/population (>15 years) %	39.2
Gini Coefficient	0.65
Palma Ratio	8.0
Democracy index: value; rank	7.56; (37)
Services component of GDP (%)	66
Offshore revenue of the Johannesburg Securities Exchange (JSE) Top 40 (%)	>40%
Foreign ownership of JSE Top 40	>40%
Doing business index (Rank)	64.9; (73)
Global Creativity Index (Rank)	0.56 (39)
Global Competitiveness Index (GCI) (Rank)	56
Exports and imports as % GDP	64.2
Open Market Index (Rank)	3.2 (50)
Mobile users/100	149.7
Internet access (%), (Rank)	49; (80)
Broadband penetration %; (Rank)	3.2 (102)
Fossil fuels/total (%)	87.2
Carbon dioxide emission per capita (tons); (Rank)	9.3; (13)
NOx level; (Rank)	21149; (30)

Sources: World Bank; StatsSA; WEF; JSE; CIA World Factbook; UNDP; Martin Institute, Economist Intelligence Unit.

Widespread poverty, unemployment and inequality remain, as attested by the low Human Development Index (HDI), high-income Gini coefficient and extreme Palma ratio. Hardship is partially mitigated by the provision of free electricity, potable water, primary health care, free education and social grants.

The economy is open, with foreign fund managers active on the JSE. Large domestic firms dominate the formal sector as are transnational corporations which earn significant income in foreign markets. Firms move abroad to grasp opportunities of globalization and to avoid burdensome regulations as reflected in the low score for Doing Business. The decline in manufacturing and the growth of the services sector, largely driven by short-lived public sector expansion, have placed a premium on post-school qualifications.

Two indicators that most closely reflect innovation performance are the Global Competitiveness Index (GCI) at rank 56, and the Global Creativity Index at rank 39, but inadequate ICT access (and high costs) limit innovation activities.

Lastly are environmental indicators that reflect the heavy dependence on fossil fuels with consequently high carbon footprint and nitrous oxides emissions. These industries are concentrated in the north of the country so that local intensities are very high.

Large conglomerates straddle an economy that is also host to some 2.25 million Small, Medium and Micro-sized Enterprises (SMMEs), of which fully 70% are in the informal sector, with 88% being black-owned. This is the legacy of apartheid that denied trading opportunities to the African majority. Most of these owners also have incomplete schooling (Bureau for Economic Research (BER), 2016). These exigencies demand innovative policies for more inclusive development.

Positive developments include access to electricity and potable water, the attainment of Millennium Development Goal (MDG) 5 to eliminate extreme poverty, more inclusive political institutions, progress on Even so, much remains to be done, and it this more inclusive and equitable society that the 1996 White Paper set out to enable.

3. Science and Technology for All

The White Paper set out to construct a framework that would support a well-managed and properly functioning NSI, making it possible for all South Africans to enjoy the economic, socio-political and intellectual benefits of S&T. That framework includes a host of policy instruments and organizations that would contribute to the goal of harnessing S&T to national development. As the Review of the White Paper states, that framework remains central to the orientation of the DST.[2]

The framework declared three goals: improvement in the quality of life; participation in a competitive economy by means of satisfying employment; and the promotion of democratic culture. This called for an efficient, well-co-ordinated and integrated system of technological and social innovation, the NSI. At this point it is essential to foreground the White Paper definition of innovation, and what it meant by an NSI. The White Paper defined innovation to be:

> the continuous production of new knowledge and its creative applications in a number of spheres (in which) the promotion of research, both applied and basic, in the natural sciences and in the social sciences, is crucial to innovation and hence to both social and economic development.

The NSI was understood to comprise of:

> 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.

It is necessary to interrogate the utility of these definitions that were formulated at the time of the first OECD and Eurostat innovation surveys that were based on the assumptions of technological, product and process (TPP) innovation.

Fundamentally the White Paper definition of innovation is narrower than the TPP approach in it accords a privileged role to basic and applied research. By contrast, TPP only considers technological innovation.

As to its definition of the NSI, the White Paper shares the OECD and Eurostat stress on the necessity of interactions but does not speak directly to knowledge creation, diffusion and application. A system model implies that actions, inputs, feedback loops outputs, outcomes and impacts operate within specified boundaries. Outputs and outcomes arise from the rational actions of those engaging in innovation activities. Impacts are more difficult to track due to the problem of attribution across multiple actions.

Unlike the OECD and Eurostat, emphasis on social-economic development is found in the White Paper definitions of innovation and the NSI. Arguably, the above distinctions and emphases necessarily inform subsequent development of policy and practice.

The White Paper next considered the essential functions that NSI actors would have to fulfil, delineating two functions exclusive to government, and four to be shared (Box 1).

2 NACI (2016) offers a Review of the White Paper. In the main this performance analysis agrees with its interpretation of the available data, but there are some cases where there is a difference, as for example in explaining certain trends (c.f. §2.2.3), the meaning of 'allocation' in the text (c.f. §2.3) and budgets (c.f. §5.1.2). The Performance Analysis probes further than the Review on the issues of interests, the persistence of science push, and coordination failure.

Box 1: Essential NSI functions and responsibilities

Government

- Policy formulation and resource allocation at the national level
- Regulatory policy-making

Shared

- Performance-level financing of innovation-related activities
- Performance of innovation-related activities
- Human resource development and capacity building and
- The provision of infrastructure.

For the purposes of this analysis, the NSI actors are: Higher Education Institutions (HEIs), post-school institutions; Science Councils (SCs); Department-Based Research Institutions (DBRIs); research entities within State-owned Enterprises (SoEs), statutory bodies (e.g., the National Health Laboratory Service (NHLS)); the scientific divisions of museums; businesses (BUS); and not-for-profit organizations (NPOs). This set includes market-oriented and non-market facing actors.

As presently constituted, civil society and the informal sector are rarely involved as actors in innovation system planning, tending to be placed in the role of beneficiaries. A rare exception to this is the work of the Treatment Action Campaign, an NPO that emerged in the struggle to address the HIV pandemic, and that is now the fourth component of a quadruple helix.

The NSI actors operate in concert with intermediary organizations including, but not limited to providers of scientific and technical services, regulators, technology brokers, learned societies, professional and industry associations.

All actors exercise unique and overlapping roles with distinct spans of influence and control, and are subject to the temporal, regulatory and spatial boundaries of the system.

Implicit in the above is the existence and nature of an implied contract between science and society. The White Paper and preceding policy formulation processes such as the IDRC/MDM Review and the S&T Initiative were at pains to speak to the perceived divide between science and society. Specific recognition was given to the importance of supporting the 'Republic of Science' (Polanyi, 1967) and the role of science in righting the wrongs of the past. A view shared by many of those involved in these processes was that the pre-1994 system combined 'own' science alongside science in the service of the State.[3] For its part, the White Paper set out to combine S&T for competitiveness alongside S&T for all.

The above provides the background against which the question 'what has worked' must be answered.

The first answers to this question come from the quantitative assessment. The assessment of performance is structured around the core attributes that characterize a functioning innovation system, namely enabling conditions including policy, regulation and financing, the provision of knowledge workers, knowledge linkages and knowledge production, knowledge infrastructure, and mechanisms for reflection and policy learning. These core attributes echo the functions as laid out in Box 1 above.

3 Basson (1996) describes two lines of research in the pre-1990 CSIR: personal versus security and weapons research. See also Rothschild (1972) and Kahn (2013; 2016) on accountability of publicly funded research.

4. Quantitative Assessment

Performance information regarding the NSI is generated through a range of performance measurement tools including the:

- Survey of the Inputs to Research and Experimental Development (Annual)
- Innovation Survey (1999/2000; 2002/2004; 2005/2007; 2008/2010)
- Annual Reports (higher education institutions; science councils; listed companies; state-owned enterprises; NPOs)
- Higher Education Management Information System (HEMIS)
- External evaluations
- External Reviews
- Statistics SA (StatsSA), SA Reserve Bank, World Bank, UN System, Eurostat, OECD, multilateral organizations, World Economic Forum, and the Institut Européen d'Administration des Affaires [the European Institute of Business Administration (INSEAD)]
- Contributions to the literature from academic and other professional sources.
-

These measurement tools are constructed each according to their own logic and primary needs. The R&D Surveys follow the *Frascati Manual* (OECD, 2015), the Innovation Surveys, the *Oslo Manual* (OECD, 2005), the SA Reserve Bank accords with the System of National Accounts, and so on.

4.1 Financing innovation

Financial resources have a major influence on the actions, roles and responsibilities of the NSI actors. Innovation activities (as defined earlier) are financed directly by the business sector drawing on own resources, loan and equity financing, and by the State through the Industrial Development Corporation, Public Investment Corporation, Land Bank, Department of Trade and Industry (dti), Economic Development Department (EDD), DST, Department of Higher Education and Training (DHET), the National Empowerment Fund, National Lottery, and others such as international donors. These funds are not quantified on a regular basis, so that the estimates of the occasional Innovation Survey will have to suffice, suggesting a quantum in the order of R58 billion in 2007 (DST, 2011). An inflation-adjusted value for innovation activities in 2014 would be upwards of R100 billion. A second indicator of the resources going toward innovation activities is government expenditure on scientific and technological activities estimated at R33.2 billion for 2013/14 (DST, 2015a).

If one adopts a broader understanding of 'innovation' to include efforts at increasing market penetration, then large amounts of funding are available from government departments and statutory bodies. So the Industrial Development Corporation finances company expansion via new processes or their entry into new markets, and the dti offers a range of sector-specific incentives that support the series of Industrial Policy Action Plans (IPAP) (dti, 2010).

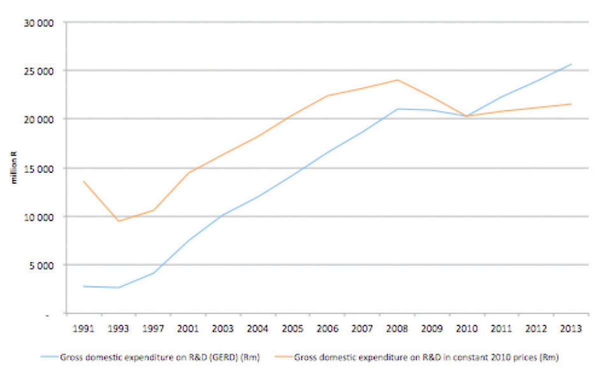
Private sector innovation funds are drawn from internal reserves, through loans or equity financing, and through the emerging venture capital sector. Since domestic firms hold large cash reserves, there is the potential for much more innovation activity than is presently the case. The reluctance to commit to investment has more to do with risk aversion than a lack of resources.[4]

The next step is to draw on the financial information provided by the Survey of Inputs to Research and Experimental Development (R&D Survey). The series of R&D Surveys goes back to 1968, acknowledging a

4 http://www.rdm.co.za/business/2016/11/15/government-and-business---where-did-it-all-go-wrong

long period of methodology development. Figure 1 displays GERD in current and 2010 Rand, showing real GERD growth of around 2% p.a. Labour costs makeup close to half of GERD and have accelerated at a real rate of 3%, so that non-labour costs have risen more slowly. The (nominal) value of GERD in 2013/14 was R25 billion.

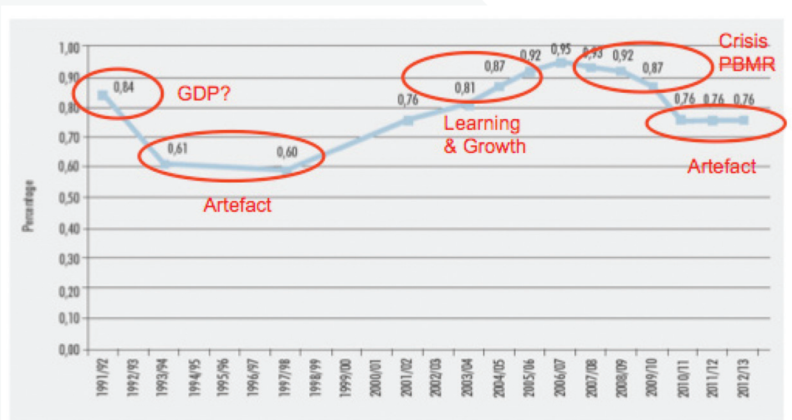
Figure 1: Nominal and constant (2010) GERD, 1991-2013



Source: DST (2015b), HSRC (2004 et seq.), DNE (1993)

The ratio Gross expenditure on R&D to GDP (GERD: GDP) is the best practice indicator of the vitality of an innovation system, being viewed as a signal of future potential (Figure 2 shows that the long-term average of GERD: GDP is around 0,75% below the 1% target long aspired to by African countries, as in the 1980 Lagos Plan and 2005 African Union AMCOST target.

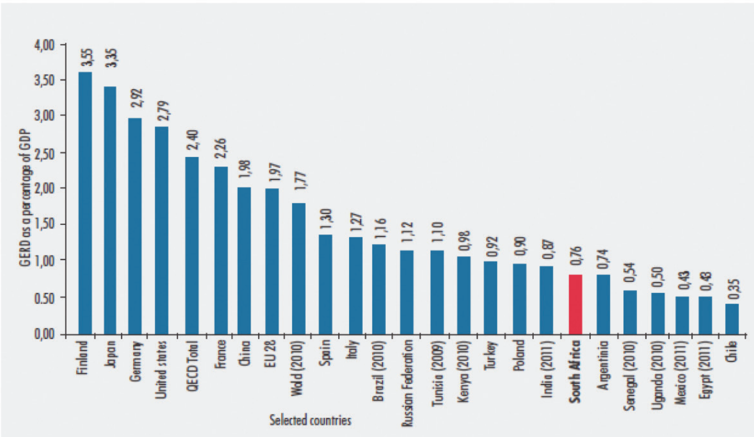
Figure 2: GERD: GDP 1991/2 – 2012/13



Source: R&D Survey Statistical Report 2012/13; DNE, 1993; OECD, 2014

A number of features are highlighted in Figure 2. The first is that GERD: GDP for 1991/92 originally published as 1,04% (DNE, 1993) has since been reduced to 0,84% as a result of the rebasing of GDP. In addition, the 1991/92 value of GDP excluded the 'Homelands' so that its value was underestimated and GERD: GDP was thus increased. Secondly, the subsequent 'decline' in GERD: GDP is most likely a survey artefact since the 1993/4 and 1997/98 surveys were of restricted scope compared with that of 1991/92. The 1995/96 omission arose as that survey did not follow standard methodology and was thus excluded from the series. No survey was conducted in 1999/2000, so that the first post-1994 official survey was that for 2001/02, followed by 2003/04 and annually thereafter. The 2001/2 to 2006/7 surveys reveal steadily rising GERD: GDP as a consequence of improved survey coverage, strong economic growth, and the injection of large funds toward the Pebble Bed Modular Reactor (PBMR). From 2007/08 onward decline set in as economic growth stalled, and the PBMR was terminated with expenditure on ‘energy resources’ declining by R900 million over the next two years. Thereafter survey coverage diminished, and GERD: GDP was eventually recorded at the low level of 0,73% of GDP, a value well below that of the other BRICS countries (Figure 3). The above reasons for the decline differ from NACI (2016) that avers that the decline is a mixture of PBMR shutdown, migration of industry R&D abroad, and a real decline of business funding by 40%. In fact, the decline of BERD is by 28%, not 40%. The claimed migration abroad of R&D is unproven; for example, Sasol is a global player that performs 95% of its R&D at home.

Figure 3: GERD: GDP for Selected Countries (R&D Survey, 2012/13)



The next matter for consideration is the source of funds for R&D (Table 2).

Table 2: Sources of Funds for R&D, 2004/05 to 2013/14 (current Rand)

YEAR	Total Funds	Government	Business	Other South African Funding Services “““	Foreign Sources
	R’000	R’000	R’000	R’000	R’000
2004/05	12 009 980	4 276 313	5 838 774	62 342	1 832 551
2005/06	14 149 239	5 403 955	6 206 837	620 849	1 917 598
2006/07	16 520 570	6 672 138	7 399 660	701 907	1 746 865
2007/08	18 624 059	8 510 101	7 945 949	180 927	1 987 082
2008/09	21 041 046	9 497 510	8 973 490	175 219	2 394 827
2009/10	20 954 676	9 313 028	8 907 527	195 682	2 538 439
2010/11	20 253 805	9 018 874	8 128 246	661 676	2 445 009
2011/12	22 209 192	9 561 917	8 663 105	653 674	3 330 496
2012/13	23 871 219	10 831 893	9 152 042	770 300	3 116 984
2013/14	25 660 573	11 007 083	10 615 902	722 361	3 315 227

* Includes science council and university own funds.

* Includes funds from higher education institutions, non-profit organisations and individual donations disbursed to all sectors.

Source: R&D Survey 2013/14

One notes that from 2008/09 onwards Government became the major domestic source of funds; local business did not keep pace while foreign funding increased. The bulk of Government funding (R10.3 bn) goes to the public sector, which might lead one to assume that this implies strong control over their R&D

activities. Butt only R1.44 bn is spent within departments and DBRIs, the bulk of funds being transferred to arm's length statutory bodies and SoEs. The highly autonomous HEIs receive R5.66 bn; less autonomous science councils receive R3.43 bn. Nominally, government has a direct influence on 5% of R&D activity. (As an aside the DST management overhead is around 4,3% of funds under its control). The next matter is the share of R&D expenditure across the sectors (Table 3). This demonstrates the decline in BERD: GERD from the 2008/09 peak to the present value of 46%. Higher education, the site of 'own' research has increased its share to 30,7% with the science councils, the site of mega science, remaining constant.

Table 3: R&D expenditure share by sector, 2004/05 to 2013/14

YEAR	Government R'000	Science Councils R'000	Higher Education R'000	Business R'000	Not-for-profit R'000
2004/05	4.3	16.6	21.1	56.3	1.7
2005/06	6.0	14.9	19.3	58.3	1.6
2006/07	6.2	16.6	20.0	55.9	1.3
2007/08	6.2	15.5	19.4	57.7	1.2
2008/09	5.4	14.9	19.9	58.6	1.1
2009/10	5.1	16.5	24.3	53.2	0.9
2010/11	5.0	17.8	26.8	49.7	0.8
2011/12	5.6	16.8	29.8	47.1	0.8
2012/13	6.0	16.9	30.7	44.3	2.1
2013/14	6.6	16.8	28.4	45.9	2.3

Source: R&D Survey 2013/14

A set of input metrics with trend indications is now presented. Some of these metrics are to be found in the NACI STI Indicator Report; others are unique to this analysis. The inputs to R&D are shown in Table 4.

Table 4: Inputs to R&D, 1996 and 2016*

Financial	1996	2016	
GERD: GDP	0,81	0,73	↘
Business expenditure on R&D (BERD) % GERD	41,5	45,9	↗
Services R&D % BERD (socio-economic objective measure)	n.a.	36,5	
Higher education expenditure on R&D (HERD) % GERD	22,1	28,4	↗
Basic Research % GERD	19,6	24,5	↗
Expenditure on R&D in Engineering and Technology % GERD	41,7	25,8	↘
Expenditure on R&D in Health Sciences % GERD**	6,9	17,2	↗
Expenditure on R&D in Social Science and Humanities % GERD	13,8	14,8	↗
Social Sciences and Humanities (SSH) % HERD**	*68*	35	↘
Defence R&D % of GERD	9.3	5.4	↘

*Note: * values closest to 2016 ** Not comparable. Source: R&D Surveys*

Basic research stands at 24,5% of GERD with HERD: GERD close to 30%, of which basic research is 52%. By contrast, 77% of science council expenditure goes on applied research and development. The BERD: GERD ratio of 46% lies at the higher end among emerging economies. Services sector R&D is now 36,5% of BERD. There has been a relative decline of expenditure for the government sector R&D performers, including the science councils, the zone where the government would appear to have the most influence. It is worth noting that when Korea's GERD: GDP was of a similar size, basic research was but 5% of its GERD.

It is obvious that there has been a drop in expenditure on the hard technologies associated with manufacturing and mining,[5] with corresponding increases elsewhere, particularly in services and areas of social importance, the health sciences, social sciences and humanities, that increased from 20,7% to 32% of GERD. This should be read alongside the decline in the share of higher education expenditure on SSH R&D, reflecting the growth in SSH R&D expenditure in the private sector. This observation begs the question: is this redistribution a consequence of government innovation policy, or is the redistribution a result of the independent actions of the performers in these sub-sectors? Also important is the decline in Defence R&D that was and is closely linked to the export of high-technology weapon systems. It is to be noted that 2013/14 Defence R&D is R1.4 billion, in sharp contrast to the R460m that is reported in the Review of the White Paper (NACI, 2016: 5). The source of this discrepancy is unknown. Weapon system development continues among Denel, Armscor, CSIR and the private sector.

Table 5 provides a listing of the R&D expenditures for the largest public sector performers. The historically disadvantaged institutions remain essentially absent from this list. It might be averred that the DHET output funding formula maintains this division. Table 5 should be viewed set alongside the information on scientific outputs and patenting that follows below.

Table 5: Main public sector R&D performers, 2013-14

	R 000s
University of Cape Town	1178888
University of Witwatersrand	896566
University of Stellenbosch	827137
University of Kwazulu-Natal	648942
University of Pretoria	644215
University of South Africa	605001
North West University	585124
Free State University	330182
University of Johannesburg	252049
Nelson Mandela Metropolitan University	216191
Rhodes University	211956
University of the Western Cape	171979
CSIR	2095576
Agricultural Research Council	1008401
NRF National laboratories*	480000
Medical Research Council	390820
Council for Mineral Technology (Mintek)	281883
Human Science Research Council	244938
Council for Geoscience	109577
State-owned enterprises+	
Denel	507000
ESKOM	130200
Transnet	83200
NECSA*	74800
Onderstepoort Biological Products	32000

*Sources: Universities and PROs (DST, 2015); SoE Annual Reports. *Author estimate*

5 'The disappointing growth and employment trajectory of the South African economy since its democratic transition is best understood as a consequence of the under-performance of its non-resource tradable sector, and of manufacturing in particular' (Rodrik, 2006: 24).

Government funding for innovation activities enters the system in many ways, but is difficult to track with precision. Large R&D performers such as CSIR and ARC receive baseline funding as well as 'contract' research income for special projects as for example titanium research at CSIR, and small farmer development at ARC.

The cumulative spending on titanium might characterize this project as an example of mega-science. Other mega-science projects are SALT, MeerKAT, and the Joule electric vehicle, all of which received their funding through the NRF. On the other hand, while government funded the PBMR, the biggest of all R&D projects, the expenditure appears under the business sector since PBMR is a registered company. The same holds for the SoEs, the largest being electricity, defence, transport and telecommunications, the first three entities fall under the Department of Public Enterprises with the latter under Communications.

Modest funding for pre-commercial stage R&D projects is available from the dti through the Technological Human Resources for Industry Programme (THRIP) and the Support Programme for Industrial Innovation (SPII). Both programmes have been subjected to recent external evaluation[6] with SPII receiving strong praise despite some observed inefficiencies in the drawdown of funding. The THRIP has a long track record of bringing industry and the universities closer together and has served an important secondary role of easing the recruitment of promising researchers into the private sector.

4.2 Talent

Any discussion on the talent pipeline must take cognisance of past and present local and geopolitical factors. Today's talent pipeline reflects the country's colonial history, British influence, and apartheid law. Despite many attempts to turn the education system around, public schooling remains weak, higher education is skewed, and the technical and vocational education and training (TVET) system is underperforming. There are exceptions – some rural schools excel and technical colleges satisfy student and industry needs; universities and business schools are among the best in the world. But South Africa is near the lowest rank on the 38-country OECD PISA assessment.

It may be noted that two large-scale government-backed social innovations sought to address the deficit. The Students and Youth into Science, Technology, Engineering and Mathematics (SYSTEM) Initiative of 1996-99 offered a 'second chance' to senior certificate students. SYSTEM was implemented at nine provincial sites, with a dedicated teaching college in Limpopo. In the order of 2000 students and 100 teachers benefitted from SYSTEM before it was terminated. The second innovation is the Dinaledi Schools, a set of some 500 quasi-academies that specialize in physical science and mathematics. A World Bank evaluation of the Dinaledi programme found that large gains were made in increasing access to higher-grade study, and that the Dinaledi Schools in the former homelands achieved scores much higher than non-Dinaledi schools. This is encouraging, but more remains to be done.[7]

As the NPC Diagnostic (The Presidency, 2011) attests, teacher quality, motivation and leadership, and community support are critical to transforming schooling. Even though more than 90% of teachers are deemed to be fully qualified, international benchmarks such as OECD-PISA and the Annual National Assessments rank learner and teacher performance low among international peers. Except for those learners that attend leading public or private schools, progression into and through higher education remains a challenge (Table 6).

6 http://evaluations.dpme.gov.za

7 http://evaluations.dpme.gov.za/evaluations/402

Table 6. Talent pipeline, 1996 and 1999

TALENT	1996	2016	
HEI STEM enrolment (%) (1996; 2014)	23,7	29,6	è
HEI Researcher headcount/PhD enrolment[1]	1.4	1.0	↘
FTE Researchers (excluding PhD and Post-Doc)	12 102	11 644	è
Female Researchers (% total)	-	42,3	ì
'Black' Researchers, Government sector (%)	<3	± 55	ì
GERD (2010 Rand)/FTE researcher (000s)	844	1 848	ì
Foreign university students (%)	<1	7	ì

Sources: D&D Surveys; HEMIS; http://www.che.ac.za/focus_areas/higher_education_data/2013/participation

A rough estimate of degree progression rates yields a figure of around 17%, a rate that is almost identical for White and African entrants. This implies unacceptable wastage of talent and resources, and suggests a mismatch between student and higher education institutions. It may be noted that the same institutions graduate thousands of foreign students from across the African continent. It would be of interest to compare their progression rate with that of citizen students.

While STEM enrolments have increased, the low throughput rate cannot meet the needs of an economy that needs to grow and do new things.

Furthermore, the low numbers opting for research careers is evident in the stasis of the total full-time equivalent (FTE) for researchers, even as research expenditure per FTE researcher has risen. That stasis in the headcount of researchers naturally translates into the reduced availability of research supervisors, implying that the system is choking.

The standard measure of FTE researchers per 1000 employed places South Africa among the lowest worldwide (Figure 4).

Figure 4. FTE researchers per 1000 employed

Source: R&D Survey 2012/13

At the macro level, South African higher education performs well on gender equity with more female than male undergraduates; at postgraduate the opposite holds. This in part contributes to a male-dominated professoriate. Racial equity has moved ahead most strongly in the government sector with a steep rise in the proportion of Black researchers in the public research organisations (PROs). This shift is often overlooked in the dominant narrative that 'the science system is dominated by white males over the age of 50. One notes that in 1994 there was but a single African graduate on the ARC payroll; today more than 50% of its research professionals are black. A massive shift has occurred, for which the Employment Equity Act of 1998 is largely responsible.

But, and this is vitally important, the total researcher complement has remained static, pointing to a replacement, rather than a growth strategy.

As to age demographics, the most recent assessment is that 'the very steep increase in the number of publishing authors over the age of 50 that was recorded between 1990 and 1998 (from 18% to 45%) seems to have stabilized. In 2005 this figure was 42% and in 2014 was very similar at 45%' (Mouton et al., 2016).

It is possible that there may be some undercounting of the researcher FTE, but this is insufficient to explain the stasis. Previous fiscal discipline, limited throughputs, emigration losses and reluctance to seek skilled immigrants all contribute, even while the large inflow of foreign students remains an untapped resource. Skills shortages are pervasive as indicated in priority order on the official scarce skills scoreboard (Table 7).

Table 7: Scarce skills scoreboard, 2014

NO	OCCUPATIONAL TITLE
1	Electrical Engineer
2	Civil Engineer
3	Mechanical Engineer
4	Quantity Surveyor
5	Programme or Project Manager
6	Finance Manager
	Physical and Engineering Science Technicians*
8	Industrial and Production Engineers*
	Electrician
10	Chemical Engineer
11	Construction Project Manager
12	Mining Engineer
	Accountant (General)
14	Energy Engineer
15	Materials Engineer
16	Electronics Engineer
17	Metallurgical Engineer
18	Medical Superintendent / Public Health Manager
	Telecommunications Engineers *
20	Energy Engineering Technologist
	Millwright

Source: RSA 2014.

The above extract from the scoreboard reveals a preponderance of shortages in engineering and other STEM education disciplines, though actual vacancy levels are not specified. Industry is calling for graduates in these areas, not postgraduates. Demand for masters and doctoral graduates is more difficult to assess, more so as the R&D Surveys show that industry does not draw in large numbers of doctorate holders for its research needs.

4.3 System outputs

The scientific outputs are displayed in Table 8. These show a fourfold rise in Black graduates, even as doctoral graduate numbers remain well below the target of the TYIP (DST, 2008). The 1 576 PhD graduates include some 250 foreign students who are required to exit the country upon graduation, and should perhaps be recorded as a separate category in official publications.

Table 8: Scientific outputs (Web of Science, Scopus, HEMIS)

	1996	2016	
Degrees awarded to Black students (1996; 2014)	38 383	145 831	↗
PhD graduates	630	1 576	↗
Foreign PhD graduates (%)	-	15	↗
Articles (Web of Science Core Collection, whole count) 1995; 2015	3 233	12 251	↗
Articles, books, conference proceedings (NSB, fractional count)***	2351	9 679	↗
World share of publications (fractional); rank (NSB)	0,38 (31)	0,44 (35)	↗
International co-authorship (%) ****	30	49	↗
Publications/Researcher incl. PhD and Post-Doc (headcount: 2003; 2013)	0.19	0.28	↗
Top 1% most highly cited 2003-2013 (*Nature*)	-	3	
ZA h-index[2], Web of Science (1996-2000; 2006-2010)	162	192	→

Bibliometric indicators are generally used as a proxy for knowledge outputs. Both whole count and fractional count measures show that in common with the global trend South Africa's science outputs have also risen. The fractional count world share has risen marginally, to 0,44% at rank 35. NACI (2015) presents whole count (WC) information and accords South Africa 0,81% of the world share.

Arguably the rise in publication volume is coupled with the growth in international co-authorship, some of which arises from participation in mega-science projects. This activity, together with increased PhD student enrolments and post-doctoral fellows goes some way toward explaining the increased publication output per researcher. It is important to recognize that participation in international mega-science projects generates articles with hundreds of authors thereby distorting conventional bibliometric analysis.

Next for consideration is the issue of the quality of science outputs, for which citation rates are taken as the standard proxy. One measure is the number of scientists among the topmost 1% most cited in a discipline, an honour shared by three South African academics - two at Wits, with the third at UCT. By comparison, Latin America has but one such research star; Harvard College has 95 and Saudi Arabia 56.

There has been a concomitant rise in citation rates; participation with foreign collaborators yields articles in high impact journals with citation rates often pulled up through the invisible college of science (Wagner, 2008). Moreover, articles arising from mega-science high-energy physics, astrophysics, astronomy and health sciences are among the most often cited. Noting the rise in publications, it is necessary to probe deeper by calculating the RCA, also known as the 'field normalized publication rate' (see Table 9).

The RCAs for South Africa show activity above the global average (1.00) in Agriculture, Astronomy, Geosciences, Mathematics, Psychology and Social Science. As an aside, it is important to recognize that South African science, like that of Brazil, and even Norway, is spread across many fields. Russia, China and India show high concentration on physics, engineering and chemistry.

Table 9: Articles with a South African address, share, RCA (fractional count), 2013.

FIELD	WORLD	ZA	ZA FC %	RCA	ZA WC %
ALL	2199704	9679	0.44	-	0.81
Agriculture	47445	328	0.69	1.57	1.01
Astronomy	13718	77	0.56	1.28	-
Biological	348402	1959	0.56	1.28	1.09
Chemistry	174242	659	0.38	0.86	0.53
Comp science	177578	530	0.30	0.68	0.28
Engineering	434503	1312	0.30	0.69	0.50
Geosciences	117131	636	0.54	1.23	-
Mathematics	54798	266	0.49	1.10	0.81
Medical science	466883	1721	0.37	0.84	-
Physics	203114	397	0.20	0.44	-
Psychology	37914	259	0.68	1.55	-
Social science	99332	1311	1.32	3.00	1.36

Source: NSB 2015, Web of Science 2016, and NACI 2014
Note: WC =whole count; FC = fractional count

This poses the question: what can be said of the quality or impact of these publications?
The conventional proxy for scientific quality or impact is the average citation rate of a journal article, individual researcher, research group, or institution over a specified time period. It is also necessary to distinguish whole or fractional rates. NACI (2015: table 3.6) provides relative whole count subject area citation rates for 2014, pointing to the outlier score of 6,84 for the combined fields of 'Physical Sciences and Astronomy' indicating that South African papers enjoy 684% higher citation rates than the global average. Mouton et al. (2016) take a different approach, reporting that the average field normalized citation count across all disciplines rose from 0,66 for the period 1996 to 1999 to a value of 1,03 for 2011-2014, implying a rise from below world average to parity. Some care is needed in interpreting these results because of the distorting effect of mega science citation inflation.

To illustrate this point Web of Science data for 2015 indicate that South African astronomy and astrophysics attract an average citation rate of 6,92 and h-index of 25; physics 4,97 and h-index 23, immunology 3,68 and h-index 15, psychology 1,14 and h-index 7, with education 0,66 and h-index 6, and religion 0,11 and h-index of 1.

Finally, the h-index has been calculated across all fields for two five year periods, 1996-2000 and 2006-2010. There are inherent difficulties in such a comparison, as citation counts are cumulative. However, it is very much the case that the bulk of article citations arise within five years of publication after which there is a steep fall off. The comparison across the two periods shows a 1996-2000 h-index of 162 in which Astronomy and Astrophysics account for three of the top 100 most cited papers, Infectious Diseases 9 and 'Other' 24. By contrast, the period 2006-2010 shows an h-index of 192 with Astronomy and Astrophysics accounting for 14, Infectious Diseases for 27 and a narrowing of spread with 'Other' at 14.

Paper-by-paper abstract and authorship analysis confirms that these changes may be explained by the prevalence of mega-science projects in Astronomy and Astrophysics, High Energy Physics and Health Sciences, as well as South Africa's unique involvement in Infectious Diseases research, notably HIV and TB. Large projects with multiple international authorships generate citations in high impact journals whereas psychology, education and religion do not. The distortion of the meaning of 'collaboration' through mega-science projects remains an unresolved matter.

Given the importance of platinum and titanium research in the TYIP and IPAP, it is important to consider associated publication outputs.

Publications on platinum over 2010-2014 have RCA of 2,43 that is well above world average (Table 10). Also shown are a set of the country h-indices suggesting that the global centres for publications (N) are the US and China. It is observed that the h-indices for South Africa and Russia, the leading platinum miners are comparable; however, the countries that are most concerned with the industrial application of platinum show much higher publication counts and h-indices.

Although South African activity is above average, the impact is in line with the level of output. One might aver that platinum research is abreast of, but not ahead of the frontier. The high RCA may be indicative of active support from the government in setting up the Hydrogen South Africa (HySA) project.

Table 10. Whole count: 'Platinum' and h-index, 2010-2014 (Web of Science)

Country	WC	h-index
ZA	490	21
AU	877	42
RU	973	29
EN	1520	55
DE	2649	73
JP	3005	61
CN	6204	91
US	7241	117

Source: Author, Web of Science

As regards titanium, the volume count is 228, with RCA of 0,73 that is below the world average, with a country h-index of 15. Titanium research may be characterized as less intensive and of lower impact than platinum, this despite significant investment at CSIR. The award of a US patent to CSIR for the continuous production of titanium powder holds promise for future development.

Domestically, the National Science and Technology Forum (NSTF) encourages scientists to strive for excellence through its awards scheme. While individual Nobel prizes have eluded South African science in the last decade and a half, Prof. Vogel of Wits was part of the climate change team so recognized with a Nobel Prize in 2015. Other scientists have gained recognition through the UNESCO-L'Oréal Award (Mizrahi, Thomson and Farrant), and the Templeton Prize (Ellis). Scientists are also recognized for their leadership and expertise through service on international bodies and panels.

The following section covers innovation outputs and outcomes (Table 11).

The conventional innovation output measures are intellectual property rights (IPR). Patenting (United States Patent and Trademark Office (USPTO) and Patent Cooperation Treaty (PCT)) shows little increase, whereas there has been a massive rise of foreign trademark registrations, perhaps consistent with the opening up of foreign markets to South African companies.

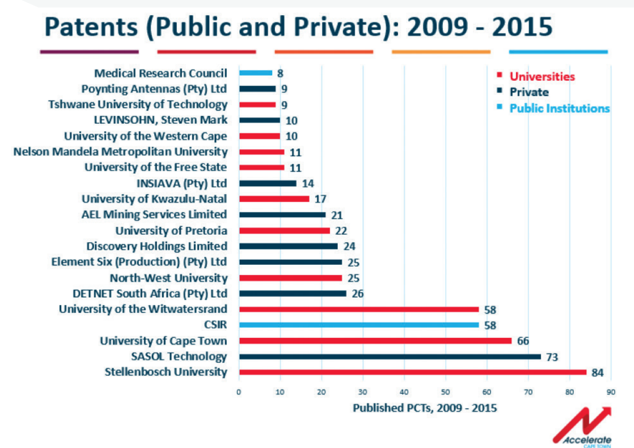
Table 11: Innovation outputs and outcomes

	1996	2016*	
US Patent awards (USPTO)	105	144	→
Patent Cooperation Treaty applications (WIPO)	390	442	→
Trademark applications (ZA resident)	7 051	19 522	↗
Trademark applications (ZA abroad)	11	5 694	↗
Plant cultivars in force, world share %; rank (UOPV)	n.a.	2710;2,6;8	↘
Sales of innovative products (2002/4); (2005/7) billion (HSRC)	177	370	↗
High technology exports % of total exports (UN Comtrade)	5	6	→
Proportion of innovating firms %	n.a.	52	
GCI; Basic requirements; Innovation (WEF)	n.a.	56; 89; 37	↘
GII (INSEAD)	n.a.	60	↘

Sources: Innovation Surveys 1995; 2005

** Official data closest to 1996 and 2016. http://data.worldbank.org/indicator/TX.VAL.TECH.MF.ZS?page=4. WIPO and USPTO databases.*

Figure 5. PCT Filings (2009-15)



Source: http://acceleratecapetown.co.za/university-commercialisation

PCT filings have fluctuated around 380 filings per year with no clear pattern of growth. The low patenting rates should not be taken to imply that innovation is not taking place across the innovation system. First for recognition is that various entities are making use of the PCT channel subsequent to South African accession in 1999. Figure 5 identifies the leading assignees: Stellenbosch University, Sasol and UCT.

Further interpretation is necessary to obtain a clearer understanding of the ranking. Firstly, the DetNet and AEL are part of the same industry group, so that DetNet/AEL could be counted as 47, placing this grouping in sixth position. These patents arise from the spillover of military R&D of the 1980s.

Secondly, INSiAVA (from the technology known as injection-enhanced silicon in avalanche) is a spin-off company that belongs to the University of Pretoria so that UP/INSIAVA could be counted as 36, placing UP at rank number seven.

Medical insurance company Discovery Holdings has a count of 24 in the period, a telling example of services sector innovation.

Next are USPTO awards shown for the top twenty assignees that have been awarded at least five patents over the period 1963-2015 (Table 12). This information should be compared with Table 4.2 in NACI (2015).

Table 12. USPTO First-Named Assignee (South Africa), 2011-2015

	2011	2012	2013	2014	2015
SASOL TECHNOLOGY (PTY) LTD	9	9	12	8	10
AMAZON TECHNOLOGIES, INC.	2	1	4	10	12
CSIR	4	2	5	1	11
UNIVERSITY OF THE WITWATERSRAND	2	4	4	4	8
SPINALMOTION, INC.	3	5	5	6	1
UNIVERSITY OF CAPE TOWN	3	1	7	3	1
CORK GROUP TRADING LTD.	0	5	2	3	4
ELEMENT SIX ABRASIVES S.A.	0	1	4	0	9
JOY MM DELAWARE, INC.	1	1	1	6	3
NORTHWEST UNIVERSITY	1	3	3	1	3
DISCOVERY HOLDINGS LTD	3	5	2	1	0
ORACLE INTERNATIONAL CORPORATION	0	0	0	1	9
UNIVERSITY PRETORIA/INSIAVA (PTY) LTD	0	0	3	4	3
DETNET SOUTH AFRICA (PTY) LTD.	0	0	0	2	6
AEL MINING SERVICES LTD	0	2	2	1	3
AZOTEQ (PTY) LTD	3	1	2	1	0
NECSA LTD.	1	1	1	2	2
KIPS BAY MEDICAL, INC.	2	1	1	2	0
SANDVIK MINING RSA (PTY) LTD	1	1	0	2	2
SOURCECODE TECHNOLOGIES HOLDINGS, INC.	2	3	1	0	0

Source: USPTO

Two features stand out in Table 12. The first is the presence of new foreign subsidiaries as assignees; the second is the sharp rise in patenting activity of the universities since around 2011.

In 2015 the foreign sub-group were assigned a total of 30 patents. If this number were subtracted from the 'national' count, this would fall from 166 to 136. Accordingly, the IPRPFRD Act may not be the main driver of growth in USPTO awards. Patenting activity of foreign entities should be the subject of further research.
Firm-level innovation has been assessed through five innovation surveys conducted over the period 1992 through to 2010, with varying degrees of coverage and response rate. Of these, the most comprehensive survey was that for 2002-2004 that achieved a 35% response rate. That survey showed that local firms tended to follow the adaptive and incremental innovation route, and that they drew on information and signals for innovation from their value chains, rather than from university or PRO sources. This is a similar pattern to that observed across the OECD member states.

Sales of new or improved goods and services provide a measure of the rising importance of innovation to firms, but only limited data from two of the innovation surveys is available. A more useful indicator of business activity might be value added, adjusted for negative externalities.

High technology exports as a proportion of the total export basket remain at a low level. In general, countries whose exports are mainly unprocessed commodities do not exhibit high levels of international patenting. NACI (2015) compares commodity exporting South Africa and Brazil, noting that the high-technology component of Brazilian exports has doubled over the last decade, while the South African level has remained static. What is missed in this comparison is that the Brazilian rise is almost entirely due to the performance of one company, namely, Embraer, with its world-beating commuter aircraft. Other than the Embraer aircraft, the composition of the two country's high technology exports is quite similar.

Given the non-examining patent regime,[8] little may be learnt from local patent registrations regarding their potential for commercializing local R&D. This may explain the enduring claim that there is a failure to commercialize local R&D, and that much of the associated IP leaks abroad. This claim goes under the title of 'lost opportunities.' In 2006 DST undertook an in-house study based on interviews and case studies of 'lost opportunities,' some being products of R&D up to prototype stage that were developed in the public and private sector and were not successfully commercialized. The outcomes of the study formed part of the motivation for the to-be Foundation for Technological Innovation, today's TIA. The study covered the Agricultural Research Council (ARC), CSIR, Mintek, Medical Research Council (MRC), South African Bureau of Standards (SABS), UCT, UKZN, Da Vinci Institute, Green Solution, and the Innovation Hub. Also included were the NRF Innovation Fund, Cape Biotech, Advanced Manufacturing Technology Strategy (AMTS), and the Tshumisano incubators, all of which claims were verified. The strong message from the study was that hundreds of potential winners were being lost. This is somewhat misleading as it is biased by the SABS input that was based on nine years of entries to its Design Award programme, totalling 150 projects, none of which was analysed for market potential.

As things stand, the Global Entrepreneurship Monitor project logs very low scores for South Africa compared with other sub-Saharan countries.[9] With low levels of entrepreneurship, the conversion of R&D into commercial products via the start-up route may be even less likely than in other countries.

A widely unacknowledged form of IPR is plant cultivar registration, for which South Africa stands at global rank 8. This is cause for celebration, as new cultivars are both a necessity and huge benefit to agricultural vitality and production. However, the time series data hold a warning in that the number of new registrations is at the lowest level since 2008, possibly as a result of the sale of seed company Pannar, as well as budget cuts for agricultural R&D.

8 Non-examination of patents allows for quick, cheap, but spurious protection.
9 http://www.gemconsortium.org/country-profile/108

The last two indicators of Table 11 place country performance in context. The GCI value is commensurate with scientific output rank, whereas the Global Innovation Index (GII) ranks the country much lower.

NACI (2015) also addresses technology balance of payments. Insofar as the ratio of receipts to payments is concerned, South Africa is the extreme outlier, sharing commonality with Mexico and New Zealand. The underlying reason for payments exceeding receipts fifteen fold is unclear, perhaps being an accounting artefact. The NACI view is sanguine, namely that the benefit of being able to absorb new technology outweighs the cost of importation. There is truth in this assertion. The stark difference between sales and receipts remains a contested issue, possibly definitional, possibly due to accounting practice. Either way, the deficit presents a research question that requires proper investigation

4.4 System linkages

Linkages are crucial to the very definition of a system of innovation, and include all modes of knowledge exchange, technology transfer, student and staff mobility, joint research and co-publication, co-innovation, bilateral and multilateral agreements, contractual arrangements, and multi-stakeholder incentive schemes.
The Innovation Fund (IF) that solicited bids from consortia is an excellent example of the latter. Participation in the networking activities of the European Union Framework Programmes stands out as a resounding success for local scientists with the DST and NRF playing a catalytic role (European Commission, 2014). Other system successes include the promotion of the careers of numerous scientists from the region, notably Drs Chibale, Nyokong and Chiwamba.

NACI (2015) in sections 3.3 and 3.4 provides a lengthy analysis of 'collaboration' among business, higher education and science councils, as well as foreign players using co-authorship as a proxy measure for collaboration. NACI notes various features of such 'collaboration' but does not seek to explain or comment on the drivers. One issue is the 'low' level of domestic collaboration. A similar phenomenon has been noted in Australia, suggesting that South Africa is not unique. Where she may be unique is in deploying an incentive – the Journal Subsidy Scheme - that militates against domestic collaboration.

It is highly likely that the real extent of university-industry collaboration through the SA Research Chairs Initiative (SARChI), Centres of Competence (CoCs) and THRIP is masked by the problem of attribution.

There is limited research on linkages between industry, higher education and PROs. Notable contributions are those of Cooper at UCT, and Kruss and associates (2015) at the Human Sciences Research Council (HSRC). Cooper (2011) found that university research centres with industry links were vulnerable to personnel movement and short-lived.

In their study of the Eastern Cape automotive sector, Kruss et al. (2015) found that the Technikon-university mergers were still in the process of settling down and industry links had thus been disrupted. This was especially so for the previously black HEIs. The same study considered the build-up to the Square Kilometre Array (SKA) programme, finding much higher industry-university collaboration as revealed through network analysis. In the view of this expert, the success of the SKA rests upon the prior existence and excellence of the telemetry sectoral system of innovation that brought together the universities of Stellenbosch, Cape Town, Wits, and Rhodes, as well as the Cape Peninsula University of Technology (CPUT), the Stellenbosch Techno Park, CSIR and diverse high technology companies. Where there was a specific need, sectoral systems of innovation emerge, and may prosper over time, as in the wine, paper and minerals sectors. The above case studies suggest that there is rather more industry-university interaction than is detected through the innovation surveys that have consistently recorded low industry usage of universities as sources of information for innovation.

Another observation on linkages is that measuring the nature and extent of international 'collaboration' is distorted by the rules of the game of mega-science projects.[10, 11] Taken at face value, South Africa collaborates with scientists in more than a hundred countries. Some of this 'collaboration' is tenuous as the publication counts arise from the requirement that all those who have worked on a mega-science project are cited whenever data arising from that project is used. A scientist in Cordoba, Argentina may not know more than two of the five hundred authors listed as contributors to a joint paper yet all of these authors will appear as foreign country collaborators. A serious rethink is needed. The editorial board of *Nature* is currently experimenting with ways of dealing with the problem.

Against the backdrop of the import substitution regime of the period to 1990, local companies have experienced both local competition from new entrants into their own previously captive market, and the opportunity, if not the necessity to go global. In the process, local firms such as white goods manufacturer Defy entered into technology licencing agreements, in their case with Swiss company Francke AG. This allowed Defy to hold onto its nearly 40% domestic market share against the likes of Samsung and Korean LG. Eventually, however, Francke decided to exit the South African market and sold on to Turkish company Arcelik, one of the largest white goods suppliers to the EU. Today Defy remains a local brand, with an offshore owner.
The converse is that South African firms march abroad and acquire businesses, as for example the case of Aspen that draws on its domestic expertise to increase its offerings into new markets. In like vein the JSE top 40 firms now derive up to 50% of their revenues abroad.[12] One might contend that this performance in new markets, involving merged entities and unique management challenges points to the existence of considerable process and organizational innovation skills at home that are then deployed abroad. This aspect of innovation activity also requires further study.

A final comment on linkages is called for. The innovation system is nominally open to the world. Unfortunately, the flows into and out of the system are poorly quantified. This is particularly so in relation to the mobility of the highly skilled. Linkages also refer to knowledge transfer, to technology transfer, uptake and impact. Here too reliable information is in short supply.

4.5 Comparative perspective

South Africa joined the BRICS group in 2011, as the country play important military, political, economic, education, and STI roles in Africa. Come 2015, BRICS ratified the Cape Town Declaration on Science and Technology that set out to promote cooperation in S&T and designated specific fields of S&T to each member state. It is appropriate, therefore, to conclude the quantitative assessment with a brief comparative perspective of BRICS science activity (Table 13). 'Technology' activity is rather more difficult to quantify.
On par with Brazil, South Africa displays high inequalities, sharing a low HDI with India. The domestic carbon footprint is very high, as are those for Russia, and China. Brazil has a low carbon footprint due to hydroelectric resources, while the value for India reflects its lower level of industrialization.

10 Mega-science projects include CERN, Geneva and other high energy physics laboratories; the Sloan digital sky project; the Planck telescope; Human Genome; Worldwide Burden of Disease project, etc.
11 The HESS observatory is operated by the collaboration of more than 170 scientists, from 32 scientific institutions and 12 different countries: Namibia and South Africa, Germany, France, the UK, Ireland, Austria, Poland, the Czech Republic, Sweden, Armenia, and Australia. To date, the HESS Collaboration has published over 100 articles in high-impact scientific journals, including the top-ranked *Nature* and *Science* journals. HESS was awarded in 2006 the Descartes Prize of the European Commission - the highest recognition for collaborative research - and in 2010 the prestigious Rossi Prize of the American Astronomical Society. In a survey in 2006, HESS was ranked the 10th most influential observatory worldwide, joining rank with the Hubble Space Telescope or the telescopes of the European Southern Observatory in Chile. https://www.mpi-hd.mpg.de/hfm/HESS/pages/about
12 https://www.enca.com/money/growth-drives-sa-firms-offshore-expansion

Table 13: BRICS S&T, 2012

	Brazil	Russia	India	China	S. Africa
Population (million)	201	143	1 220	1 354	51
GDP PPP$ (billion)	2 330	2 486	4 833	12 260	576
GDP/capita PPP$	11 600	17 400	3 870	9 050	11 300
Gini coefficient	51.9	42.0	36.8	47.3	63.1
Income decile 10/Income decile 1	54	7	9	18	43
Human Development Index (HDI)	85	55	136	101	121
CO_2 tons/capita	2.15	12.18	1.64	6.18	9.18
Global Competitiveness Index (GCI)	56	64	60	29	53
• Stage	2-3	2-3	1	2	2
• Basic requirements	79	47	96	31	95
• Institutions	80	121	72	47	41
• Efficiency enhancers	44	51	42	31	34
• Financial market development	50	121	19	54	3
• Innovation and sophistication	46	99	41	34	37
Defence expenditure/GDP %	1.5	4.0	2.5	2.0	1.2
USPTO/million	1.3	2.4	1.4	4.0	3.1
Plant cultivars in force/million	8.6	29.3	n.a.	2.6	48
GERD/GDP %	1.2	1.12	0.88	1.98	0.76
BERD/GERD %	45	26	30	74	46
Researchers/1000 employed	1.4	6.2	0.4*	1.8	1.6
Web of Science (WC)	36 111	27 303	46 348	183 760	9 217
Web of Science (WC)/million	180	191	38	136	181
Main fields of publication	Clinical medicine Biology Biomedical	Physics Chemistry Engineering	Chemistry Clinical medicine Engineering	Chemistry Engineering Physics	Clinical medicine Biology Chemistry

Sources: OECD, UNESCO, World Bank, Web of Science

South Africa, like China, is rated as an efficiency driven economy, with Brazil and Russia transitioning toward being innovation-driven, and India a factor-driven economy. Five of the GCI sub-indices are compared, with South Africa scoring high for institutions, financial market development, and innovation and sophistication. The depth of institutional development, and financial acumen of the services sector are hereto attested. Defence expenditures are very high in security conscious Russia, China and India, all three being nuclear and space powers, and lower for Brazil and South Africa. As to innovation outputs, South Africa, despite its low absolute volume of USPTO assignments, leads with China in relation to population size, with South Africa in pole position for plant cultivar registrations that are vital to food security.

In the 'science' domain, South Africa's GERD: GDP is lowest, with BERD: GERD in mid-range. Bar Russia, the stock of researchers is low for BRICS. In contrast to the low value of GERD: GDP, South Africa's modest science output is similar to Brazil and Russia in relation to total population. According to the Glanzel (2001) typology, Russia, India and China show the characteristic of the 'eastern' type with a concentration on physics, chemistry and engineering, while Brazil and South Africa are bio-medical in orientation. In brief, South Africa holds its own as a science player among the BRICS and remains an active partner in that formation.

4.6 What worked?

A brief answer to this key question is that the quantitative evidence speaks of a system under construction and finding its way, with pockets of excellence alongside areas of lower prominence. The publication RCA (see Table 9) suggests that researchers hold their own in Agriculture, Astronomy, Biological Sciences, Geosciences, Mathematics, Psychology, and Social Science. Yet, the RCA does not pick up on prowess in Infectious Diseases and Palaeontology, where local scientists are among the world's most highly cited academics. Computer Science activity is low, yet local Computer Sciences graduates are highly sought after abroad. For this reason, the average field normalized citation rate is a somewhat better measure, a measure that suggests significant strengthening visibility, if not expertise, over the two decades. One might thus aver that competitive science has been maintained and built. Second, the shift toward socially relevant research suggests that another goal of the White Paper is being met. There are both contributions to curiosity-driven research and responses to actual need. In addition, the White Paper calls for competence in 'flagship' science is being addressed through Archaeology and Astronomy.

As to innovation more broadly, there is growth in university patent awards. This may be a consequence of the benefit-sharing provisions of the IPRPFRD Act, though it is really too soon to be sure of this. Trademarking and plant cultivar registrations remain at high levels both being essential to protect exports and foreign trade activities. Innovation is occurring in both the private and public sectors. This is mostly incremental and adaptive, but essential nonetheless.

The number of degrees awarded to African students has shown a phenomenal increase, with 3000 Africans obtaining engineering degrees in 2014, compared with 1750 for white students. Significant demographic shifts are occurring, though the combined output is still short of industry demands.

In the PROs white researchers now share laboratory space with an equal number of peers from other groups. The boardroom excluded, such shifts are smaller in industry and higher education.

The historic debt of South Africa to its SADC hinterland is being repaid many times over through the value added to those economies in the person of the thousands who are trained in South Africa's excellent universities, and who later return to their homes.

The key question whether the above achievements have contributed to an improved quality of life will be left open pending the qualitative assessment.

5. Qualitative Assessment

The qualitative assessment enquires into the ToC that informs the various instruments that have been deployed since 1994. With this in mind, the first task is to explicate the ToC that underpins the White Paper and thereby to suggest the roles that the post-apartheid innovation system was to fulfil. This, in turn, allows investigation into the overall fit and achievement of the set of new organizations and policy instruments, each with their own ToC.

5.1 The White Paper on Science and Technology

The White Paper is the major post-1994 policy instrument intended to energize science and technology for competitiveness and social ends. This change process was elaborated with existing institutions and organizations in place. Path dependence and inertia therefore ensured that various pre-1994 instruments continued in operation, including PRO legislation, the FRD/NRF Rating System, the Journal Subsidy scheme; THRIP; the 'innovation' funding by the IDC and dti; SPII; the Science Vote (to 2005), and the dominance of the 'Big Five' research universities. It may be noted that the Rating System and Journal Subsidy were instituted in the 1980s as devices to encourage scientists to carry on their own research in South Africa, rather than to be tempted to emigrate.

In addition, one notes that the PROs enjoy considerable autonomy and influence, applying their funding largely according to their own assessment of priorities as provided in their founding legislation. See for example the CSIR Act (RSA, 1990a: §3), and the Agricultural Research Council Act 1990 (RSA, 1990b: §4[1] q). This autonomy has a bearing on the span of influence of the Department of Arts, Culture, Science and Technology (DACST) and its successor, the DST.

It was noted above that the pre-1994 contract between science and society involved 'own' science alongside science for the State. This period marked the apogee of the apartheid State, and gave rise to the world's first human heart transplant (own science), and the construction and testing of atomic bombs (science for the State). This conjecture begs the question: is a contract now in place, and if so, what is its character?

The White Paper emerged from a lengthy process of stakeholder engagement over the preceding five years, involving political formations, activist-scientists, government officials, business, labour, universities and PROs. The subsequent White Paper assigned business the main role toward achieving its goals (Box 2) while the government would offer leadership, incentives and support to meet the new challenges posed by highly competitive markets. *Inter alia* there would be support for the technology needs of SMMEs and a redistribution of resources away from the government toward business R&D to be balanced by the ongoing provision of R&D public goods and addressing R&D market failure. Special attention would be given to R&D that could affect the quality of life, to ensure that regulatory frameworks to promote environmental sustainability were in place, and that the benefits of the ICT revolution were shared.

Box 2: High-level goals of the White Paper (DACST, 1996)

The basic requirements for an S&T policy ... embodies a coordinated effort to achieve excellence in serving the national goals ... that focuses simultaneously on maintaining cutting edge global competitiveness and on addressing the urgent needs of those of our citizens who are less able to assert themselves in the market by

- Promoting competitiveness and employment creation
- Enhancing quality of life
- Developing human resources
- Working towards environmental sustainability
- Promoting an information society

The White Paper indicated that:

> fundamental research activity should not be regarded as impractical, because it is the preserver of standards without which, in the long term, the applied sciences will also die… (and that) scientific endeavour is not purely utilitarian in its objectives and has important associated cultural and social values. It is also important to maintain a basic competence in "flagship" sciences such as physics and astronomy for cultural reasons. Not to offer them would be to take a negative view of our future - the view that we are a second-class nation, chained forever to the treadmill of feeding and clothing ourselves (idem: 16).

To attain these goals and objectives the White Paper expected that DACST would balance the demands of big science, fundamental research and service-oriented science, technology development, infrastructure, basic needs provision and human resource development (idem: 17). This would be achieved via the mechanism of a system of innovation that would 'create, acquire, diffuse and put into practice new knowledge that will help (the) country and its people achieve their individual and collective goals' (idem: 20). Most critically, the 'national system of innovation can only be judged as healthy if the knowledge, technologies, products and processes produced by the national system of science, engineering and technology have been converted into increased wealth, by industry and business, and into an improved quality of life for all members of society' (idem: 19).

The motivation for the adoption of the NSI approach was to (i) promote coherence and integration among national activities (ii) to identify needs independent of institution or organisation agendas, and (iii) focus on innovation rather than the production of knowledge (DACST, 1996)

The White Paper recommendations were developed and implemented within the modernizing agenda of the Mandela Administration. This agenda comprised legislation toward redress as in the Employment Equity Act, Broad-Based Black Economic Empowerment (BBBEE) Act, Labour Relations Act, and the modernizing Public Finance Management Act (PMFA).

Despite fiscal discipline, the RDP created a space for infrastructure investment, and investment was duly motivated for the SALT (optical) that exploited the comparative advantage of Southern Skies.[13] Flagship science was thus one of the first winners.

White Paper implementation saw a range of policy processes and instruments intended to shape the NSI, including the R&T Audit, R&T Foresight, R&D Strategy, TYIP, IPPFRD and R&D Tax Incentive. Open borders have been promoted through the ZA-EU Agreement, S&T Bilaterals as well as working with the SADC, New

13 The Southern Geographic Advantage is deeply embedded in South African science, going back a century to the heyday of warrior-politician-scientist Jan Christiaan Smuts who was its major proponent (Dubow, 2006).

Partnership for Africa's Development (NEPAD), African Union (AU), and BRICS.

Alongside came new organizations and organizational enhancements as in NACI, NSTF, BRICS, the Academy of Science of South Africa (ASSAf), Innovation Fund, SARChI, TIA, NIPMO, South African Council for Natural Scientific Professions (SACNASP), South African National Biodiversity Institute (SANBI), Centres of Excellence (CoEs) and Centres of Competency (CoCs), South African National Energy Development Institute (SANEDI), and SANSA. This compendium of actions represents considerable policy experimentation and learning. In a narrow sense, and in agreement with NACI (2015), all the above represent the fulfilment of White Paper goals. As attested to in the quantitative assessment, the devil is in the detail.

5.2. Toward system intelligence

This section begins with the examination of two non-statutory processes, the Research and Technology Audit that the then Financed R&D (FRD) conducted over 1995-1997, and the DACST R&T Foresight of 1996-1999. The Audit took shape before DACST was up and running and comprised surveys of institutions, personnel, infrastructure, R&D inputs and the technology needs of business, with the resulting information to become available through an on-line database. FRD (1998: iii) expected that the Audit would 'undoubtedly provide an essential framework for the National Research Technology Foresight Project that is currently underway to plot a course for a science and technology-influenced future for South Africa' as it had considered the very 'heart and soul of the science and technology system.' In the event the database was not operationalized, and as noted earlier, the 1995/6 'R&D Survey' methodology was incompatible with the *Frascati Manual* guidelines (OECD, 2015). The Audit was not subjected to independent evaluation.

The R&T Foresight study involved some 200 regular participants with balanced gender, age and group representation. One of its most important contributions was that it served as a channel for the entry of new blood into the leadership and policy layers of the science system. The R&T Foresight Synthesis Report was launched at a gala event under the patronage of President Mbeki, but the intended Foresight Implementation Plan was later abandoned due to a lack of donor funds, thereby raising serious questions regarding the original intent. There is no available evidence that the Audit influenced the Foresight, nor that the Foresight had a strong influence on the way that DACST policy unfolded. The Foresight study was also not independently evaluated.

The policy maker requires complete, relevant, valid, accurate, timely and maintainable STI information to serve as the basis for decision making. STI data reposes in a diverse range of organizations, including StatsSA, the SA Reserve Bank, SA Patent Office, dti, Industrial Development Corporation (IDC), NRF, DHET-HEMIS, HSRC Centre for Science, Technology and Innovation Indicators (CeSTII), and Stellenbosch University-CREST. The DST/NRF Research Information Management System (RIMS) remains a work in progress, and the NACI STI Information Portal is yet to take shape. There is an overall absence of coordination across these repositories so that one might term the situation as one that is 'data rich, but information poor.' Many of these data sources are inaccessible to independent researchers and the informed public, further limiting potential use of the databases.

In the case of the R&D Surveys the published value for GERD: GDP has remained static for several years despite the fact of increasing state funding for the system of innovation. This raises questions regarding survey accuracy, capacity and coverage.[14] The implication is that more resources need to be deployed toward obtaining a complete R&D survey, lest decisions be made based upon partial data.

14 Two examples suffice. R&D Survey 2013/14 (DST, 2015c) reports R&D expenditure for NRF National Facilities of R249 million, but this value excludes SKA expenditure of R199 million. There is also the historic problem of how to impute space charges for public sector entities.

As mentioned above there are other gaps in system information. The Innovation Surveys have stalled, and in any case, their design is limited to the private sector only so that public sector innovation, social innovation and informal sector innovation are automatically excluded. There is also a dearth of case studies on innovating firms, be these operating domestically or internationally.

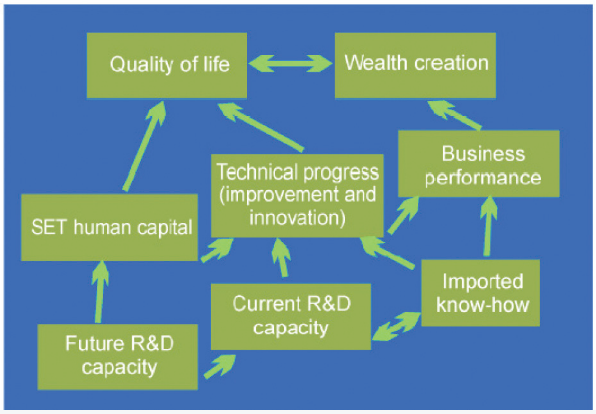
5.3 Towards system steerage

The assertions, targets and recommendations of the two main steerage instruments are now evaluated. Given time and information constraints this evaluation constitutes expert judgement, tested as possible with stakeholders.

5.3.1 R&D Strategy

The first policy instrument for examination is the R&D Strategy. Unlike the White Paper, the ToC underpinning the R&D Strategy may be characterized concisely. The R&D Strategy is quite explicit in articulating its ToC via a schematic (Figure 6) whereby R&D drives innovation and associated (positive) outcomes. This amounts to the endorsement of a linear model of innovation. It is significant that this schematic was fully adopted by DST and NACI, appearing in their policy statements and reports over an extended period, as in the formulation of the Ten-Year Plan for Innovation (DST, 2007) and the indicator reports of NACI (2013; 2015) that follow the schematic logic box by box and according to its sequential logic. Linear model thinking is thereby deeply ingrained in the DST and NACI worldview.

Figure 6. From capacity to outcomes - how R&D impacts economic growth and quality of life (DST, 2002)



This schematic places R&D at the core of the NSI, and is avowedly supply-side driven. In essence, the logic is that R&D is the main driver of innovation, much as was stated in the White Paper definition of innovation. Accordingly, the Strategy represents a clear shift from innovation systems thinking to that of a research-led system. It should also be recorded that the R&D Strategy was crafted internally to DST. There was no stakeholder process. The detailed articulation of the R&D Strategy logic, intents and associated outcomes are laid out in Table 14 below.

Table 14. Analysis of the R&D Strategy

The termination of key technology missions resulted in a drop in GERD: GDP from 1,1% (1990) to 0,7% (1994).
This is an incorrect assertion as the key military missions were already terminated from late 1988 (Batchelor and Willett, 1998). The recorded drop was most likely an R&D Survey artefact.
Adequate responses to new diseases and to old forms of new diseases, whether these diseases affect humans or animals, need to be informed by local research programmes.
This is a sound choice, but there was a demonstrable lack of response to the HIV epidemic, the gap being filled by the Treatment Action Campaign and health science research community.
From a security perspective, even being a smart buyer of rapidly developing technology rather than a developer requires a critical mass of local scientists doing research in relevant areas.
A sound approach, but in general critical mass was not attained in key fields of interest.
S&T capacity is losing ground - an overwhelmingly white, male and ageing scientific population is not being replaced by younger groupings more representative of our demographics.
This assertion is based on an extrapolation of information on the Higher Education sector. Replacement has occurred most strongly in the PROs. Weakness of school science and mathematics and immigration policy restrict growth. Gains are being made in engineering and social sciences.
Reduced levels of both investment and performance by the South African private sector in R&D.
This assertion is contradicted by the R&D Survey post 2001/2. The data upon which the claim was made remains unknown.
Inadequate intellectual property legislation and infrastructure.
Benefit sharing legislation was promulgated in 2008, and NIPMO was duly created. The assertion suggests overall lack of capacity, which is not reflected in the acknowledged expertise of the IP legal community. The IPRPFRD Act is under review and it is too soon to determine impact.
Fragmented governance structures - setting output targets for PROs – aim for synergy and holistic view of S&T spending by government.
This assertion is difficult to assess since the PROs set their own policy and enter compacts with Ministers. Central coordination is elusive, as is shown in the difficulty encountered in collating cross government budgets for R&D and Scientific and Technological Activities (STA).
It is critical … that we strategically support our global science initiatives far more actively than we have done in the past
There has been exemplary participation in the EU Framework Programmes; DST has influenced NEPAD and AU S&T policy and its Flagship programmes. SA supports the SANBio project and has hosted numerous high-profile STI conferences. She is the site of the largest component of the SKA.
Mission 1. Biotechnology
Following the National Biotechnology Strategy (DACST, 2001) four Biotechnology Regional Innovation Centres were established. These utilized some R1 billion before being absorbed into the new TIA. There were very limited IP production and commercial outcomes up to the inception of the Ten-Year Innovation Plan (TYIP) (Cloete et al., 2007).
Mission 2. Information Technology
ICT development has occurred independently in the business sector and public sector. In the latter area, CSIR Icomtek was re-launched as the Meraka Institute. DST lobbied for and provided the funds for a High-Performance Computing Centre, as well as support for the SA National Research Network. The subvention of the Sunsat microsatellite held out promise for developing a local industry. Even so no significant startups emerged – Shuttleworth, the major innovator, did not utilize government support. PRO outputs were lower keyed, but still important, as, for example, the wireless mesh technology, digital operations research, and telemetry.
Mission 3. Technology for manufacturing
Technology for manufacturing was largely driven through the Advanced Manufacturing Technology Centre set up at CSIR. Its achievement, bar the deployment of Fab labs, remains unknown and was not addressed in either of the 2003 and 2009 CSIR Reviews. AMTS was absorbed into the TIA in 2009.
Mission 4. Technology to leverage knowledge and technology from, and add value to, natural resources sectors

CSIR absorbed the Chamber of Mines Research Organization and continued to work on rock mechanics with some notable success. Support was given to coal research through the Deep mine Project. Resources were also targeted at Titanium with major backing from DST. Platinum research 'toward the hydrogen economy' was promoted through five Centres of Competence that worked with Impala Platinum, while applications for fluorochemistry were centred on NECSA Pelchem. Attempts to find a strategic partner to develop pharmaceutical applications for fluorine were unsuccessful. Nuclear engineering was revived through the construction of the helium test rig at Pelindaba, though that work ceased when the Pebble Bed Modular Reactor was terminated.

Mission 5. Technology for poverty reduction

European Union funds served as the main source of support. According to OECD (2007), there was limited evidence of a determined thrust toward addressing poverty.

Termination of the Science Vote

The introduction of the Strategic Management Model (SMM) signalled the ending of the Science Vote as of 2004/05. The SMM sought to located sectoral research within the relevant home departments with DST playing the lead role in frontier science. The NACI role as allocator of the Science Vote ended, as did the limited scope for coordination through central budgeting.

The NRF will be the lead agency for human resource development through the pursuit of excellence in areas of important natural or knowledge advantages - astronomy, human palaeontology and indigenous knowledge.

The ongoing pattern of grant awards mirrors researcher demographics; the selection mechanisms remain unknown; IKS outputs are not visible. The Rating System was extended to the Social Sciences and Humanities from 2006, with SARChI instituted from 2007 along with the Centres of Excellence. Expanded support to the Innovation Fund saw considerable growth in budget and staff skilling. Astronomy and human palaeontology continued to capture the public imagination.

Creating a clear distinction between sector-specific line departments and the DST, which should play an integrative role.

See comments on the SMM. There is some evidence of core budget shortfalls, and the integrative role of DST is far from evident (see also NACI, 2016).

Ensure international best practice w.r.t. government funding of STI.

This attribute is not directly measurable being evidenced in the introduction of the R&D tax incentive and the IPRPFRD Act.

DST to coordinate coherent performance management system for all government-owned laboratories. DST to report on cross-government R&D budget

See comments on the SMM. The Balanced Scorecard approach of 1998 remains in place with each science council making it sown adaptations.

The Foundation for Education Science (FEST) and Technology to become the Institute for the Promotion of Science

IPS was not created; FEST was de-proclaimed and transferred to NRF where it became SAASTA.

Foundation for Technological Innovation (pending) — financing agency for innovation in technology missions across public and private sectors, from concept to market – though, with a key focus on high-cost development and market acceptance stages through commercialisation, incubation and diffusion.

FPI was created in 2008 as the TIA. by merging the BRICs, Innovation Fund, Thumisamo incubators, and AMTS. The formation of TIA encountered difficulties with staff exodus, forensic investigation, board replacement, and subsequent re-launch. There was loss of financial and human capital with little output. TIA remains a work in progress.

Relocation of the CSIR

CSIR was transferred to DST after 2004. Since then its contract income from industry declined from 25% of revenue in the early 2000s to 6,8% in 2015 (Walwyn and Scholes, 2006; CSIR 2015: 147). 'Contract' flows from DST and the public sector substituted for this shift of income sourcing. CSIR replaced its strapline 'Your technology partner' with 'Our future through science.'

Revitalization of HSRC

HSRC underwent restructuring in 2001 to become a client-facing organization. Subsequently, contract income rose to almost 50% of revenue alongside steep growth in scientific output. Concerns with loss of state control were raised in Parliament. HSRC continues to perform important work on the aetiology of HIV especially nosocomial causes, as well as on social cohesion.

Line departments would have the responsibility to set research goals and budgets of their PROs and would be involved in innovation in collaboration with DST.

Science Council autonomy was maintained. Strategies were adapted to reflect national priorities and frameworks. Collaborative 'innovation' remains difficult to enumerate, though the prevalence of contracts with government departments suggests that a gap is being filled. Further inquiry is needed in this regard. There is some evidence of line department reluctance to increase baseline budgeting for their Science Councils. The inclusion of performance reporting in the Auditor-General audit process increases management burden and the risk of perverse compliance.

Basic research to be a shared function of DST and Department of Education (DoE).

This goal might have been achieved by default. The DoE/DHET formula-based subsidy for university research is mainly oriented toward basic research and comprises an R3 billion transfer to central university funding. DST exercises a light steerage role through the selection of SARChI and CoE foci.

Venture capital stimulation and fiscal incentives… the responsibility of DTI and…and IDC

Little was accomplished in this area. Startups appear to be wary of state equity demands in return for public funding.

The R&D Strategy depends on doubling government investment in S&T by 2005/06 to raise the GERD: GDP to somewhat over 1%

Nominal doubling of Government intramural expenditure on R&D (GOVERD) was achieved; GERD: GDP peaked at 0.95% in 2006/07 declining thereafter as the PBMR was terminated and the global recession impacted.

To summarize, implementation of the R&D Strategy was most apparent in the rearrangement of the organizational landscape, the introduction of new incentives for research, and the provision of R&D infrastructure. The formation of TIA through the merging of seven organizations was a challenging process that might serve as an object lesson for future restructuring efforts.

Regarding innovation activities and outputs, it is difficult to detect shifts in focus and output that are directly attributable to the Strategy. In fact, the Strategy was not accompanied by a blueprint, perhaps reflecting the distributed, autonomous and self-organizing nature of the innovation system.

5.3.2 Ten-Year Innovation Plan

The crafting of the Ten-Year Innovation Plan (TYIP) occurred ahead of, and in parallel with the OECD Review. Like the R&D Strategy, the Plan was developed internally by the Department. While sketching out desired outcomes a decade into the future, the Plan demonstrates deep continuity of approach with the R&D Strategy. The Plan is structured around five Grand Challenges, very much in line with the then widespread enthusiasm for Grand Challenge approaches to innovation policy. The crafters of the TYIP argued the Plan would provide 'a forward-looking blueprint that charts the course for growth in science, technology and innovation' (DST, 2008: iv) with specific targets set for each Grand Challenge. The Farmer to Pharma grand challenge builds on the biotechnology mission of the R&D Strategy; Space S&T shows continuity with the ICT Mission; Energy Supply is similar to the natural resources Mission; Human and Social Dynamics is identical to the Poverty Reduction Mission. Global Dynamics (Climate Change) is a stronger articulation of previous attention to environmental science and the Southern Geographic Advantage. So, there is much continuity of focus, with the organizing schematic of the Plan echoing the linear model of the R&D Strategy (idem: 9).

A brief appraisal of each Grand Challenge is presented as Table 15.

Table 15: Analysis of the Ten-Year Innovation Plan
I. Farmer to Pharma (Bio-economy)
Target: Being one of the top three emerging economies in the global pharmaceutical industry, based on an expansive innovation system using the nation's indigenous knowledge and rich biodiversity. Not attained though JSE listed Aspen (Pty) Ltd is now the largest producer of generic pharmaceuticals in the southern hemisphere. Aspen does not produce its own active pharmaceutical ingredients, but has expanded into such production through licencing agreements and acquisitions.
II. Space science and technology (Information technology)
Target: Deploying satellites that provide a range of scientific, security and specialised services for the government, the public and the private sector. Stellenbosch University spin-out company Sunsat received support to design and build three micro-satellites. But Sunsat fell into debt, collapsed and was then absorbed into the new SA National Space Agency (SANSA). Radio-astronomy was supported through KAT-7 and MeerKat, that sourced detectors from EMSS. KAT-7 successes was instrumental to the bid to host the SKA.
III. Global change science with a focus on climate change
Target: Being a world leader in climate science and the response to climate change. Many South African scientists have served on the Intergovernmental Panel on Climate Change (IPCC). Some nine SARChI professors declare specific research interests in Climate Change.
IV. Energy Supply (Technology to leverage knowledge and technology from, and add value to, natural resources sectors)
Target: A diversified, supply secured sustainable energy sector, and achieving a 25% share of the global hydrogen and fuel cell catalysts market with novel platinum group metal (PGM) catalysts. A secured 'sustainable' energy mix came about despite electricity supply failures and reluctance to embrace renewable energy resources. The belated opening of the electricity market via the IPP process was a success, demonstrating the benefits of public-private partnerships. Late adoption of technologies, under considerable pressure to fill the energy shortfalls, saw the technologies imported, with little local R&D content. The 25% target for full cell catalysts was not met. Fuel cell R&D is in place through the HySA CoC. Further resources will be needed to deepen capacity and boost scientific outputs if HySA is to become a global leader.
V. Human and social dynamics (Technology for poverty reduction)
Target: Meet the 2014 Millennium Development Goals to halve poverty. StatsSA (2013) reports that this Goal was achieved. The underlying driver thereof is the system of social grants that provide a safety net for children, the elderly and the structurally unemployed

As part of the drive toward a knowledge-based economy, the TYIP set indicators and targets (Table 16) to guide the direction of investments and actions over the next decade (idem: 8).

Many of these indicators were considered in Chapter 4.0, so the present analysis will be limited to indicators 1 to 5.

A construct that might have informed the idea of the 'innovation chasm' (1) is the prior 'technology colony' model of CSIR executive De Wet (1999) that then morphed into the narrative of the 'innovation chasm.' The idea of an innovation chasm is similar to the 'valley of death,' namely the part of the innovation adoption cycle where failure is most likely due to lack of funding – 'which means improving access to finance, creating an innovation-friendly regulatory environment and strengthening the NSI' (DST, 2008: viii).

Table 16. Toward a knowledge based economy

Indicator	2018	2016
1. Address the 'innovation chasm'	?	?
2. Economic growth attributable to technical progress	30	15
3. National income derived from knowledge-based industries	>50	?
4. Proportion of workforce in knowledge-based jobs	>50	?
5. % Of firms using technology to innovate	>50	65
6. GERD/GDP (0.92 in 2005; short-term 2008 target was 1%)	2	0.73
7. Global share of research outputs (0.5% in 2002)	1	0.8
8. High and med-tech exports/services % of exports/services	55	36**
9. Number of South African-originated US patents	250	140
10. University exemption in mathematics and physical science	10	8*
101. % Science, Engineering and Technology (SET) graduates in public higher education (28% in 2005)	35	29
12. Number of SET PhD graduates per year (561 in 2005)	3 000	1130
13. Number of full-time equivalent researchers	20 000	11644
14. FTE researchers/1000 workforce employed	2.6	1.6

*Notes and Sources: * not comparable; ** Matthee et al., 2016.*

Indicators 2 to 4 could not be updated, as the methodology underpinning their selection is unknown. Indicator 5 is also problematic – the first official Innovation Survey recorded that 53% of South African firms as innovating. This value placed South Africa among the top three most innovative countries recorded in such surveys; three years later the figure had risen to an improbable 65%. This sharp rise came about through a decision on categorization whereby firms that abandoned an innovation process were counted as innovators. The innovation surveys seek to generate large data sets that may be interrogated to inform policy. Extending and improving these surveys remains an essential task for the DST.

Noting the high rate of innovation recorded a decade back one might conclude that the success of South African firms abroad suggests innovation adroitness, rather than a chasm. These companies are worthy of further investigation, perhaps through future innovation surveys. It may be noted that the present instrument already includes some items that may be used to fill this information gap.

Meeting the stretch targets of the TYIP was always going to be a challenge; none has been fully attained, with those for PhDs and researchers demonstrating the largest shortfalls. The Plan, as successor to the R&D Strategy, continues with a supply-side R&D driven ToC, but the education system has been unable to meet the set target for Human Capital Development (HCD).[15]

Performance toward meeting the Grand Challenges has been patchy. The bio-economy thrust has been slow to take form. Energy supply was a debacle, whose genesis and resolution lies beyond the span of influence of DST. The fact that renewables came to the rescue of the grid is a tribute to the ability of industry and government to work together using local project management and engineering skills to assemble solutions at short notice, so much so that renewables now provide close to 5% of electric power.

15 The ASSAf (2010) PhD Study offers recommendations to address the shortfall.

Space science and technology enjoys the successes associated with KAT-7 and the first light event of MeerKAT. These projects demonstrate significant local expertise in signal detection and processing, and speak to the resilience of the telemetry sectoral system of innovation. DST support has been pivotal to this work.

In climate change, South Africa has a voice in the structures of the IPCC, thereby recognizing expertise in the fields of ecology, environmental science, water resources and modelling.

As to human and social dynamics, much has been contributed to understanding the aetiology of HIV. There are other examples of public sector innovation as in the new portal for educator support, the system of social grants, and online tax collection. These innovations are essentially non-technological in character, with their execution depending upon the supply of skills from the higher education in general. The poverty reduction MDG was attained, even as inequality has remained stubbornly high. It might be fair to conclude that little has emerged regarding the direct relationship between STI and socio-economic development.

It is also important to recognize that the precepts and targets of the TYIP gained traction beyond the DST, informing the technology policy section of the New Growth Path (DED, 2010: 23) and the various iterations of the IPAP from 2010 going forward.

Human capital needs were to be dealt with via the new system of Delivery Agreements between Ministers and the Presidency, notably Delivery Agreement 5, §4 whereby DHET and DST were to work together to increase graduate outputs. However, the DHET doctoral output was pegged below the TYIP target, to be 1350 by 2014, suggesting differing viewpoints between the two Departments.

5.4 Towards system learning

This section explores two major post-1996 reviews of the NSI, namely, the *Review of Innovation Policy* (OECD, 2007), and the *Ministerial Review of the STI Landscape* (DST, 2012).

5.4.1 OECD Review of Innovation Policy

The standard OECD Innovation Policy Review template was followed for this study: construction of a country self-assessment (NACI, 2006); expert team on-site investigation and assessment; presentation of the findings in a challenge-response format; and finalization. The OECD (2007) tendered its innovation policy advice immediately prior to the global financial crisis while the TYIP was being formulated. Its main findings are as follows:

> The radical political changes in the 1990s did not lead to collapse of the former innovation system, since many of its basic building blocks remained in place while being restructured, re-scaled and reoriented, with new elements being added (OECD, 2007: 4).
> There is no clear understanding of what the contribution of the overall innovation system actually is – and hence no basis for assessing whether it is adequate or not… The compelling vision for innovation-driven national economic and social development articulated in the 1996 White Paper has not been adopted widely enough by the Cabinet or within the range of government departments to achieve the intended pervasive impact… the national innovation system is not making an adequate contribution to poverty reduction and the erosion of the second economy… [and]… the ageing structure of research performers in universities, combined with the limited ability of the human resource pipeline to deliver sufficient replacement cohorts, suggests that, far from being expandable, the current levels of university R&D may not even be sustainable (7).

> At every level of the system – in the different science and technology fields, publicly funded research organizations, national projects and support for new sectoral innovation systems there is evidence that resources available are too limited to have the desired impact (8).
> Innovation policy should be receptive to the needs expressed by all stakeholders, extending beyond the STI community (11).

In essence, the OECD (2007) argued that South African innovation policy assigned too large a role to the State and that more space should be accorded to the role of the business sector. The recommendations warned of the dangers inherent in the country's torn social fabric and that much more had to be done to address social needs.

It might have been expected that the Review would evoke a considered response from the Department. The public expressed satisfaction with the Review and strong appreciation for its endorsement of the planned TIA that was incubating in the Department after a gestation period of five years. The official response to the Review was via a NACI Advisory to the Minister that resulted in a restricted Cabinet Memorandum.
That period overlapped with the 2004 appointment of the first scientist to occupy the Ministry, a Minister who then forged strong relationships beyond the DoE, especially with the Department of Public Enterprises (DPE), that was responsible for the PBMR. This relationship found the two Ministers leading the 2005 discussion on human resources for knowledge production that *inter alia* created the momentum for founding the SARChI. The DoE appeared to be absent from these discussions.

Subsequently, the 2009 General Election saw the appointment of a new Minister of Science and Technology, previously at Education, who set up the Ministerial Review of the STI Landscape.

5.4.2 Ministerial Review of the STI Landscape

The ten-person Review Committee was mainly comprised of academics from higher education and was tasked with:

1. Assessing the OECD Review and its recommendations, key policies, strategies and reports of the DST and its public entities, the role of the private sector in STI, and
2. Making recommendations on the framework conditions to achieve coordination and coherence… (to) deliver innovation-driven national economic and social development, appropriate institutional arrangements and structures, and the location and levels of investment responsibility for the NSI.

Further to the task, the Committee found that:

> No formal response to the OECD Review of the NSI was ever made public. Shortly thereafter, the DST's Ten-Year Innovation Plan (TYIP) appeared, but some of the most central recommendations of the OECD Review were not addressed in the plan, especially bringing the private sector more centrally into the NSI, and resolving the considerable vertical and horizontal coordination difficulties arising from the current governance and institutional architecture of the NSI… The fundamental need for a platform authoritative enough to coordinate and steer both state and other sectoral innovation remained unresolved (DST, 2012: 9).

It framed its work within the dominant innovation system paradigm, performing its assessment against the attributes that a well-functioning innovation system might be expected to meet, namely to assure enabling conditions, provision of skilled personnel, support for linkages and knowledge exchange, provision of infrastructure, and mechanisms for system learning. The Ministerial Review recommendations and evaluative comments follow in Table 17. To assist in the appraisal of the recommendations those where there is clear evidence of full or partial implementation are **highlighted in green**.

Table 17. Recommendations of the Ministerial Review
1. Establish a National Council on Research and Innovation (NCRI) for the prioritisation, for agenda-setting, oversight and high-level monitoring
Not implemented. Top level STI policy makers felt that such a body might duplicate the role of the National Planning Commission. Possible overlap with envisaged IPAP Industry Research and Advisory Programme.
2. Research and Innovation Vote should be established… to function as a macro-coordinating mechanism to ensure that the country's public researchers in all public research-performing institutions are adequately supported
The need for this new instrument was already announced in the Minister's motivation for the 2011 S&T Budget Vote. The Research and Innovation Vote remains a subject of ongoing negotiation
3. NACI should be transformed into a new statutory Office for Research and Innovation Policy (ORIP).
Not implemented. However, steps have been taken to promote system coordination through a broad-based NACI Board that includes the heads of all science councils.
4. The Ministry and Department of Science and Technology should henceforth primarily function as a pervasive, systemic formulator and coordinator of NSI-related policy and strategy, consistent with the decisions of the NCRI, allocating macro-resources, promoting system learning through the oversight of effective and integrated monitoring and evaluation, maximising international cooperation and resources, systemically overseeing public research organisations, and providing best-possible knowledge infrastructure
Given that the NCRI and ORIP were not implemented, Recommendation 4 would no longer apply. Full system oversight and coordination remain beyond the span of influence of the Ministry.
5. The NSI needs at least three well-functioning 'core' policy nexuses, each structured through a written collaboration agreement spelling out how policy harmonisation and the coordination of implementation action plans would be ensured
Not implemented. These actions relied upon the implementation of Recommendations 1-4.
6. Purposeful elaboration of a new, additional mode of public grant-making based on the principle of cooperatively allocated sectoral funds. The priority sectors… (to) be identified by the NCRI from time to time
This new mechanism has been implemented through the new Sector Innovation Fund and nine Sector Innovation Programmes (SIPs). In accord with Review thinking the SIPs bring a range of parties together to determine STI needs and then jointly to fund STI projects. DST has taken on the brokering role that NCRI could have effected.
7. NCRI should commission a review of the science councils and all other public research organisations (PROs).
DST has commissioned the STI Institutional Landscape (STIIL) review. This remains a work in progress. Its findings were unavailable to the investigators at the time of writing.
8. Systematic efforts should be made to bring industry and government closer together, and to strengthen the response of the system to demand signals from business and industry, on the one hand, and social spheres, on the other hand.
The absence of the NCRI maintains a hiatus in ensuring that demand signals are understood and acted upon timeously. This recommendation is partially addressed through §6 above.
9. Government departments that form the key pillars of the research and innovation system must draw to their ranks staff with direct experience of the business, civil and research environments so as to enable cross-sectoral collaboration.
Not implementable. This was a bold recommendation of the Review
10. Review of present and further possible incentive schemes for their accessibility, simplicity and effectiveness, with broadening as required (THRIP, SPII, tax concessions).
DPME has conducted evaluations of THRIP and SPII; these documents are available at www.dpme.gov.za. The R&D Tax Incentive review is available at www.dst.gov.za
11. The Technology Innovation Agency (TIA) should immediately be externally reviewed in terms of 'fitness for purpose', aimed mainly at promoting its success as a pivotal new element in the NSI. The National Intellectual Property Management Office (NIPMO) should likewise be formatively reviewed after a further period of initial functioning.
Review of TIA implemented, but findings are not in the public domain. NIPMO is functioning as envisaged.
12. Immigration policies and intellectual property regimes need to enable the openness of the NSI.
Scarce skills regulations are 'under review;' anecdotal evidence is that immigrant skills are discouraged. The impact of the IPRPFRD has not been assessed; the IPRPFRD Act is under review.
13. An explicit strategy should be developed for the advancement of social innovation within the National System of Innovation… (including) a multi-stakeholder forum, mandated by the NCRI, to advise government on a limited number of national social innovation priorities… and a Social Innovation Fund
Not implemented as envisioned; a Task Team on Innovation for Inclusive Development is completing its work.
14 – 22
These somewhat partisan recommendations on human capital development and higher education argued for greater resources to be redirected toward higher education, a decision beyond the span of influence of DST. Nonetheless, DST did expand the SARChI and CoE programmes with subsequent evaluations finding that both succeeded in retaining skills and growing next generation researchers. SARChI has created 192 research chairs who supervise over a thousand doctoral and post-doctoral students. The sixteen CoEs have the potential to expand further, but there are claims of competition from the SARChI programme. Fedderke and Velez (2013) have criticized SARChI selection criteria questioning whether it represents efficient use of scarce resources.
23-28

These recommendations address Knowledge Infrastructure. It is noted that the Infrastructure Roadmap has been published, and that considerable resources have flowed toward SANReN, the Centre for High Performance Computing (CHPC) and radio astronomy.
29 ORIP is to (become) a centralised facility to serve as a repository of evaluation information on the NSI, and an expert site for its distillation and distribution to inform strategy and steerage at the highest levels and more broadly.
Not implemented. The location and function of HSRC-CeSTII was investigated in 2013, it being decided that the Centre would remain in HSRC. The coordination of STI information remains unresolved.
30-34
Recommendations address MEL more broadly; call for institutionalization of Foresight. Not implemented.
35-42
Recommendations deal with basic and higher education, financing, incentives and public-private sector relationships more generally. They constitute 'advice,' difficult to act upon due to limited span of influence.

It is obvious that few recommendations fall into this class. The response of the DST appears to have been to defer the adoption of the recommendations which impacted directly on its established mandate and, instead, move ahead in areas within its span of influence and for which funding became available, as in international networks, infrastructure, SARChI, CoE, etc. For reasons outlined above, the 'apex' measures were not adopted. Recommendations on higher education that fell within the span of influence of DST were promoted; others that were closer to the thinking of the Committee members from the higher education sector were not.

5.5 National Development Plan

Last for discussion is the National Development Plan (NDP), the seminal work of the first National Planning Commission. The Cabinet-approved Plan placed innovation central to its vision, with the words 'innovation' or 'innovative' appearing no less than 145 times in its four hundred pages. In so doing the Plan raised awareness of the intrinsic value of research and innovation, arguing that 'South Africa needs to sharpen its innovative edge and continue contributing to global scientific and technological advancement. This requires greater investment in R&D, better use of existing resources, and more nimble institutions that facilitate innovation and enhanced cooperation between public S&T institutions and the private sector' (The Presidency, 2012: 33).

The Plan articulates a bold future for the country with numerous areas where STI would play an important role in supporting the emergence of new industries, increasing arable land, and creating new farming methods, to mention but a few. The Plan offers important recommendations on skill formation and retention, notably to offer seven-year work permits to foreign doctoral graduates, and most importantly to improve staff qualifications in higher education. There is much to celebrate in Vision 2030.

Where the Plan falls short is through uncritical repeating of the substance and targets of the TYIP. Moreover, the Plan introduces a contradiction regarding the role of the state in the innovation process. On the one hand, it avers that 'The best solution is for the state to play an active role both in funding and in guiding the type of research and development that the private and public sectors conduct' (idem: 131) and on the other hand that 'The freedom of scientists to investigate and of entrepreneurs to innovate is critical' (idem: 331). The tension between these two positions calls for more detailed elaboration.

5.6 What worked?

The starting point of the qualitative analysis was the White Paper. It is difficult to evaluate the social contract of that visionary document, a contract perhaps too broadly scoped, and likely to fall short. 'STI for society' would have had to be driven at the highest level of government, as a standing item demanding regular attention of Cabinet, but was not. This possibility ended with the demise of the Ministers' Council on S&T.

Considerable organizational innovation and change has taken place. For example, the Innovation Fund began life inside DACST. It then migrated to the NRF where it remained for a decade and grew an expert team, after which it was merged into TIA, there to be joined with the four BRICs. The IF had initially functioned through the mode of competitive thematic calls but became less focussed with time. In its later phase, the IF also backed the Joule electric vehicle project into which some R450 million was invested before the project was abandoned. While the IF pioneered the concept of the 'living evaluator,' namely an expert who worked with each funded project during its life cycle, no authoritative *post hoc* evaluation of the value gained from the close to R2 billion invested in the IF is in the public domain. Much organizational development occurred, but the associated learning is in danger of being lost.

Across the divide, the vitality of the services sector is largely due to non-technological innovation, an activity that has not received advocacy through the above policy statements.

On the other hand, NRF has produced regular evaluations of its major human capital development thrusts, notably SARChI and the Centres of Excellence (NRF, 2010). The most recent NRF evaluation (Ofir, 2016) inquired into the social impact of the SARChI and CoE programmes, Thuthuka, the Grants and Equipment projects, and found that potential socioeconomic impact was strongly determined by the nature and focal area of scientific inquiry so that it was not always possible to show, or even to demand evidence of 'value for money.' The evaluation was not tasked to determine the desirability of the projects under scrutiny, but rather their utility in action. This type of evaluation is a significant step towards learning, accountability and transparency.

One of the important functions of the innovation system is to provide scientific and technical advice to government and other actors. How then does this advisory activity manifest in South Africa? To what extent can and does NACI play this role? Do we understand the nature, depth and competence of advisory capacity across the system? Is the highly decentralized corpus of knowledge adequate to the increasing complex times we live in? To what extent are the ASSAf consensus reports being utilized by decision-makers? What is obvious is that when government issues a call for informed comment or advice, civil society, the universities, business, labour and academia response vigorously. This is a sign of a mature innovation system replete with disciplinary knowledge, learned associations, chambers of commerce, business associations, industry lobby groups, registrars, and professional organizations. There is considerable expertise available to the government on request, even on a *pro bono* basis. This is an unacknowledged strength of the system. This capacity arises from the pursuit of curiosity-driven research, applied research, and user-oriented research, much of which arises through the self-organizing nature of science itself.

Other organizational innovations include the SANReN rollout, the Microscopy Centre at NMMU, university CoEs and CoCs, a pilot plant to produce foot and mouth disease vaccine, and facilities such as IIDMM at UCT; DDMRI at UKZN, the Wits Reproductive Health and HIV Institute, SALT, KAT-7 and MeerKAT.
In terms of their inbuilt ToC, a number of aspects of the R&D Strategy 'worked' as did those attributed to the TYIP. These successes include the organizational changes involving CSIR, NRF, TIA, NIPMO, SAASTA and SANSA. The more ambitious quantitative targets were not attained.

The thread linking White Paper, R&D Strategy and TYIP is the translation of R&D into commercializable products through a linear model of innovation. This success has been much less in evidence than intended, despite the R&D Tax incentive and the IPRPFRD Act. On the other hand, the research base provided through Flagship science has prospered in the form of palaeontology, astronomy, mathematics and theoretical physics projects. Health science has prospered with very strong international links to governmental and multilateral donors and philanthropies.

Achievement in the field of Indigenous Knowledge Systems (IKS) remains hard to assess, possibly because local traditional knowledge, unlike the cases of India, China and other eastern countries, is essentially uncodified and passed on by instruction. IKS practitioner claims are therefore difficult to pin down. It is possible that interaction with Latin American IKS, also an uncodified body of knowledge might yield benefit.

Read today, the OECD (2007) was prescient in raising the spectre of civil unrest as a consequence of service delivery failures, or, put differently, the inability of the economy to enable the poor to enter the mainstream either as employees or as first-time entrepreneurs. Service delivery failure is largely political in nature rather than arising through technical knowledge deficits – a phenomenon that might be termed the poverty of politics, rather than a poverty of technology *per se*.

DST, through Mission 5 of the R&D Strategy, and Grand Challenge 5 of the Ten-Year Plan has used soft money to create a number of technology demonstrators, but subsequent dissemination as ‘innovation’ is hard to find. The intentions might have been noble, but take up has not occurred. Independent impact evaluation that examines the needs (and assumptions) that these demonstrators were to meet is urgently needed.

6. Critique

The concluding chapter provides a summative view of what worked, and what did not, followed by recommendations for action.

What then is the summative view - is the NSI glass half full or half empty? The answer has two parts, firstly that the glass is perhaps half full. It was never intended to be full for all.

The second is that there is a clear and present danger that the contents of the glass may stagnate. There are pockets of excellence, many below critical mass, but the constraints on the system are stretching it to breaking point.

These assertions should be understood in the context of an economy that has pockets of wealth, in a sea of poverty, and that is underperforming against a host of measures. Innovation does occur in all sectors, public, private and informal and South African firms simply could not flourish on the global stage without the wherewithal that the NSI provides. Yet present growth is close to zero so that even 'trickle down' cannot occur. To an extent, the NSI is but a reflection of the socio-economic milieu in which it is embedded.

The White Paper set out a social contract that promoted science excellence and science and technology for all. The resulting policy mix was largely focused on excellence by way of the R&D Strategy and the TYIP, assisted through instruments such as the DHET Subsidy Formula, NRF Rating Scheme, Innovation Fund, R&D Tax Incentive, SARChI, CoEs and CoCs. These instruments largely support 'own science,' with some directed research. Strong support was given to the mega-science projects for commercial and science cultural reasons.

Yet, the quest of science and technology for all did not receive major emphasis from the government, as evidenced in the reliance on donor funding for the realization of the poverty reduction and alleviation goals in both the R&D Strategy and TYIP. The social contract is a continuation of the pre-1994 accommodation.
If sustaining curiosity led research was the overarching goal of the White Paper, then the policy mix was appropriate to that end, the elusive target of attaining GERD: GDP of 1% notwithstanding. Breaking through the 1% level is needed if a shift from resource exploitation to deeper knowledge working is to be achieved. But, such as shift is predicated on a change in the industrial mix – R&D spending becomes necessary as one's product or process mix becomes more complex and engages with serious competitors. As this frontier is encountered, R&D becomes necessary. If industry remains a 'business as usual' mode, R&D would be a luxury.

This goes some way in explaining why, if the NSI goals were innovation, economic growth and reduction in unemployment, both the public and private sectors were less than successful. To this should be added the low Business Confidence Index, as well as external assessments of the country's economic prospects all of which point to the need for structural changes. These shortcomings cannot be attributed solely to the NSI, its associated policies and leadership.

As already discussed, with the exceptions of the IPPFRD that provides for benefit sharing, and the Sectoral Innovation Programmes, the policy mix is based on linear model science push rather than demand-led response to need. By design, the White Paper on Science and Technology speaks more to science than innovation. Yet the dti and EDD have significant funds to promote small and medium-sized business development, product and process innovation. Division into silos is a constant of governance.

The OECD, Ministerial and White Paper Reviews concur on the subject of science push, but exhibit fundamental differences as to the future role of the state. For the OECD Review, the innovation policy mix gave too strong a role to the state. A softer enabling stance was advocated through which business would take the lead, except where there was market failure in the provision of public goods.

By contrast the Ministerial Review envisaged a stronger role for the state not only as funder, but as broker in the prioritization, agenda setting and coordination process. The state was further urged to hold public sector entities to account, and to ensure that higher education research was more adequately supported. The latter emphasis probably reflected the dominant membership of higher education in the Review Committee.

Following the Review of the White Paper, its Synthesis Report took the optimistic view that the now modernized NSI had acquired capabilities that could be transformed into innovation competencies alongside actions to mitigate social capital deficits. The state would assume the task of developing trust, social capital and partnerships across the NSI. This vision aligns with that of the NDP that calls for a new social contract. In the first instance, this would require a national dialogue under the stewardship of eminent persons, and is a task probably beyond NSI stewardship.

Three Reviews, three divergent views.
By its very nature Science involves elites that left to their agenda might find it easy to extract the wherewithal to pursue own ends. The same holds for scientist-officials. How then to set priorities and agenda, ensure accountability and avoid moral hazard? The Ministerial Review called for an NCRI, but this was not adopted as it would appear to have encountered resistance within DST whose mission was 'to coordinate and manage the NSI.'

In this context, it is noteworthy that DACST terminated the broad-based Research and Foresight Technology process that could have assisted in informing the agenda. Moreover, the lack of stakeholder involvement in the generation of both R&D Strategy and TYIP means that senior scientist-officials took it upon themselves to determine agenda and priorities, and then to attempt coordination toward these ends. Given the revolving door for sectoral department officials, DST/NACI management, and the executive layer of the science councils, it is reasonable to assume an ongoing cultural exchange whereby science council autonomy shapes departmental thinking and vice versa. The long history of CSIR and its own strongly independent stance would be an important element in this shared culture.[16]

This leads to speculation that research led policy that favours 'own' science implicitly mitigates against coordination. As Kaplan (2008) points out, a recurring policy failure is that resources are spread too thinly to achieve impact. This scattering arises through the limited span of influence of DST, but is also a consequence of the self-organizing Republic of Science, a complex adaptive system that evades coordination. The implication is that there is little real desire among scientists and among scientist-officials, for overarching coordination. In this vein, the persistent refrain of the Southern Geographic Advantage supports the philosophy of science push, with the promise of beneficiation to come. Yet possession of an asset does not mean one is best equipped to add value to that asset, nor that a market exists for the products of such. To develop and exploit natural assets requires financial, human, social and technological capital and if these are in short supply, they may have to be imported with the sharing of benefit.

Linear model thinking is a deeply ingrained in the ToC informing policy, and new mechanisms will be needed to build needs-driven and inclusive innovation. One such mechanism is the DST Sector Innovation

16 See Meiring-Naude and Brown (1977: 79), in particular the historic CSIR position that 'Research cannot be dictated and organized from above; it must grow from within the organization.'

Programme and Sector Innovation Fund that brings together stakeholders including industry associations. Such stakeholder forums are best able to identify needs and to engage in open innovation processes to share benefit. Though the present level of funding is an order of magnitude smaller than what the Ministerial Review had envisaged, the Sector Innovation Programme and Sector Innovation Fund are steps in the right direction. Addressing social inclusion and the Sustainable Development Goals (SDGs) must serve as the lodestar for policy re-orientation, with the NDP providing a roadmap for intervention and investigation. One example from the NDP serves to highlight what might be done, namely, to backcast the steps to achieve food security under conditions of climate change by extending food production to new crops, new techniques, new zones and new farmers. Other priority areas for innovation and research are energy, water, safety and security, and ecosystem sustainability.

Linking innovation and research to user needs is key to this reorientation that would *inter alia* call for a redesign of the PROs as a collective. It would also require re-appraisal of relevant legislation ranging from the co-generation of electricity, to water rights and the field testing of genetically-modified organisms (GMOs). Informal sector innovation beyond survivalist innovation is alive and well, and occurs across the country, as does criminal innovation, of which no more will be said. What role if any should government play in fostering informal sector innovation, be this at national, provincial or municipal level? One solution is for government 'to get out of the way' meaning that restrictive by-laws should be set aside where no harm is likely to occur. Informal trading was suppressed during the apartheid years, and the petty legislation that made this possible is often still on the law books and enforceable. Enabling would-be entrepreneurs to enter new markets, and to offer new products may be catered for by providing walk-in centres that would offer advice and a modest range of free services to persons wishing to forge ahead.

Next is the issue of the social impact of the NSI. Despite the change in political order, the political economy remains one that exhibits social and economic exclusion as elite groups extract opportunities for themselves. Such extraction stands central to environmental degradation and harm to human lives in the workplace and homes. The NSI is part of that political economy and may even contribute to exclusion by virtue of its high barriers to entry. The expectation that the NSI alone can solve the problems of unemployment, inequality and poverty is optimistic, unless the NSI is redefined to mean 'all societal actors' or the polity as a whole.

The performance analysis debunks the claim that the research for the social sciences and humanities is underfunded. As noted earlier, slightly more than a third of higher education research expenditure goes to these fields, a level among the highest in the world. The social sciences and humanities RCA is correspondingly high, but with moderate impact. There is real capacity to inform, shape and monitor social intervention.

What has been achieved in social innovation has come from autonomous actions by civil society, the universities and elements of the science councils, rather than as a consequence of government-directed science. This is seen, for example, in the emergence of the Treatment Action Campaign (TAC) and the response of the health science research community to HIV/AIDS. This brought social entrepreneurship activists and the Republic of Science together around a common issue. The founding of the TAC with its later spin-off Section 27 marked the re-emergence of the social entrepreneurship movement in South Africa, with civil society having taken something of a back seat during the first decade and a half of post-apartheid governance. A vibrant social entrepreneurship sector is taking form and is using social media to considerable effect as for example the RLabs counselling project in Cape Town. This activism is occurring in spite of government policy, not through it. Activists are clearly well-educated people with a vision of a better future. They acquire their skills through the post-school education and training system, sometimes through company training, in law school, journalism and education and IT departments. Parts of the system work very well.

Yet the Reviews and this analysis concur that NSI expansion is jeopardized by the lack of skilled personnel as the school-university pipeline is generally inefficient. Transformation of innovation system demographics has largely come about through the replacement of deceased staff and retirees, especially of those that had opted for voluntary retrenchment. DST programmes have supported talent, notably in mega science, and the SARChI, CoE and CoC programmes.

During the period of high economic growth, organized labour bid up public sector salary levels with spillover benefit for the research community. Faced with budget envelopes that barely kept pace with inflation, management was forced to delay the filling of vacant or new posts. As a consequence of these restrictions, the NSI is too small to meet the task at hand, is losing institutional memory and capacity, and, rare exceptions aside, much research is individual (rather than group focused) and sub-optimal in size.

Three remedial measures are suggested. The first is to improve school to post schooling-workplace efficiencies. The basic education system is failing to produce school leavers who are possessed of the wherewithal to proceed into post-school education and training with a reasonable expectation of success. On the side of the post-school institutions, there is a need to ensure that all staff have recent, relevant experience of the level at which they offer instruction and that they have the necessary communication skills so to do. It might be thus argued that both student and instructor are disadvantaged. Changing mindsets, ensuring adequate preparedness, and providing support structures will take time, resources and the cooperation of the research and instruction community.

on of foreign student graduates and to undertake large-scale recruitment of foreign skills to build nodes of critical mass. This requires political will and a shift in the oppositional stance of organized labour. The third is to accelerate the importation of skills from abroad by means of a user-friendly work permit system. (An often ignored NSI success is the implicit development aid given to sub-Saharan Africa in the form of hundreds of thousands of university graduates, tens of thousands of postgraduates, and research networking.)

This brings the critique to the matter of two policies that are not working satisfactorily. Motivated by the desire to boost business sector investment in R&D, DST introduced the R&D tax incentive even though the international evidence for additionality was tenuous (Aerts and Thorwath, 2008). To contain rent seeking DST took on the role of R&D project auditor. The audit requirements, in turn, created a burden on firms who might apply and ended up selecting the largest firms, with disappointing participation and little evidence of additionality. The abandonment of the *ex-post* tax credit system was followed by the more onerous pre-approval process. This restricted uptake even further but gave rise to an unintended consequence whereby some firms with unsuccessful pre-approval applications declined to participate in the R&D Survey 'as we are not doing R&D' with the result that BERD was further depressed.

A joint government-industry task team reviewed the incentive (DST, 2016a). Its recommendations have not been acted upon save for a minor change to the legislation. Given the complexity of the R&D tax incentive, it might be appropriate to phase out the incentive and to redirect the saving of administration time elsewhere. Recognizing the difficulty that SMMEs experience in maintaining in-house R&D capability, an R&D voucher scheme targeted at SMMEs might be considered as an alternative. Eligible firms would be able to cash in such vouchers with registered R&D service providers. Random auditing should deter rent-seeking behaviour. The second instrument is the Intellectual Property Rights from Publicly-funded R&D Act. That Act (also under review) increased the regulatory burden on the innovation system, and may have discouraged joint R&D between industry and the public sector, much as happened in the US in the wake of the Bayh-Dole Act. The Act may thereby reduce linkages that are an essential feature of an innovation system. Where the Act might be succeeding is by encouraging academics to seek patent rights with the promise of sharing future royalty flows. The recent upturn in USPTO and PCT activity may be a positive consequence of the benefit-sharing provisions. A pragmatic and disinterested reappraisal of the benefit-sharing rules of the IPRPFRD Act, including onerous foreign exchange rules is to be anticipated.

Beyond the IPRPFRD and patenting, more attention is needed to understand the importance for innovation policy of other modes of IP protection, namely trademarking, registered designs, copyrighting and plant breeders' rights.

Policy learning requires the institutionalization of both *ex-ante* and *post hoc* impact evaluation. While the White Paper set the scene for external reviews of the PROs, with the first round being disseminated as the Science, Engineering and Technology Institution (SETI) Review, the practice has weakened with reviews now occurring randomly with their results frequently withheld from public access and scrutiny. The performance analysis team requested the NACI Secretariat to obtain reviews of all PROs over the two-decade period. Despite official backing, only two NRF and HSRC reviews dating back to 2010 were received. The PRO review system appears to be broken.

Government departments and PROs find themselves in a state of constant adjustment to the changing political environment. Over the two decades under review, the sentinel message has shifted from the Growth and Development Strategy to the current Presidential Outcomes with the consequence that departments and PROs find a need constantly to repackage their personae as they account to their Boards, the Auditor-General and Parliament. The danger of perverse compliance is real as accounting officers are pressured to devote scarce resources to meet demands for 'accountability' that may be of low intrinsic value. Control and oversight boards may also find themselves drawn into insubstantive performance accounting. This is particularly the case for Science Councils whose intellectual output volumes are inherently unpredictable quarter-by-quarter.

System intelligence must review the past and anticipate the future. The main review indicators are populated through the R&D and Innovation Surveys, both of which are experiencing difficulties with coverage. These are technical matters that are open to resolution by those responsible for the surveys. The DST has committed to address these matters (DST, 2016b). Enhancing capacity to address present shortcomings is insufficient, and thought must be given to future measurement requirements that inclusion would demand. New indicators are emerging. GDP faces major challenges with indicators of wellbeing on the agenda, while progress toward the SDGs demands quantitative and qualitative measures. Altmetrics is thus also becoming a growing field that will require resources.

Other policy-relevant material in short supply is case study analysis of innovation in firms, the informal sector, and society at large. Addressing this gap might be best served by a virtual network of researchers drawn from across the universities and PROs. In addition, the dispersal of STI information across multiple sites and its inaccessibility continues to be problematic. Coordinating access to, and support for the sharing of STI information according to agreed protocols could be another function for NACI going forward. The intended National STI Information Portal may contribute to addressing this gap. The CoE for Scientometrics and Science Policy might be expected to play a pivotal role in building associated capacity. But there is no institutional foresight or back cast capacity for the NSI, which presents considerable risk, given the changing nature of work, innovation, consumption and co-production. The Ministerial Review recommended that such foresight capacity be built in NACI, and this remains a valid option. The 4th Industrial Revolution will impact decisively on the meaning of work, leisure, and longevity in ways that are difficult to appreciate and comprehend. We don’t know what we don’t know. Without foresight capacity we shall not know.

Challenging poverty, unemployment and inequality through inclusive and sustainable development must now move to centre stage with appropriate organizations created for this purpose. Thought should be given to putting in place a network of demand-led, dedicated and distribution centres that are able to respond to the needs of youth, and especially women, intelligently and rapidly.

‘Own’ curiosity-driven research can, should and will play its role in such work when framed consistently with responsible research and innovation. This requires *ex-ante* appraisal and objective followup that considers both intended and unintended consequences.

Vision 2030 scopes a new social accord built on inclusive development. Research and innovation are central to its realization.

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(Footnotes)

1 Problem of comparability. 1996 data is for masters and doctoral studies in universities and technikons.

2 The h-index measures the productivity and citation impact of an author's publications.