Paper presented in the IV Globelics Conference at Mexico City, September 22-24 2008

Globelics

Science and Technology and Economic Growth in South Africa: Performance and Prospects.[1]

Dave Kaplan

1. . INTRODUCTION

The main contribution to economic growth in South Africa prior to the early 1990s resulted from factor accumulation – principally capital, but also labour. Technological progress, as measured by total factor productivity (TFP) growth effectively made no contribution. From the 1990s however, this situation reversed. The economy shed labour such that labour made a negative contribution to growth. With low levels of investment, capital made a much smaller, albeit positive, contribution to growth. TFP growth, by contrast, became the major source of growth (Fedderke, 2005: 10).

It is of singular importance that TFP growth became so significant in a context where there are very major unemployed human resources – and with this magnitude increasing. That technology and capital accumulation have underpinned growth at the same time as the contribution of labour has been negative underpins the major divide in South African society – those with command over capital and skills and indeed those who have formal employment whose productivity and remuneration have risen, have benefited from a pattern of growth that has also seen increasing numbers unemployed. At the same time, growth rates have been modest.

A critical component of any future growth strategy must aim to ensure higher levels of factor accumulation – both investment, and particularly labour. Indeed, in the presence of major unemployment and under-utilisation of labour and low rates of investment, factor accumulation offers the most potential for enhancing growth, and also for improving equity. But, enhancing technological advance, TFP growth, will also be of importance.

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[1] This paper is a modified version of a paper, *Science and Technology Policy in South Africa: A Critical Assessment of Past Performance and of Proposed Future Directions,* presented at a conference in Oxford, Confronting the Challenge of Technology for Development: Experiences from the BRICs, 29-30 May, 2008.

The contribution of TFP to overall economic growth in South Africa, receives little recognition. One significant illustration of this is the South African treasury appointed international panel. Based largely at the Kennedy School, Harvard University, the panel examined South Africa's policies for growth and specifically its ambitions to achieve both a more ambitious growth target and simultaneously more inclusive employment generating growth. A number of proposals were made by the panel (for a summary see Haussman, 2008). However, the Panel made no study of or recommendations in respect of innovation or technological change more broadly – despite this having been the principal contributor to growth.

This paper examines South Africa's technological performance and concludes that a number of indicators suggest that while there was some increase in output in the 1990s, there are clear signs of slowing down if not system stagnation. Addressing this slowdown would make an important contribution to enhancing the overall long term growth rate.

The first part of this paper provides a high level assessment of the innovation performance of the South African system. The second part centres on the recent Review of South Africa's Innovation Policy by the Organisation for Economic Co-operation and Development (OECD) (OECD: 2007OECD). The third part of the paper centers on a report by the responsible government department, the Department of Science and Technology (DST), that defines the Government's strategic goals and aspirations for the S&T system, detailing a ten-year plan, 2008-18, for South Africa (DST: 2007). The paper concludes with some broad proposals for future policy directions.

2. SOUTH AFRICA'S INNOVATION PERFORMANCE

The S&T system faced a variety of threats and constraints in the early 1990s (OECD, 2007: 43-44). But, there was no collapse. The system was stabilized and a substantive re-reorientation of the system towards the new goals of the first democratic government was successfully achieved. As the OECD report expressed it, "…the most striking achievement of South Africa has simply been to defy the extremely poor framework conditions facing the innovation system in the early 1990s"(OECD, 2007: 4).

2.1. Inputs

Indeed, the system has grown steadily. Between 1993 and 2004, gross expenditure on R&D (GERD) almost doubled. GERD increased from 0.60 to 0.87 per cent. Since 2001, GERD as a share of GDP has increased by five per cent per annum. All performers of R&D have seen steady increases in spending. Of particular importance is that the share of business enterprises in R&D is high and its share has been increasing. Business now accounts for 56.3 per cent of R&D. This is a larger share of R&D than in most comparator countries (OECD, 2007: 5). Higher education (21.1 per cent) and the Government (20.1 per cent) are each responsible for approximately one-fifth of R&D performed, with the not-for-profit sector making up the remainder.

The business sector provides 45 per cent of total R&D funding. Sixty-eight per cent of R&D in the business sector is carried out by local business and a further 18.4 per cent by foreign business. The Government provides 32 per cent and foreign sources provide 15 per cent of total R&D funding. Both the Government and the higher education sector are recipients of significant R&D funding from business and the foreign sector. The funders and performers of R&D are summarized in Table 1.

Table 1. Funders and performers of R&D, 2004/05 (R millions)

Funder	Business enterprise	Government	Foreign	Other SA	Total
Performer					
Business	4,735	519	1,280	430	6,964
Government	296	1,726	312	178	2,512
Higher Education	426	1, 610	241	257	2,534
Total	5, 457	3,855	1,833	865	12,010

Source: DST, 2007a: 23

In 2004/5, there were a little less than 30,000 full time equivalent personnel engaged in R&D. At 2.7 researchers per thousand employees, this is low relative to other developed countries but also relative to a number of countries with a comparable GDP per capita. Although South Africa devotes comparatively large resources to R&D, this is not reflected in a greater number of researchers employed. The reason is that South African research workers command significantly higher salaries than in comparable countries. Moreover, while the number of FTE researchers has increased, this has been slow – by only seven per cent in the period 1992-2004.

This growing commitment of resources has been accompanied by extensive policy experimentation. Grounded in the overall concept of the national system of innovation (NSI), policy design has drawn extensively from international experience and thinking. It has included policies to improve governance of the innovation system; the more effective functioning of key performers of S&T, especially the science councils; new mechanisms for funding R&D and innovation; and development of new organizational arrangements and programmes to support R&D and to undertake R&D directly.

While there is clearly considerable room for improvement, extensive institutional reform and ongoing evaluation have enhanced efficiency of organizations as well as increased inter-organizational co-operation. The institutions undertaking, financing and supporting innovation, in the main, function effectively.

More resources combined with an effective and improving institutional structure and innovative and directed policy changes might have been expected to yield significant results. However, the output indicators for the S&T system are disappointing.

2.2. Outputs

2.2.1 Publications

In terms of publications, there has been only a slight increase in South Africa's scientific publications, as listed by the Institute for Scientific Information, after 1994. In relative terms, South Africa's global share has declined significantly from a peak of 0.7 per cent in 1987 to 0.48 per cent in 2003. In contrast, other comparator countries, such as Brazil, Taiwan, Province of China, the Republic of Korea and India, starting from a lower base have overtaken South Africa as their share of world publications has climbed steadily (Pouris, 2003: 425-6).

2.2.2 Patents

The situation with regard to South African patents registered abroad is broadly similar to publications. There has been a slight increase in patents since 1994, but no clear trend is evident. Indeed, the number of South African patents registered in the United States declined significantly in the period 1998-2005.

Table 1: Patents of South African Origin Granted by the United States Patent and Trademark Office (USPTO), 1994-2007

	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07
Utility Patents	101	123	111	101	115	110	111	120	113	112	100	87	109	82
All Patents	109	127	116	114	132	127	125	137	123	131	115	108	127	116

Source: USPTO, 2006(a); USPTO, 2006(b)

Data for 2007 supplied by Paul Harrison of the USPTO, 18/01/2008

South Africa's relative position in terms of patents has declined. The share of all foreign patents registered in USPTO has consistently declined from 0.28 per cent in 1992 to 0.13 per cent in 2007. For utility patents, South Africa's share declined from 0.3 per cent in 1992 to 0.11 per cent in 2007. A recent study of the patenting activity at the USPTO by the five most innovative South African universities concludes that their performance is well below that of other countries (Lubango and Pouris 2007:7).

In terms of South African patents at the Patent Co-operation Treaty (PCT), the trend is less defined. PCT only became operative in South Africa in March 1999. Since that date, there has been no clear trend and considerable fluctuation. However, as with South African patents at USPTO, the number was lower in 2007 than in 2001. Moreover, as with USPTO, South Africa's share of all foreign PCT patents declined consistently – from 0.42 in 1999 and 2000 to 0.26 per cent in 2007.

Table 2: Patents of South African Origin in the PCT, 1994-2007

	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'05	'06	'07
SA Patents	30	42	72	84	114	317	387	419	384	357	411	358	422	360

Source: WIPO Statistics Database

Table 3 shows the number of patent applications at the local Companies and Intellectual Property Office (CIPRO). The number of patents remained constant in the period 1994 -1998 and, then, declined by a third. Numbers picked up again in 2001 but have since been slowly declining. The drop in 1999 can be attributed to South Africa becoming a part of the PCT system in March 1999. Overall, local patenting at about 270 patents per million population is low and, at least since 2001, on slowly declining trend.

Table 3: Patent Applications at the Companies and Intellectual Property Office (CIPRO), South Africa, 1994- 2005.

	'94	'95	'96	'97	'98	'99	'00	'01	'02	'03	'04	'0
Total Patents	10,414	11,050	10,956	11,734	11,953	7,838	7,793	10,553	10,408	9,955	10,396	10

Notes: Data are for provisional and complete patent applications. 1994-97 from Teljeur; 1998-2005 from Innovation Fund, 2007

Source: Teljeur, 2003:55; Innovation Fund, 2007:36

A recent study concluded, "…at least 50 per cent of the patent applications filed at CIPRO in this period (2000-02) were filed by foreign nationals, with the biggest contributors being USA and German nationals", (Innovation Fund, 2007:28). From the table below, a clear and consistent trend is evident for the period 2001-2006: (1) the overall number of patents has been stagnant; (2) the number and the share of South African patents has been declining; (3) *pari passu* the number and, particularly, the share of foreign patents has risen significantly.

Table 4: Number and Share of South African and Foreign Patent Applications (Filed and Granted) at CIPRO, 2000-02 and 2004-06.

	2000	2001	2002	2004	2005	2006
Total	7,793	10,553	10408	10,420	10,456	10,787
South African	5,204	4,985	4721	4,587	4,328	4,058
Foreign	2,589	5,568	5687	5,843	6,128	6,729
Foreign per cent of Total	33	53	55	56	59	62

Source: Data for 2000-02 from Innovation Fund, 2007: 28. Data for 2004-06 supplied by CIPRO

A detailed breakdown of patents filed in South Africa by country reveals that every country increased the number of its patents between 2004 and 2006. However, patenting by South Africans declined in the same period, by nearly 12 per cent.

Table 5: Patents filed in South Africa, by country of origin, 2004-2006

Year	ZA	US	GB	FR	DE	NL	CH	JP	Others
2004	4,587	1,953	506	275	716	223	387	268	1,517
2005	4,328	2,112	529	284	782	193	373	313	1,443
2006	4,048	2,269	555	429	858	270	434	277	1,666

Source: Data supplied by CIPRO

2.2.3 Royalty Receipts and Payments[2]

The technology balance of payments (TBP) reflects a country's commercial transactions related to international technology and know-how transfers. It consists of payments made or

[2] This section is based on data supplied by the South African Reserve Bank. Royalty payments and income are not currently published by the Bank. It, therefore, gave permission to the author to outline the data trends but not to publish the actual data.

received for the use of patents, licences, know-how, trademarks, designs and technical services. These receipts and payment are, generally, registered as royalties paid abroad and royalties received from abroad.

In South Africa, consistent data for royalties received is only available from 2000. Analysis of the data regarding royalties from 2000, shows that in the period 2000 to 2007, royalties received from abroad increased by 58 per cent, amounting to a compound annual rate of 6.8 per cent. In the same period, royalties paid abroad increased by 360 per cent, amounting to a compound annual growth rate of 20.1 per cent. Moreover, royalty payments greatly exceeded royalty income. In 2000, royalty payments were some ten times royalty income. In 2007, royalty payments were 30 times royalty income.

The widening adverse technological balance of payments and, more significantly the relatively slow growth of royalty receipts from a very low base, are a further indication of South Africa's weak overall performance in innovation.

2.2.4 Shares of Global Trade

A country's performance in global trade in industries where innovation is central to economic success is an important output indicator, particularly in respect of business sector R&D. In the period 1992-2005, South Africa's exports of high technology products grew at 9.5 per cent annually. While, at first sight, this appears impressive, it is lower than the global average (11 per cent), and well below that for developing countries (21 per cent). As a result, as with scientific publications and patents, South Africa's share of global high technology exports has declined. This cannot be attributed to South Africa's dependence on commodity exports. Brazil's share of global high technology exports has increased, and the share of high technology exports in total country exports has risen significantly. South Africa's export performance was similar to that of Argentina. The share of high technology products in South Africa's total exports is much lower than that of Brazil and marginally lower than Argentina.

Table 6. Share of Global High-Technology Exports, 1992-2005 and Share of High-Technology Exports in Country Exports, 1992-2002: South Africa, Brazil and Argentina

	1992	2005
Share of Global High-Technology Exports		
South Africa	0.07	0.07
Brazil	0.29	0.49
Argentina	0.05	0.03
	1992	2002
Share of High-Technology Exports in Country Exports		
South Africa	1.63	2.51

Brazil	3.9	10.5
Argentina	2.1	2.6

Source: COMTRADE, TIPS and own calculations

2.2.5 Composite Indicators

There are a number of composite indicators that measure the ability to generate, adopt and utilize new knowledge. The Knowledge Economy Index (KEI) compiled by the World Bank, probably the most widely used, is based on the average of the normalized performance of a country or region in four areas – economic incentives, institutional regime, education and human resources and the innovation system and ICT. In terms of KEI, South Africa has declined since 1995. By contrast, other commodity-based exporters, such as Brazil, have seen a rise in the index, as has the upper middle-income countries group. Overall, South Africa is currently ranked 50 out of 140 countries, a decline of nine places since 1995. South Africa's performance on KEI is, again, similar to that of Argentina.

Table 7. Knowledge Economy Index (KEI): South Africa in Comparative Perspective, 1995-Latest Year

	1995	LATEST YEAR
South Africa	**6.08**	**5.64**
Brazil	5.14	5.50
Argentina	6.41	5.49
Upper Middle-Income	6.38	6.50
World	6.41	5.93

Source: World Bank, 2007: 7

Accessed at http://info.wordbank.org/etools/kam2/KAM_page7.asp 07/09/2007

2.2.6 Constraints on Performance

In summary, the resources committed to R&D in South Africa are commensurate with other countries at similar stages of development and have been increasingly significantly. Moreover, business accounts for a very significant and rising share of expenditure on R&D. However, the number of personnel engaged in research is lower than for many comparable countries and has risen only slowly. This reflects the high price of skills engaged in research, which, in turn, is a consequence of the limited supply of the needed skills.

The high level output indicators – publication counts, patents (local, US and PCT), royalty receipts and payments, shares of global trade and composite KEIs – all tell essentially the same story. Despite the injection of more resources and introduction of a raft of new policies derived from international experiences, which have significantly improved the policy environment, at aggregate level, South Africa's innovation performance is largely stagnant if not declining slightly.

3. THE OECD REVIEW

The OECD review provides an assessment of progress of the S&T system to date. Based on this assessment, the review also makes recommendations primarily directed at identifying the appropriate strategic goals and principles for future government action. The review was commissioned by the National Advisory Council on Innovation (NACI). NACI also produced a background report to the OECD mission, which outlined the structure of the system, performance and policy (NACI, 2006).

The poor performance of the system, as evidenced consistently by all of the output indicators, strongly suggests the existence of systemic-wide constraints. There is an emerging consensus that the key system-wide constraint is a severe shortage of skills (Blankley and Kahn, 2005; Kahn, 2006; Kaplan, 2007; NACI, 2006). The OECD review confirms this consensus characterizing human resource development as, "…perhaps the issue that will be central to all other aspects of the development of the STI system over the next decade" (OECD, 2007: 87).

OECD identifies a looming crisis in human resource development in two areas. The first is a large and growing engineering gap. "A very large gap appears to be opening up between the supply of design, engineering and related managerial and technical capabilities and demand for such resources being generated by the increased rate of investment across the economy" (OECD, 2007: 7). The second is the very limited supply of university graduates capable of undertaking research. Unless this is addressed, the entire innovation system will be constrained (OECD, 2007: 7).

The gross enrolment ratio (GER) for secondary schools has increased only moderately, from 87 in 2000 to 89 in 2005 (Department of Education, 2002: 6; Department of Education, 2006: 7). The number of school leavers passing mathematics at higher grade has remained stable at some 20,000 annually since 1997, a pitifully low number. Overall, the national university participation rate declined, from 17 per cent in 1993 to 15 per cent in 2001. The Government is aiming for an overall participation rate for higher education of 20 per cent by 2012, which would require the higher education system to increase by one-third. University undergraduate enrolments and qualifications have expanded by some 3.6 per cent annually, but the growth for engineering (1.4 per cent) and natural sciences (2.4 per cent) has been much lower. Currently, only 20 per cent of all graduates are in science and engineering. While doctoral enrolments have increased significantly, overall, university doctoral graduations have grown by only three per cent annually (NACI, 2006: 64-65).

A consequence of the slow growth in the supply of human capital combined with an economy growing more rapidly and growth becoming ever more skill demanding is that the numbers undertaking research have virtually stagnated. The full-time equivalent researchers count grew by only seven per cent in the period 1992-2004, see Table 5.[3]

Table 5: FTE Researchers by Sector, 1992-2004

Sector	1992	2004
Business	3,395	4,411
Government	2,428	2,342
Higher Education	3,631	3,374

[3] The number of researchers in government and higher education has clearly fallen. There has been a moderate increase in business of 30 per cent over 12 years, but some of that probably reflects better survey coverage (Kahn, 2007: 10).

Total	**9,454**	**10,127**

Source: NACI, 2006: 57 and OECD, 2007: 51

The centrality of the constraint on the S&T system arising from the shortages of high-level skills evidenced by the macro numbers is confirmed at the micro firm level. A recent study of 20 successful high technology firms found that the inability to acquire more high-level skills was the major factor inhibiting these firms from expanding (Kaplan, 2007).[4]

The evidence is clear. Any further expansion of the S&T system will be predicated on a significant expansion in the supply of skills. OECD's assessment is that, overall, to facilitate expansion of the system, the university system needs to expand by one-third (OECD, 2007: 89). Since university education is the end of a long pipeline and the number of graduates emerging from school, especially in mathematics and sciences, is static, such an expansion will necessarily, under any circumstances, take a considerable time.

While many agree on the centrality of the skills shortage constraint, the precise import of this for policy and development of the system have not been fully appreciated. Since skills are the identified binding constraint, addressing this issue should receive the highest priority. In terms of policy sequencing, it is essential that the skills constraint be addressed first. Indeed, a number of other policies and programmes to enhance the development of the S&T system will not be effective, and may even be positively detrimental, in the absence of an easing of the skills constraint.

In a review of the new National Research and Development Strategy (NRDS) (DST, 2002) in *Science, Technology and Society* in 2004, when the skills constraint was already in evidence although not as acute as currently, I argued, "more resources devoted to S&T in the context in which skilled researchers and research mangers are in fixed supply may well have the unintended consequence of inflating returns to the factor that is in fixed supply, namely skilled researchers, managers and their organizations without any commensurate rise in S&T output". I proposed a sequencing approach, "… prioritizing skill; development in the short term and only later, when skills have been enhanced, attempting an ambitious expansion of the S&T system" (Kaplan, 2004: 276). Since 2004, despite the additional resources committed, there has not been a notable increase in system output.

Similarly, in the absence of an expansion in the supply of skills, any additions to the number and breadth of the areas of scientific and technological development to be supported can only succeed by attracting scarce skilled resources to the new additions from somewhere else in the system. The case of the Pebble Bed Modular Reactor (PBMR) is indicative. The recent expansion of the PBMR development programme was only achieved through PBMR obtaining many of the additional skills it required at the expense of innovation activities and organizations elsewhere (OECD, 2007: 136).

The OECD report drew attention to the existence of, "…multiple projects chasing thinly spread resources" (OECD, 2007: 135). In 2002, NRDS proposed four new missions for S&T. The OECD findings were that two of these new missions had not been implemented, namely technology related to resource-based industries and technology and innovation for poverty

[4] The OECD report similarly quoted senior managers of a mining engineering company, "We have a huge skill shortage. This company could do twice the export business if we had the people", (OECD, 2007: 103)

reduction. The lack of implementation in respect to technology and innovation for poverty reduction is particularly problematic with the high levels and persistence of poverty in South Africa despite moderate economic growth. NRDS regarded this mission as particularly critical in the areas of health and education and envisaged projects such as development of affordable household energy systems (Kaplan, 2004: 281). OECD concluded, "... there appears to be no overall framework which coordinates and sets priorities about what the innovation system is doing with respect to poverty reduction or where the main problems and limitations are located" (OECD, 2007: 138). The failure of implementation is likely also to have reflected stretched organizational and human resource capacities.

The constraint imposed on the system by a shortage of skills has already curtailed the output and productivity of the system as a totality and limited the new technology missions introduced under the NRDS in 2002. Recognition of the current effect of the skills constraint is particularly germane in the context of ambitious proposals for the S&T system as outlined in the ten-year plan (see below).

3. 1 Current Policy Shortcomings

The OECD report acknowledges that considerable progress has been made in the S&T policy regime. There have been substantial improvements in system governance, development of new mechanisms for public funding of innovation and management of state supported organizations for innovation, the science councils. But OECD identifies six shortcomings in the current policy regime:

- Over-emphasis on public R&D performing institutions

The organizing concept for policy makers has been NSI. But this has often been mapped too narrowly with a pronounced focus on the publicly funded R&D institutions. This over-emphasis has obscured the role of the business sector, as an important agent in potentially overcoming the critical shortage of skills through its own training efforts as well as a source of R&D. This over-emphasis has also led to an under-estimation of innovation generating activities, such as design, engineering and associated management activities, especially in the services sector. The policy-making and advisory bodies have focused on R&D, particularly public sector R&D, rather than developing a holistic picture of the innovation process.

When policy-makers turn their attention to the business sector, in the view of OECD, too much attention is paid to small firms. There is insufficient recognition of the critical role played by large firms. Large firms are often best placed to accumulate knowledge and invest in training. Moreover large firms are significant diffusers of new technical knowledge, especially to smaller firms that are their suppliers and customers. In South Africa, significant knowledge has diffused from the large mining companies to a range of engineering service firms (OECD, 2007: 96).

Institutional arrangements to provide a context in which business enterprises, particularly large ones, would be induced to intensify accumulation and dispersion of knowledge are poorly developed (OECD, 2007: 97).

- Lack of articulation between identified priorities and actual implementation

As outlined earlier, the OECD assessment was that two of the four technology missions prioritized in NRDS had not been implemented. The mission to develop technology and knowledge to leverage resource-based industries had purportedly not been implemented because the industry was considered mature. However, this disregarded the potential for diversification out of the innovative strengths in resource-based industries, successfully undertaken in other countries such as Australia (OECD, 2007: 137).

With respect to the second mission–technology and innovation for poverty reduction–the content of the proposed programme and implementation mechanisms were never clearly specified (OECD, 2007: 137-8).

In addition, large programmes that were not previously identified as priorities are being implemented with alacrity. In this regard, the OECD report singled out PBMR which was neither one of the four missions nor one of the six established or planned centres of excellence. As the OECD report stated, the major scale of PBMR has meant that its impact is being felt across the innovation system given its demands for scientific and human resources (OECD, 2007: 138). PBMR is by a significant margin the largest project employing skilled engineering and scientific labour, said to exceed 600 most of whom are very highly skilled, thus contributing significantly to the shortage of skills. According to OECD, "… it is a significant contributor to the growing demand-supply gap for design and engineering capabilities – probably helping to restrict the ability to achieve important investment-related objectives in other areas of the economy. It is also impinging on R&D at other points in the innovation system. For example, the CSIR has recently lost more than twenty Engineers and Scientists to the PBMR programme, presumably making it more difficult to achieve other important priorities such as its contributions to major DST missions …" (OECD, 2007: 136).

There are other examples not mentioned in the OECD report While not as large as PBMR, they are, nevertheless, significant, such as support for technology development for the armaments and aircraft industries:

?? Insufficient specialization and differentiation on the part of governance and innovation performing organizations

The OECD report recognizes that there has been considerable experimentation with new organizational forms. Given the diversity of South Africa's challenges and changing contexts, both national and global, such experimentation is to be welcomed. However, a number of organizations have similar R&D functions, resulting in insufficient specialization and differentiation. The National Research Foundation supports both research and innovation. The Medical Research Council both funds and undertakes research. A number of the organizations performing R&D have overlapping activities. A conspicuous example of this is the expectation that all of the universities should be somehow engaged in supporting small firms.

?? Limited horizontal integration and coordination of the governance structure

Interaction between the various bodies that fund R&D and other innovation-support activities is largely informal. While co-operative interaction between the different government departments engaged in NSI is more established, "… there are a number of areas where greater integration is required, for example, with respect to research in higher education as between DST and the Department of Education; innovation support measures for business as between DST and the Department of Trade and Industry and with respect to the development of innovation capabilities through training in business enterprises" (OECD, 2007: 9).

NACI reports to a single department, DST. This limits NACI's capacity to address cross-departmental issues (OECD 2007: 9). Of particular importance, OECD has pointed to the lack of a co-coordinating body at cabinet level with responsibility for holistic oversight and overall direction of the totality of research and innovation policy (OECD, 2007: 141).

?? Lack of integration at national, provincial and local levels

The OECD report noted a lack of what it termed “vertical articulation” at national, provincial and local levels (OECD, 2007: 140). “There appears to be fairly weak integration between national level policy and organizations and innovation-related policy and support measures at provincial and local level” (OECD, 2007: 9).

?? Resources too thinly stretched over too many activities

The OECD mission heard a number of assessments to the effect that the resources devoted to particular fields of S&T were too limited to have significant impact. “There appear to be quite widespread concerns that within particular fields of research, development or other innovation activities the available resources are often ‘spread too thinly’ across projects, programmes and organizations. The consequence is that the scales of activity are too small to achieve effective impact – or more precisely, too small to achieve the intended aims” (OECD, 2007: 131). The mission gave examples of material sciences, biotechnology and vaccine development.

At organizational level, OECD saw evidence to suggest that there was too much diversity and, consequently, too little focus and absence of critical mass. The Council for Scientific and Industrial Research (CSIR), South Africa’s largest publicly-funded research organization, for example, covers a very wide range of fields with very limited resources resulting in very limited output and impact (OECD, 2007: 132-133). OECD particularly notes that there was no evidence of CSIR discontinuing or deliberately scaling down any of its activities. Mr. Sibisi, CSIR President and Chief Executive Officer, in the subsequent discussion of the OECD report, confirmed that it had been easy to initiate new areas of activity but very difficult to close down anything. Finally, the specifications of the categories for research activity for development are frequently very wide. As areas for policy attention and funding support, biotechnology and nanotechnology, for example, , “… are much too heterogeneous to serve as focal points for meaningful priorities – partly because the segments of such fields that are the most important vary widely across the sectors where they may contribute to innovation” (OECD, 2007: 139). Given the limited activity in respect of at least two of the four technology missions identified by NRDS, OECD suggests that it would be appropriate to revisit the strategic priorities identified.

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 (OECD, 2007: 8).

That resources are currently spread too thinly, at every level of the S&T system, is a very strong finding. It is of critical importance for the future of the system.

3.2 Policy Recommendations

Prior to embarking on a number of policy proposals, the OECD report suggests a series of, what it terms, strategic goals and guiding principles, which should provide a framework for determining government policy in S&T:

1. Orient away from dependence on resource-based industries to more knowledge-intensive production: OECD’s principle proposal in this regard is to encourage diversification from resource-based industries (RBIs) into specialized supplier industries and services.
2. Reduce the gap between the formal and the informal/second economy: OECD found little evidence of R&D being explicitly engaged to advance poverty alleviation but advanced no concrete suggestions in this regard.

3. Enhance knowledge infrastructure capacity: This entails expanding research capacity in higher education and in public research institutes, as well as ensuring closer linkages between them aand between them and the business sector.

To achieve these goals, the Government should adopt the following guiding principles:

?? In addition to market failure, recognize the broad range of failures and bottlenecks that impede the development of the system and provide a justification for state intervention.

?? Adopt a broad approach to innovation, including non-R&D-based activities that draw on creativity.

?? Achieve a balance in innovation between efficiency and equity.

?? Rather than a balanced, all-round approach to developing the system, there is an urgent need for reforms, particularly in respect of "… the generation of people able to lead within the R&D system" (OECD, 2007: 11).

?? Build a shared vision among all the stakeholders, including but extending beyond the S&T community.

?? Reconcile the need for quality, relevance and critical mass. This requires concentrating resources in areas where capabilities can match opportunities, end-users are actively involved in the definition of priorities and there is rigorous selection of project and research performers.

?? Develop efficient governance structures that reconcile the need for a participatory approach while ensuring the concentration of resources where they are most effective and enhance implementation.

Having delineated the goals and the guiding principles that should inform policy, OECD proposes six areas for action. Each area contains a number of policy proposals:

1. Widen system perspectives

The central role of business as a generator of innovation and as a trainer of human resources for innovation and the importance of activities, other than R&D, for innovation, should be recognized. The role of investment financing institutions in supporting investments in knowledge-capital should be investigated.

This wider perspective also entails ensuring that the national innovation system is maximally open to international flows of knowledge and human resources. It also entails examining policy measures that encourage demand for, and not solely the supply of, knowledge and innovation.

2. Improve the funding of university research

Currently, South African universities, on average, receive 50 per cent of their funding from the Government through a complex formula incorporating number of students, student throughput, fee income and other factors. The OECD report proposed that the formula be re-assessed so as to provide more incentives for high quality work (OECD, 2007: 14). The overall impact of all funding on building new areas of excellence should be evaluated. While most funding should be allocated to the most competitive researchers, some funds should be ring-fenced in order to support newcomers to research.

3. Develop greater differentiation in publicly funded R&D and innovation support organizations

OECD found evidence of overlapping mandates and duplication between publicly funded research institutions. They noted this as, "…an important weakness of South Africa's innovation system" and suggested, accordingly, "… the government should consider whether the time has come to develop greater specialization and differentiation in the functions of public organizations undertaking R&D and innovation support activities" (OECD, 2007: 15).

In particular, OECD was concerned at the situation of SMEs. "A major gap in current innovation policy is indeed the lack of comprehensive support to innovation in SMEs … innovation policy appears to do surprisingly little in the area of operational technical support for SMEs" (OECD, 2007:15). Drawing on what it regards as successful programmes initiated elsewhere, OECD makes a number of proposals as to the support that the Government should offer to SMEs. OECD also provides a number of best practice examples. These include advisory or brokerage services to enable firms to assess their needs and engage the help of professionals such as the UK Business Links or TEKES in Finland; services such as the FRAM programme in Norway to tackle non-technical aspects of business (); such testing and certification services as GTS in Denmark; vouchers to enable firms to buy services from research institutes; aid for product development; loans and investments on favorable terms; and regional- and cluster-based technology and innovation centres. OECD cautions against programmes that attempt to link SMEs to universities. Specialized technical support to SMEs, they advance, is best provided by non-university technical colleges (e.g., the TETRA programme in Flanders).

The OECD examples of successful support to SMEs are drawn solely from the industrialized countries. Many of these are already available to SMEs in South Africa. Moreover, OECD does not "map" its proposals onto current institutions in South Africa. The result is lack of clarity as to which institution is, in the view of the OECD mission, best suited to provide which support. As a consequence of these limitations, OECD provides some potentially interesting proposals, but much more investigation is needed to select the key support activities, define how they should operate and determine their institutional positioning within the South African context.

4. Strengthen human resources

OECD recognizes that the Government is making considerable efforts to strengthen education and training. However, consistent with its finding of a severe shortage of skills and the engineering gap, OECD proposes that the Government take a number of additional steps. These include more support for postgraduate and post doctoral students, particularly black ones; introduction of a completion bonus to encourage doctoral students to finish their studies; and adjust the cost-based university fee system, which serves to discourage students from entering high fee programmes such as engineering.

The Government should also to do more to encourage firms, especially larger ones, to invest in training of high skilled workers for innovation. Funding mechanisms to support such investments in training and maximize spillovers should be considered. To this end, an addition should be made to the existent levy-grant training scheme, which is specifically targeted at corporate training in larger firms and for higher-level skills.

On the international front, the Government should adopt a more proactive role in actively attracting skilled people from abroad. Foreign firms could be used more to advance human resource development through training and skill transfer. Similarly, where large scale government infrastructure projects draw on foreign technology, steps could be taken to encourage investment in training and development of local skills.

5. Improve governance structures

OECD makes two specific recommendations with respect to governance. The first is the establishment, at cabinet level, of a body that would have oversight of the entire S&T system. In this regard, OECD was particularly attracted to the Finnish model. The Finnish Science and Technology Policy Council, constituted under the Chairmanship of the Prime Minister, is credited with playing an important role in Finland's success in research and innovation (OECD, 2007: 147). The second specific recommendation was that the advisory function, performed by NACI, would, then, be directed to the new over-arching policy body rather than to DST.

In South Africa, lack of coordination as between the different government departments is a major problem concerns. The Department of Trade and Industry (DTI) has a number of programmes to support innovation in business enterprises. Many departments, including Health, Water and Forestry and Mineral and Energy, fund and support research. The Department of Public Enterprises supports a major programme in nuclear energy research (see below). These are all much larger and better resourced departments than is DST. An overarching S&T council, as proposed by OECD, may ensure system oversight. But, of itself, it is unlikely to secure effective coordination of S&T funding and performance across departments.

6. Re-examine the major national innovation priorities and missions

The lack of fit between the priorities identified in NRDS and implementation – manifested in two of the four specified missions not being implemented while other areas that were not specified attracted large resources and were aggressively implemented – led the OECD mission to call for a wholesale re-examination both of the priorities and governance system that generated these priorities.

In the definition of priorities, consideration should be given as to whether priorities should be defined by sector or technology, as well as the likely impact of any selected priorities on the informal or second economy and the impact they will have on employment generation and on facilitating changes towards a more knowledge-intensive economy.

3. 3 Conclusion

The OECD mission report provided an analysis of the state of S&T in South Africa. Based on this analysis, the mission suggested a menu of policy proposals. While recording a number of positive features the the OECD report gives the impression of a system that is attempting to do too much with too little. This is particularly the case given the severe shortage of skills required for innovation and supporting activities, in general and the gap in respect of engineering and related managerial and technical capabilities, in particular. This perspective led the OECD mission to propose a number of policies designed to ensure greater focus, associated changes in governance processes and emphasis on accelerated development of human resources.

The overall perspective and associated policy recommendations are a useful vantage point from which to assess the future directions proposed for the S&T system by DST.

4. THE DST TEN-YEAR PLAN

DST has put forward a ten-year plan, 2008-14, for South Africa's innovation system (DST, 2007). At the time of writing, the plan is in the form of a draft document for discussion.

The plan sets out a vision of where South Africa needs to be in 2018 (DST, 2007: 5) and outlines a series of concrete goals to be achieved. The plan is, however, more than simply a bold vision. It calls for targeted interventions in pursuit of this bold vision. "Nations that have achieved accelerated growth in outputs and capabilities have acted decisively, targeting investments in areas of strategic opportunity" .

The plan outlines a bold stance, targeting specific outcomes for 2018' (DST, 2007a: 8). In similar vein, the plan's report declares, "... an opportunity exists for bold interventions that will secure a greater share of global markets" (DST, 2007: 5).

4.1 System expansion and goals

The plan envisages that South Africa will undergo a major transformation towards a knowledge-based economy. This transformation will be evidenced through progress in a number of indicators. These indicators are economic growth attributable to technical progress, at 30 per cent (ten per cent in 2002): national income derived from knowledge based industries; workforce employed in knowledge-based jobs; proportion of firms using knowledge to innovate, at more than 50 per cent; GERD/GDP, at two per cent (0.87 per cent in 2004); global share of research outputs, at one per cent (0.5 per cent in 2002); high-medium technology exports as percentage of all exports, at 66 per cent (30 per cent in 2002); and number of South Africa-originated United States patents, at 250 (100 in 2002).

Achieving these goals would represent a very significant expansion of the system and a sharp reversal of the trend of South Africa's declining comparative global performance. To achieve this turnround, would require improvement in a series of enablers. These are – matriculants (school leavers) with sufficient expertise in mathematics and science to enter university, at nine per cent (3.4 per cent in 2002); science, engineering and technology (SET) tertiary students as percentage of all tertiary students, at 30 per cent; annual PhD graduates, at 2,200 (963 in 2002); gross availability of SET graduates to economy, at 450,000 (235,438 in 2002); number of full-time equivalent researchers at 20,000 (8,708 in 2002); and total researchers per 1,000 population (DST, 2007: 9).

4.2 Grand challenges

Much of the plan is concerned with outlining five grand challenges. These are seen as a way of expanding the research agenda, in general, as well as achieving specific outcomes (DST, 2007: 34):

- Biotechnology
- Space Science and technology
- Energy
- Climate change
- Human and social dynamics

It is envisaged that there will be significant innovation over a wide area in respect of each of these challenges. The objectives for each are specified as a series of envisaged outcomes. A brief outline of the range of activity in regard to each challenge and some of the key envisaged outcomes are given below.[1]

Biotechnology

The Government has spent more than R450 million on biotechnology over the last three years. Given a range of natural advantages, a supportive policy environment could allow South Africa to be positioned as "…a major producer in the pharmaceutical, nutraceutical, flavour, fragrance and bio-pesticide industries" (DST, 2007: 13). A number of results are envisaged. Foremost, South Africa would, "be 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" (DST, 2007:15).

Space science and technology

In October 2005, the Minister of Science and Technology announced a three-year satellite development project. From 2005 through 2008, the Government will invest R26 million to secure a mission-ready small satellite and increase technological capacity. The programme is centred at the University of Stellenbosch. The DST ten-year plan proposes a national space agency. This has come to fruition with the announcement by the Deputy Minister of Trade and Industry, of the South African Space Agency. The agency will co-ordinate activities in space sciences, earth observation, communication, navigation and engineering services. A core objective in this area is, "…to win a growing slice of the global satellite industry" (DST, 2007: 16). Among otherresults, it is envisaged that, by 2018, South Africa will have, "independent earth observation high-resolution satellite data available for all of Africa from a constellation of satellites designed and manufactured in Africa, undertaken at least one launch from South African territory in partnership with another space nation, and have in place a 20-year launch capability plan" (DST, 2007: 18).

Energy

South Africa currently undertakes significant research in energy. There are two main foci. The first is conversion of coal and liquid natural gas to oil. This research is undertaken by South African Synthetic Oil Ltd (SASOL), the former state-owned company. SASOL is the largest R&D performer in the business sector with an annual research budget of some R500 million. The second focus is nuclear energy. Since 1993, Eskom, the state-owned electricity generator and distributor, has been developing the Pebble Bed Modular Reactor (PBMR). PBMR draws on an original German technology for nuclear power generation. It is being significantly improved, adapted and incorporated into a technologically new, Generation 4, pilot plant that is due to be completed by 2012. Government funding for PBMR is currently running at more than R1 billion annually. It is the largest research project and employer of skilled engineers nationally and contributes materially to the growing shortage of design and engineering skills (OECD, 2007: 135).

DST envisages a series of major R&D initiatives in energy: clean coal technologies, nuclear, renewable energy and hydrogen and fuel cells. Among the results envisaged are, "expand the knowledge base for building nuclear reactors and coal plants parts; source more than fifty per cent of all new capacity locally; a twenty-five per cent share of the global hydrogen infrastructure and fuel cell market with novel PMG catalysts and have demonstrated, at a pilot-scale, the production of hydrogen by water splitting, using either nuclear or solar power as the primary heat source" (DST, 2007: 21).

Climate change

South Africa will lead research in Africa on understanding climate change, the impact of these changes and how to mitigate adverse effects. It is envisaged that South Africa will be, "an internationally recognized science centre of excellence with climate change research and modeling capability, benefiting the entire continent and an internationally recognized centre of excellence focused on the Southern Ocean and its contribution to global change processes" (DST, 2007: 22).

Human and social dynamics

DST will develop a long-term programme to increase basic understanding of human behaviour. This will entail increasing use of computer modeling and have cognitive, behavioural and social applications. There will also be research in paleoanthropology, archaeology and evolution genetics. "This research will provide evidence-based support for interventions in learning processes and education, indigenous knowledge systems and heritage legacy" (DST, 2007: 23). No anticipated results are stipulated in respect of this challenge.

4.3 Enhancing innovation and human resources

Finally, the plan addresses the issue of human resources. Achieving the targets identified for the system and for the grand challenges will require a very significant expansion in the provision of high-level skills. The PhD rate will have to increase by a factor of five over the next 10-20 years. Other targets will be 210 research chairs at universities and research institutions by 2010 and 500 by 2018 (58 were in place in 2006); a 2.5 per cent of global share of research publications (2006: 0.5 per cent) and 2100 Patent Co-operation Treaty international applications originating in South Africa (2004: 418), (DST, 2007:31).

In addition to the five grand challenges, the plan provides for enhancement of innovation through creation of a technology innovation agency (TIA). An innovation chasm, namely a gap between the research that is produced locally and what the market demands was first identified in NRDS in 2002. The role of TIA is to bridge that gap through funding, investment and venture capital support, brokering and complimentary services.

4.4 Concluding Remarks

The DST ten-year plan clearly specifies a very ambitious agenda for S&T over the next decade. It would add substantially to the areas of research activity that would receive public support and funding while maintaining all of the areas proposed in 2002 in NRDS. This would clearly compound the system problem of too few resources being too widely spread. The problem is exacerbated in that many of the grand challenges are very capital-intensive and require major injections of funding in order to reach critical mass.

5. CONCLUSION: POLICY SEQUENCING

The OECD mission was concerned that too much was already being attempted, with the result that resources were being spread too thinly. As a consequence, OECD concluded that scales of activity were too limited to secure significant results. Noting that two of the technology missions established in 2002 by NRDS had not been implemented, OECD recommended a complete re-examination of the priorities and consequent missions specified by NRDS. The import of the proposed re-examination is clear, namely to reduce the number of technology missions. By contrast, the DST plan emphasizes the importance of continuing to support all of the technology missions established by NRDS. Similarly, the science missions (astronomy, palaeontology, antarctic and marine sciences, biosciences, social sciences, earth systems and environmental systems), early stage research projects such as nanotechnology and increased R&D for conventional sectors that boost key national priority sectors such as agriculture and health, all of which were identified by NRDS, should continue to receive support (DST, 2007: 30). In addition, the DST plan specifies a wide raft of new areas for support, the grand challenges.

The OECD mission was also concerned that the research categories that qualified for state support were far too widely specified. The mission argued strongly that much more focus was needed to ensure identification of meaningful priorities, areas of innovation qualifying for support be more limited and areas that did qualify be more clearly and tightly specified. In regard to a number of the grand challenges proposed by DST, such as biotechnology and space, a large number of fields are identified while the specification of some of the grand challenges is vague and unfocused, human and social dynamics, in particular.

The contrast is clear. The OECD mission has called for the S&T system to curtail the spread of its innovation activities as well as be more focused and clearer in its specification of that focus. The DST plan envisages an S&T system that will significantly increase the spread of its innovation to a series of new activities, many of which are broadly specified. Moreover, it will do so without curtailing any of its existing activities.

What of the human resource dimension, namely the critical shortage of skills for innovation and the implications for growth? There is evidence that R&D expenditures in South Africa have had a positive impact on growth in total factor productivity, which has, in turn, been the major source of economic growth, at least until recently. Human capital formation, specifically the output of school leavers and university graduates has been the second factor underpinning total factor productivity growth (Fedderke, 2005: 34). As illustrated above, all the output indicators indicate that increasing expenditures allocated to R&D are now having diminishing returns and that this results from critical shortages in the supply of skilled labour. Thus, the limited supply of skilled labour independently retards growth, but also does so through the impact it exerts on the output and productivity resulting from R&D expenditures.

Any further expansion and improvement in performance of the NSI is predicated on significantly increasing the supply of skills. However, high-level skills are the end of a long educational and training pipeline. As a consequence, expansion in supply is almost always slow and incremental. Moreover, in the South African context, there is neither recent historical experience nor current indications to suggest that any significant expansion of that supply is likely in the short term. The number of PhDs graduating, for example, has been expanding at only three per cent annually. To meet the targets specified by DST would require an annual increase of nearly 30 per cent, some ten times the current rate of growth. Moreover, there are no indications that there is currently the requisite number of students qualifying for entry into tertiary education or the capacity to massively expand tertiary education.

Rather than a policy of attempting to advance on all fronts, priority needs to be given to development of high-level skills. Rather than attempting to do everything at once, policy needs to be sequenced, the first priority being expansion of high-level skills for innovation. Addressing this issue will be central to enhance the productivity of the NSI and, by extension, to underpin higher rates of economic growth.

REFERENCES

Blankley, William and Kahn, Michael (2005), 'The history of research and experimental development measurement in South Africa and some current perspectives', *South African Journal of Science,* 101, March/April, pp.151-156.

Department of Education (2002) *Education Statistics at a Glance in 2000*. Department of Education, Pretoria (February).

Department of Education (2006) *Education Statistics at a Glance in 2005*. Department of Education, Pretoria (November)

Department of Science and Technology (DST) (2002), '*South Africa's National Research and Development Strategy'*, Pretoria: DST, available at: http://www.dst.gov.za/legislation_policies/strategic_reps/sa_nat_rd_strat.htm

Department of Science and Technology (DST) (2007), *'Innovation towards a Knowledge-Based Economy. Ten-Year Plan for South Africa (2008-2018)'*, Draft. Pretoria: DST. July 10.

Department of Science and Technology (2007a), *National Survey of Research and Experimental Development (R&D) (2004/05 Fiscal Year).* Pretoria; DST.

Fedderke, Johannes (2005) 'South Africa: Sources and Constraints of Long-Term Growth, 1970-2000. The World Bank Informal Discussion Paper Series on South Africa. Paper No. 2005/01.

Hausmann, Ricardo (2008) 'Final Recommendations of the International Panel on ASGISA' CID Working Paper No. 161 (May). Center for International Development, Harvard University

Innovation Fund (2007) The State of Patenting in South Africa. Special Report. Analysis of the South African patent landscape (Mclean Sibanda). Innovation Fund Intellectual Property Management Office, Pretoria.

Kahn, Michael (2006), 'After Apartheid. The South African national system of innovation: from constructed crisis to constructed advantage?' *Science and Public Policy*, 33(2), March, pp.125-136.

Kahn, Michael (2007), 'Internationalisation of R&D: where does South Africa stand?' *South African Journal of Science*, 103, January/February, pp.7-12.

Kaplan, David (2004), 'South Africa's National Research and Development Strategy: A Review', *Science*, *Technology and Society* 9(2) pp. 273-294.

Kaplan, David (2007), 'The constraints and institutional challenges facing industrial policy in South Africa: a way forward' *Transformation* No. 64 pp.91-111.

Lubango, L. M and Pouris, A (2007) Industry work experience and innovation capacity of South African academic researchers. Technovation (December) vol. 27. No. 12. pp. 788-796.

National Advisory Council on Innovation (NACI) (2006), '*The South African National System of Innovation: Structures, Policies and Performance. Background Report to the OECD Country Review of South Africa's National System of Innovation'*, Pretoria: NACI. July, 21.

Organisation for Economic Co-operation and Development (OECD) (2007), '*Review of South Africa's Innovation Policy'*, Paris: Directorate for Scientific and Technology Policy OECD. 26-27 March.

Pouris, Anastasios (2003), 'South Africa's research publication record: the last ten years', *South African Journal of Science*, 99, September/October, pp. 425-428.

Teljeur, E (2003) Intellectual Property Rights in South Africa: An Economic Review of Policy and Impact. The Edge Institute, South Africa.

United States Patent and Trademark Office (2006a) *Patents By Country, State and Year Utility Patents (December 2006.* A Patent Technology Monitoring Team Report. U.S. Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Team. http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_utl.htm

United States Patent and Trademark Office (2006b) *Patents By Country, State and Year – All Patent Types (December 2006.* A Patent Technology Monitoring Team Report. U.S. Patent and Trademark Office, Electronic Information Products Division, Patent Technology Monitoring Team. http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cst_utl.htm

World Bank (2007) *Knowledge for Development (K4D*). Accessed at http://info.worldbank.org/etools/kam2/KAM_page7.asp.