Internationalization of R&D: where does South Africa stand?

Michael Kahn*

INTERNATIONALIZATION OF TRADE HAS extended to services and intangibles such as research and experimental development (R&D). The emergence of knowledge economies with porous borders raises questions concerning the preparedness of countries to manage their systems of innovation in response to these changes. This article draws on the recently completed 2004/5 R&D survey, and other local and international data sources to consider the extent to which South African R&D is positioned to respond to the challenge of the internationalization of R&D. This entails looking at the behaviour of the main role players in the system of innovation, the extent to which they are open to local and global interactions, competitive advantage, and the implications for policy. The evidence suggests that, from an R&D perspective, the emerging South African knowledge economy is still more 'closed' than 'open'. Actions that may contribute to attracting international R&D investment and collaboration include development of skilled people and the further enhancement of direct and indirect R&D incentives.

Internationalization of R&D

Scientific research has a long history of internationalism. Academic researchers corresponded and travelled widely over the centuries, exchanging information and teaching in many different countries, even during times of warfare. Merton[1] famously characterized this knowledge exchange as the 'universality of science.' On the other hand, the internationalization of corporate research and experimental development (R&D) is a more recent phenomenon that follows quite different dynamics. Its spread has intensified under the current wave of globalization and the communications revolution and is a major policy concern for industrialized countries.[2]

Corporate R&D laboratories emerged in the late 19th century in the German chemical industry. That organizational form then spread to Belgium, the United Kingdom and United States. Next came corporate laboratories that sprang up around the new platform technologies of electrical energy and petrochemicals.[3] These new R&D institutions were large and localized to the industrializing world, such as Edison's Menlo Park in New Jersey. The concerted move to internationalize corporate R&D began after the Second World War, an example being IBM that established its main R&D facility in New York in 1945 but within a decade had set up IBM Zurich (1956), to be followed by IBM Haifa (1972), IBM Tokyo (1982), IBM Beijing (1995) and IBM Delhi (1998).

This spreading of R&D value chains is now found in manufacturing industry such as aerospace, automobiles, electronics and semiconductors. The same holds for the health sciences—Switzerland's Novartis manages its R&D from Boston in the US and has significant R&D facilities in Switzerland, Austria, the United Kingdom, Singapore and Japan. Multinational corporations as part of their globalizing strategy establish R&D facilities abroad as subsidiaries that are largely funded from the parent. Both the IBM and Novartis examples point to a northern hemisphere concentration of interest. Latin America and Africa are essentially absent.

The UNCTAD World Investment Report on the internationalization of R&D speaks to the growth of this phenomenon and alerts one to both the promise and peril that it holds for developing countries:

> R&D internationalization opens the door not only for the transfer of technology created elsewhere, but also for the technology creation process itself. This may enable some host countries to strengthen their technological and innovation capabilities. But it may also widen the gap with those that fail to connect with the global innovation network.[2]

The relocation of R&D to countries with lower cost but high quality researchers creates an obvious problem for policy—on the one hand, how to retain R&D at home, but also how to attract new R&D performers? Countries that cannot attract foreign-funded R&D as part of foreign direct investment potentially forgo two benefits—the investment itself and the possibility (but not certainty) of R&D spillovers.[4] The presence of new R&D institutions often manifests in increased patenting activity, such as the cases of China and India, where up to a third of their patents awarded at the US Patent and Trademark Office are assigned to subsidiaries of foreign-owned companies.[5]

Higher education institutions (HEIs), through their knowledge infrastructure, as the producers of research personnel and as research performers, play an important role in promoting the internationalization of company R&D. The international competitiveness of HEIs is therefore an additional factor in attracting and sustaining foreign-funded R&D. In this respect, higher education league tables, their limitations notwithstanding, are an important source of information regarding the quality of universities. Shanghai Jiao Tong University Institute of Education[6] and the *Times Higher Education Supplement*[7] provide rankings of the world's top universities that yield some indication of the relative strengths and weaknesses of country and local innovation systems in regard to the measured attributes. These include publication and citation rankings, the quality of staff, and the presence of foreign staff and students.

Relevance for South Africa

South Africa is seeking to enhance its R&D performance as a key component of its economic growth strategy. Such enhancement involves all the actors in the system of innovation, including foreign-owned companies. Accordingly, an examination of the extent to which South Africa is an R&D player on the international stage must consider the country as a preferred destination for inward R&D investment. Similarly, South African transnationals may themselves be meeting their R&D requirements internationally with possible relocation of domestic R&D capacity abroad.

Since the advent of democracy in 1994, the South African economy has been liberalized and opened up. South African transnationals have found it easier to conduct business abroad. Public companies listed on the Johannesburg Securities Exchange are permitted to list on foreign bourses, and direct investments abroad have been encouraged through liberalized foreign exchange rules. South African public companies active in mining, financial services, transport, energy, retail and leisure, energy and food chains now operate across Africa and further afield. Their success abroad is supported by their R&D activities at home, while a small number of companies (Sappi, De Beers, Sasol) operate R&D facilities abroad. Likewise, an increasing number of foreign multinationals are now conducting R&D in South Africa.

In this paper I assess South Africa's prospects for attracting further R&D to its

*Centre for Science, Technology and Innovation Indicators, Human Sciences Research Council, Private Bag X9182, Cape Town 8000, South Africa.
E-mail: mkahn@hsrc.ac.za

shores and, if possible, to benefit directly from the knowledge generated. I make use of data from the 2004/5 R&D survey,[9] including the size and orientation of the R&D system, R&D performed by foreign firms, the flow of foreign funds to local R&D and to R&D collaboration. This is supplemented with analyses of publication, patenting and trade activity. These data serve to highlight the role of foreign-funded R&D especially in the area of clinical trials and their relationship to the pharmaceutical industry. The analysis is set in the context of local framework conditions, enabling one to highlight both the strengths and weaknesses of the system of innovation and to obtain some measure of its 'R&D openness'. High inward flows of funding for R&D, the establishment of associated laboratories by foreign companies, and co-publication and co-patenting are some of these measures.

Evidence from the R&D survey

The 2004/5 R&D survey shows that South Africa's gross expenditure on R&D (GERD) at R12.07 billion is comparable (in PPP$) with Mexico, Norway, Poland and Turkey.[9] The GERD:GDP ratio at 0.87% is the highest yet recorded for South Africa and places the country at a level similar to Portugal, Brazil and Hungary, and ahead of Greece and Poland, offering the prospect that the R&D strategy[10] target of 1% for 2008/9 might be reached. The sentinel findings of the 2004/5 survey are shown in Table 1.

Compared with the European Union[12] average of 1.93%, South Africa may be characterized as a low research intensity economy. The spatial distribution of R&D effort across the country is such that Gauteng province, however, with its provincial GERD to gross geographic product ratio of 1.42%, is on a par with many R&D-intensive regions in Europe. Gauteng is correctly identified as the innovation hub of South Africa and, in effect, of Africa.

Business (including non-profit organizations and state-owned corporations) expenditure on R&D (BERD) of 58% is followed in almost equal measure by higher education's expenditure on R&D (HERD) at 21.1% and the science councils (including government) at 20.9%. This proportion of BERD to GERD is typical of the OECD economies and stands close to the European Union average.

Table 1. Inputs to research and experimental development in South Africa, 2004/5.

	R&D (R billion)	% GERD	Researcher FTE*
Business	6 964	58.0	5 300
Higher education	2 534	21.1	3 506
Science councils	2 509	20.9	2 039
Total	12 007	100	10 845

*Full-time equivalent. It excludes the contribution of postgraduate students.

Table 2. Research field expenditures for the three sectors, 2004/5.

	Business		Higher education		Science councils	
	R thousands	%	R thousands	%	R thousands	%
Basic sciences*	906 156	13.0	415 000	16.4	329 825	13.1
ICT	1 280 249	18.4	98 240	3.9	155 543	6.2
Applied sciences	861 271	12.4	43 653	1.7	68 277	2.7
Engineering science	2 101 662	30.2	307 141	12.1	459 742	18.3
Medical sciences	1 017 278	14.6	440 249	17.4	321 732	12.8
Life sciences	423 350	6.1	342 448	13.5	944 969	37.6
Social sciences	374 667	5.4	887 240	35.0	231 293	9.2
Total	6 964 633	100.0	2 533 971	100.0	2 511 381	100.0

Source: HSRC (2006).
*Basic sciences include chemistry, physics, mathematics, and marine science.

The 2004/5 R&D survey records 10 845 full-time equivalent (FTE) researchers (excluding postgraduate students). At 1.6 FTE researchers per 1000 of the workforce, the country is at the low end of international ratings.[9]

I next turn to the focus of R&D expenditure using research fields[12] as the measure of concentration of effort. For convenience of analysis, these are clustered as shown in Table 2. The business sector shows a strong emphasis on engineering sciences, much of which is due to companies that exploit mining and energy resources. This sector cumulatively directs 63% of effort towards the three areas of ICT, applied science and engineering, followed by the natural sciences at 19.2%, and medical science at 14.7%.

Higher education has its strongest focus on the social sciences and humanities, which at 35% of HERD is high by world standards—Canada,[13] for example, allocates 14% of HERD to the social sciences and humanities, whereas for Australia[14] the spend is of the order of 25%. The next largest emphasis for higher education is natural and life sciences at 29.9%, followed by the health sciences at 17.4%.

At first glance the science council emphasis on 'Life Science' (35.3%) appears exceptional. However, this arises through the combined effort of the Agricultural Research Council and the Medical Research Council as well as components of the CSIR. Engineering sciences is second at 18.3% with natural sciences third at 13.1%.

System outputs

The next matters to address are the journal and patent contributions that prior R&D investment generates (Table 3). I begin by considering journal articles captured on the Thomson-ISI databases that have at least one South African author. Roughly 90% of these publications emanate from higher education, the bulk authored at the 'big five' research universities (Cape Town, Kwazulu-Natal, Pretoria, Stellenbosch, and Witwatersrand). The country output stands at around 3900 ISI articles annually.[15]

King[15] places South Africa's publication output at world rank 29 and notes its almost static, if not falling, share. Albuquerque,[16] on the other hand, while agreeing that the publication output is stagnating, shows that in terms of scientific revealed comparative advantage (SRCA) South Africa, over the two decades from 1981 to 2001, exhibited consistent specialization (SRCA >2) in geology/petroleum and mining engineering, general and internal medicine, veterinary medicine and animal health, animal sciences, and aquatic sciences. For 2001 it demonstrated leadership (SRCA >4) in the three fields of geology/petroleum and mining engineering, animal sciences, and entomology/pest control, an achievement unique among what he terms 'immature national systems of innovation'. The strength in agricultural R&D is further evidenced by the observation that the ratio of agricultural R&D expenditure to agricultural share of GDP stands in excess of 2%, which is high by world standards.[17]

The other conventional output measure is patent registration, especially awards at the US Patent and Trademark Office

Table 3. South African publications and patents.

	ISI 2004†	USPTO* 1985/2004
Business	50	257
Higher education	3 500	5
Science councils	350	130
Total	3 900	392

Sources: †Thomson-ISI and *USPTO.

(USPTO). Unfortunately, analysis of patents is much more complex than that of publications because patents are designed to protect ideas whereas journal publications promote their dissemination. A first pass analysis (Table 4) is to consider USPTO awards to South African assignees granted at least five such patents over the period 1985 to 2004. In this table I have grouped the CSIR parent and its business sector subsidiaries as a single entry.

These data show that the government sector was awarded 171 (more than 40%) of patents, amongst which the CSIR, with its 100% owned subsidiary companies, accounts for no less than 88, or 22%. Sasol follows with 37. Today, the CSIR is one of the largest performers of R&D in the country, while hydrocarbon giant Sasol is among the top 20 R&D spenders of the world's leading oil and gas companies.[18] Sasol began its history in 1956 as a state-owned corporation but was essentially privatized in 1980. Albuquerque[16] shows that state dominance also occurs in India, whose own CSIR heads the list of USPTO awardees.

The above first pass interpretation is flawed for one obvious and one subtle reason. Significant in its absence from the list of USPTO assignees is diamond producer De Beers, which appears strongly in the corresponding European Patent Office awards. The reason for De Beers' absence in the USPTO list is the legal injunction in the United States that prevailed against the company until 2003, arising from alleged breach of anti-trust law. Accordingly, up to that time De Beers did not seek US patents in its own name.

From the perspective of internationalization, the historic USPTO data show that foreign companies are the assignees of 19% of the South African-assigned USPTO patents (Table 4). In other words, indigenous companies hold the bulk of USPTO patents with South African inventors. This pattern is similar to what is found in India, but quite dissimilar to open economies like Ireland or Belgium. Secondly, a detailed analysis of the 121 USPTO patents recorded in 2005[19] with South African inventors shows that 19 (15%) included foreign inventors. For the 109 patents with a South African as first inventor, however, the number of foreign co-inventors falls to the low level of 7 (6%). By implication, all patents with a foreign inventor as first assignee must include a South African as co-inventor or they would not be captured by the database query. The lower level of 6% co-invention suggests that South African patenting behaviour as recorded at the USPTO shows a tendency toward being 'closed.'

Table 4. South African first-named assignee at the US Patent and Trademark Office, 1985–2004.

Assignee	Number	Sector	Own
CSIR	88	G	D
Sasol Technology (Pty) Ltd	37	B	D
AE & CI Ltd	22	B	D
Circuit Breaker Industries Ltd	17	B	D
Lilliwyte Société Anonyme	15	B	F
Denel (Pty) Ltd	14	G	D
Water Research Commission	14	G	D
HL & H Timber Products (Pty) Ltd	13	B	D
Mintek	18	G	D
Crucible Société Anonyme	11	B	F
Atomic Energy Corporation of South Africa Ltd	11	G	D
Windsor Technologies Ltd	11	B	F
National Energy Council	10	G	D
Tobacco Research and Development Institute Ltd	8	G	D
General Mining Union Corporation Ltd	8	B	D
Eskom	8	G	D
British Technology Group Ltd	7	B	F
Plessey South Africa Ltd	7	B	D
Programme 3 Patent Holdings	7	B	D
Zarina Holdings C.V.	7	B	F
Boart International Ltd	6	B	D
Rotaque Proprietary Ltd	6	B	D
African Oxygen Ltd	6	B	D
Ipcor NV	6	B	F
Johannesburg Consolidated Investment Company Ltd	6	B	D
Sentrachem Ltd	6	B	D
Slic Trading Co. Ltd	6	B	D
Supersensor (Pty) Ltd	6	B	D
University of Pretoria	6	H	D
Claas Selbstfahrende Erntemaschinen GmbH	5	B	F
Farmarc Nederland B.V.	5	B	F
Johannesburg Construction Corporation (Pty) Ltd	5	B	D
Molex Inc.	5	B	D
Plascon Technologies (Pty) Ltd	5	B	D
Rooperol (NA) NV	5	B	F
Schering AG	5	B	F
Total	392		

B, Business; G, government/science council; H, higher education.
F, foreign owned; D, domestically owned.

Returning to Albuquerque's patent analysis,[16] South Africa's long-term capability according to the World Intellectual Property Classification vests in medical and veterinary science and hygiene, basic electrical elements, and construction and conveying. It is obvious how this expertise connects with the science strength in general and internal medicine, veterinary medicine and animal health, and animal sciences shown in the high SRCA scores. To link 'Construction and conveying' to the science base one must refer to the WIPO classifications that then demonstrate the link with mining, tunnelling and the transport of ores. 'Basic electrical elements' covers the vast field of electronics, detectors, radar and proximity fuses with their defence and aerospace origins, but strangely enough does not show up as a field with SCRA >2. However, this field does link with the expenditure by research fields as demonstrated in Table 5 (see research fields 10705, 10501, 10503, and 10601) that speaks to the seven-decade history of telemetry in the country.

So, higher education publishes and business patents and South Africa ranks low on the world stage in both. Normalization for the size of the economy does improve the ranking slightly.[20] One little-known area of high achievement in intellectual property protection is that of plant breeders' rights,[21] where the country is ranked fifth in the world after Japan. The high level of investment in agricultural R&D, the consistent scientific production in agricultural sciences (SRCA >4) and the working relationships between the ARC, tertiary education agriculture faculties and provincial agriculture departments explains this achievement.

Knowledge workers everywhere are in flight

The Shanghai Jiao Tong University ranking scheme for universities ranks Harvard first and the University of Cape Town at position 248, the only African university in the top 250, and one place behind the University of Buenos Aires. The *Times Higher Education Supplement* ranking of the top 200 universities also ranks Harvard first and includes the com-

Table 5. Expenditure by research field (10 largest items).

Research field*	Description	Expenditure (R)
10703	Mining and mineral processing	728 384 331
10701	Mechanical and industrial engineering	550 448 495
10705	Electrical and electronic engineering	534 831 732
10501	Information systems	519 087 429
11012	Pharmaceutical industry	509 079 486
10503	Software	457 256 736
10601	Aerospace technologies and engineering	390 799 350
10702	Chemical engineering	381 359 125
10602	Manufacturing and process technologies and engineering	218 454 835
11007	Clinical sciences	204 533 381

Source: Database of 2004/5 R&D survey. *According to survey classification.

ment that 'no African university comes even close to getting into our top 200.' This diagnosis stands alongside local concerns regarding the vitality of South African universities.[22]

The previous section considered system outputs. I now give attention to the most important input—people. Skilled staff perform research and one customarily measures this potential contribution to R&D in terms of headcounts and the associated full-time equivalent (FTE) as in Table 6. It is evident that the number of FTE researchers in higher education and government has remained more or less static over the last thirteen years. The business sector, on the other hand, shows a significant increase though some of this growth is an artifact resulting from improved survey coverage.

The static complement of university FTEs is extremely serious especially as student enrolments have virtually doubled over the same period.[23] One takes cold comfort from the fact that the slight rise[24] in ISI journal publications over the period of examination, coupled with the falling number of university researcher FTEs, implies rising university researcher productivity.

In the same way that there is a spatial concentration of R&D in the country, there is also concentration across higher education. The R&D survey shows a distinct gap between the 'big five' with their present researcher headcounts above 1000 and R&D expenditures in excess of R300 million. The group of five 'growing research intensive' universities and universities of technology clusters around R100 million.

Table 6. Researcher full-time equivalents* (FTE), 1992[39] and 2005[40].

Sector	1992	2005
Business	3 395	5 300
Government	2 428	2 039
Higher education	3 631	3 506
Total	9 454	10 845

*Excluding postgraduate students.

What is evident is the small and static nature of the population of academic researchers. The continued scientific excellence as evidenced in the SRCA scores is testimony to the resilience of this key component of the system of innovation. It would be exceptional indeed, however, given the modest size of research expenditures and the huge loss of talent occasioned through political conflict and uncertainty for the universities to perform much beyond their present levels. Substantial injections of talent and technology will be needed for this to become possible.

Much is being done to increase the volume and quality of the flow from school to university and undergraduates to research careers, but this takes considerable time to yield results.[25] Accordingly, one must also consider the presence of foreign students and research staff in the universities. Though the number of foreign students is relatively high by world standards, and above the 5% requirement laid down in the SADC Protocol on Education and Training,[26] the proportion of foreign staff is low.[27] What is most important is that, unlike the practice in the United States and Europe, significant numbers of foreign Ph.D. graduate students do not stay on in South Africa after completing their studies. The National Science Foundation[28] reports that 30% of the Ph.D. stock in the United States is foreign born.

Measuring openness

Openness may be measured through consideration of the nature and volume of trade in capital, goods, ideas, flows of R&D and, one might add, people. I now follow the approach of Spithoven and Teirlinck[29] to examine openness in the business sector. A convenient measure of openness is the proportion of exports to GDP. For the European Union's original 15 member states this averages 36%, with Belgium at 82%, Germany at 35%, Portugal at 30%, the United Kingdom at 26% and Greece at 20.5%. Further afield, Japan is at 11% and the United States 10%. South African exports to GDP stand[30] at 22%. Relative to the EU South Africa appears 'closed' whereas in relation to the economic giants of Japan and the US it looks open. This argument is inconclusive given disparities of scale, the role of commodities in South Africa's exports and its negative balance of payments in technology. Overall, the economy appears to be more 'closed' than 'open.'

Another measure of openness concerns the presence of foreign firms in the host economy, and in particular the amount of R&D that foreign firms perform. This stands at 15% in the U.S., 25% in Germany, 45% in the U.K., and 65% in Ireland.[11] In South Africa subsidiaries of foreign firms perform some 21% of BERD, suggesting openness. This level of engagement requires further analysis, a starting point for which is the source of funds for this R&D activity.

The 2004/5 R&D survey records R1.2 billion flowing from abroad to the business sector. Of this some R700–800 million is in the area of clinical trials for phase II and III studies,[31] which indicates local availability of the necessary subjects, skills and regulatory frameworks. According to the OECD Frascati Manual, clinical trials phases II and III are counted as R&D. This investment is attracted to the country by the availability of local expertise that is manifest in the publications strength and strong international networks for co-publishing. Harhoff *et al.*[32] term this strategy of firms 'home based exploiting'. Of course, clinical trials phases II and III in themselves do not contribute to the development of new products in local laboratories especially where the data are exported for analysis and further interpretation. The spillover effects are likely to be low while the financial inducement to be involved as a researcher in the trials may be high, thereby crowding out other, more risky R&D. The point is, however, that the contract research organizations conducting clinical trials with local pharmaceutical companies, universities and other research groups potentially enable local industry to integrate backwards along the clinical trials value chain to include phase I work and eventually drug discovery. This is the route that India and China are following[33] and the same could be encouraged in South Africa.

This analysis implies that foreign funding by the business sector of R&D activities other than clinical trials amounts to some R400 million, or 6% of BERD, a very low figure. From this financial perspec-

Table 7. Percentage of R&D performing firms (n = 165) that report R&D collaborations.

Collaborator firm	Local firm	Foreign
Local university	59	68
Own local firm	43	20
Other local firm	49	48
Local science council	55	44
Foreign university	15	8
Foreign science council	12	4
Other foreign firms	29	24
Own foreign firm	18	60

Source: Author's calculations from 2004/5 R&D survey database.

tive, business is 'open' for clinical trials, but appears closed more generally.

The 2004/5 R&D survey also inquired into the existence of R&D collaborations between firms, other participants in the national system of innovation and their foreign collaborations.[40] Of the 511 firms for which non-nil data were captured, one third (140 local, 25 foreign) provided returns on their collaborations. This subset of 165 firms (Table 7) accounts for 60% of BERD, and is thus biased toward large R&D performers. A second bias in the sample is that the financial services sector is poorly represented. A dedicated survey currently under way suggests, however, that financial services engage in little R&D collaboration.[35] These cautionary remarks should be borne in mind in the subsequent analysis.

The data show that the dominant source of collaboration for both local and foreign firms is local higher education, followed by local science councils and government, and both local and foreign 'other' companies. In fact, foreign firms demonstrate a higher rate of collaboration (68%) with local higher education than do local firms (59%), an aspect skewed by clinical trials. The local and foreign firms are also similar in their low rate of interaction with foreign science councils and government, foreign higher education, and foreign 'other.' The most obvious difference in collaborative behaviour is that local companies interact more with their local subsidiary companies (43%) than do foreign companies (20%); conversely, foreign companies interact more with foreign parent companies (60%) than do local firms (29%). This finding confirms what might be expected, namely that parent–subsidiary R&D relationships are vital.

What is surprising is the high proportion of companies reporting a link with tertiary education. A tentative conclusion is that both local and foreign R&D performing firms are quite well associated with the local public sector and that they display strong linkages within the local business environment. This is recognition on the part of foreign firms that local higher education is a valuable source of expertise.

This is quite different from the finding of the University of Pretoria/Eindhoven[36] 1998–2000 innovation survey, namely, the low value ascribed to local universities or science councils as sources of 'external information' in the process of innovation. That innovation survey found that only 13% of firms regarded the universities as very important, while for research laboratories this was 9%. Arguably, the survey populations were different: the R&D survey sought out R&D performers while the innovation survey was a random sample of all firms. Nonetheless, at face value the difference in the reported role of the universities is stark.

The questionnaire item on collaboration in the R&D survey serves to tease out some aspects of network activity, but is unsuitable to gauge their strength, frequency and direction. Further research at firm level is needed to elucidate further.

It is also useful to examine the extent of foreign funding of university research. The 2003/4 R&D survey recorded foreign funding at 11% of HERD, whereas the 2004/5 survey detected some R300 million (12% of HERD). This latter figure is known to be an under-count as some universities channel their foreign inflows into wholly owned university companies that are included in the business sector of the R&D survey. The point is that the university sector is also open to foreign funding. This level of foreign funding is high by global standards, a large proportion going to the health sciences and in particular to basic research on infectious diseases such as HIV/AIDS and tuberculosis as well as to phase II and III clinical trials.

Now consider co-publication with foreign academics. The most recent published data on South African co-publication is the study of Blankley *et al.*,[43] who found co-authorship in 19% of publications, the highest being in clinical medicine (27%), plant and animal sciences (11%), and physics (10%), with the lowest in computer science (1%) and education (1%). The strongest collaboration was with authors in the United Kingdom followed by Germany and France. It is interesting to note the concordance with Albuquerque's SRCA data that shows the strength in general and internal medicine (SRCA >2), and animal science (>3), which seem to be research fields open to collaboration. However, geology/petroleum/mining engineering, with SRCA >8, does not feature as an area with foreign collaborators.

Challenges and opportunities

The extent of internationalization of South African R&D has been measured using the proxy of R&D expenditure, science and technology outputs, and the existence of R&D collaborations. South Africa's national system of innovation is small and is still imprisoned by the apartheid legacy of neglecting skills development, a skewing exacerbated by the need of the state for additional staff to effect its transformation and service delivery agendas. Growing the volume of R&D toward the 1% target assumes that additional funding and, most critically, that several thousand more skilled researchers will be available to do the work. But the science system experiences an internal brain drain to government and the business sector, and an exodus of brains to feed the appetite of industrialized countries.

Playing on the international stage is modulated by the availability of knowledge workers and the attractiveness of the knowledge infrastructure. So the first point of leverage is the role of government in deciding which framework conditions should be addressed to improve national R&D competitiveness and openness. Such conditions include measures to grow and retain qualified staff, as well as to keep foreign postgraduates in whom investment has been made. A target of retaining, say, one third of foreign doctoral students might be a starting point. The Department of Science and Technology's programme of new research chairs aims to inject talent into the system and to do so in designated research fields. This is an important development to make the system attractive but also to steer research more actively. Allied to this must be a more flexible application of immigration regulations to attract foreign skills, and keep them.

Being or becoming attractive as a place to learn, research or teach asks individuals to make a personal choice. Such choice has a parallel in the investment decisions that firms make regarding where they will set up shop to manufacture or conduct R&D. The 2005 World Bank Investment Climate Survey[44] concludes that four factors are important in shaping such decisions of firms: stability and security, regulation and taxation, finance and infrastructure, and workers and labour markets. So, for example, foreign firms may be attracted to establish R&D

capacity in a country in response to the new enhanced R&D tax incentive allowing the deduction in their accounts of 150% of R&D current expenditure, or because a critical mass of appropriate researchers is available. Thus far the South African Revenue Service has treated all domestic taxpayers equally, so that by implication the subsidiaries of foreign multinationals would also be eligible for the new tax incentive. Moreover, foreign subsidiaries are also permitted to access government R&D grants through the Support Programme for Industrial Innovation and the Technological Human Resources for Industry Programme.

One might argue that personal decision-making will take into account factors similar to those identified by the investment climate survey. The proposed benefit sharing in the draft Intellectual Property Rights Bill potentially makes university research careers more attractive. Likewise, the research chairs programme offers new opportunities. It is also important is to play from one's strength. This manifests in the areas of mining and energy, defence and aerospace, and medicine. Completing the clinical trials chain to include phase I and discovery must become medium-term objectives. Moreover, we should understand the implications of foreign direct investment flows represented by the ingress of multinational corporations such as Mittal, Barclays, General Motors, Ford, Cisco, Amazon, Parmalat, Danone, Pechiney, Bouyges, Vodafone, and Chevron, to name but a few. Although 18% of BERD comes from abroad, only a third goes to general industrial investigation. Active measures are required to grow this proportion to promote R&D by foreign firms to improve our competitiveness and enable spillovers.

The evidence in this paper suggests that, from the R&D perspective, the emerging South African knowledge economy is still insufficiently 'open'. Co-inventorship shows low international participation, and co-publication, at least when last analysed in the late 1990s, was also at low levels. However, there are growing signs of inward R&D investment, which must be encouraged. While one recognizes significant pockets of expertise, these operate within a small science system that is not expanding rapidly enough. Greater investment in people and infrastructure, and the promotion of enabling framework conditions, remain priorities.

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