Scientific research in the natural sciences in South Africa: A scientometric study

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DATES:
Received: 30 July 2011
Revised: 04 Sep. 2012
Accepted: 25 Mar. 2013

KEYWORDS:
natural sciences; growth; collaboration; bibliometry; South Africa

HOW TO CITE:
Sooryamoorthy R. Scientific research in the natural sciences in South Africa: A scientometric study. S Afr J Sci. 2013;109(7/8), Art. #0001, 11 pages. http://dx.doi.org/10.1590/sajs.2013/20120001

As a leading producer of scientific publications on the African continent, South Africa has made remarkable progress. However, attempts are yet to be made to comprehend the empirical reality of scientific production in South Africa. One way to do this is to analyse specific science disciplines (such as the natural sciences), publication outputs and their features. A bibliometric study was undertaken of the publication trends and patterns of South African researchers in the natural sciences from 1975 to 2005 (choosing selected sample years), using the Thomson Reuters' Web of Knowledge database of selected indexed natural science journals. Characteristics of natural science publications, such as the trends over the years, were revealed as well as the collaborative dimensions involved in the production of scientific papers in these disciplines in South Africa. The connection between collaboration and publication, as well as between collaboration and sectors of authors was evident. The key findings of this study were that authors were based mostly in universities and were collaborative in their research endeavours. In addition, the participation of international collaborators has increased.

Introduction

In the production of scientific publications that are indexed in the Thomson Reuters (ISI) Web of Knowledge, South Africa is a leader on the African continent. During 2000–2004, South Africa's contribution to Africa's indexed scientific publications was 30%, the highest percentage to be achieved by any country on the continent.[1] In some of the natural science disciplines South Africa has fared well. During 2000–2004, South Africa topped other African countries in ecology (1187 publications), geosciences (1302 publications) and mathematics (275 publications), but lost its first position to Egypt in other natural science subjects such as chemistry and physics.[1]

Bibliometric analyses in the study of research practices in the natural sciences are well established.[2] Examining South African publications drawn from the ISI Web of Knowledge for 1980–2000, Pouris[3] found that while the number of publications produced by South Africans had increased in absolute numbers, the rate of growth had not been on a par with the international growth in scientific publications (a compound rate of 2.4% compared with 3.7% internationally).

Onyancha and Jacobs[4] investigated the nature of the capacitation of research in the natural sciences in South Africa for the period 1986–2006. They used bibliographic data and reported a mixed pattern of growth in different natural science disciplines. Certain disciplines within the natural sciences, such as biology, chemistry, geology, biochemistry and physics, were dominant in the institutions of higher learning in South Africa. Onyancha and Jacobs highlighted the interdisciplinary nature of research activities between some disciplines (for example, physics and environmental sciences) within the natural sciences. Most importantly, they noted the declining and inconsistent pace of growth in the number of researchers publishing indexed articles in the natural sciences in South Africa.[4]

Ingwersen and Jacobs[5] recorded variations in publication output and citations across selected fields between 1981 and 2000. Jacobs[6], on the other hand, investigated the patterns of research collaboration in the natural and applied sciences in South Africa between 1995 and 2003 and found that the publication output of South African researchers tended to be influenced by their collaborative tendencies.

Aside from the aforementioned studies, no study has been undertaken to analyse the production of scientific publications and their characteristics, patterns and trends in the natural sciences in South Africa over a reasonable duration. There are, however, some scientometric studies pertaining to South African scholars[7-9] which deal with specific disciplines or groups of disciplines such as the medical sciences and engineering.

This study examines, for the first time, the growth, trends and patterns in the production of scientific publications in the natural sciences in South Africa over a long period of time (longer than any previous study). Visible trends in publications are evident in their authorship, such as the fractional count of publications, partnering countries, sectoral origin of authors, South African authors and their partners, and the types of collaboration involved in the production of these publications are reported. While drawing on the characteristic features of the publications, the relationship between the production of publications and collaboration with its variant forms has also been examined.

The study should be viewed against the historical and political context of South Africa. Specifically, this analysis pertains to the period between 1975 and 2005, during which the scientific system in the country was influenced by a range of socio-economic and political factors.[10] Apart from these internal factors, South African science was also influenced by external forces, such as the international scientific community, that affected its nature, growth and development.[5,11]

Data and methods

Data were derived from ISI Web of Knowledge, specifically the Science Citation Index Expanded (1945–present) database. Widely used in bibiliometric analyses, the database provides generous information for the study of collaboration in the form of co-authored publications. Limitations aside, the Science Citation Index (SCI), relative

to several other bibliographic databases, has the advantage of a wide coverage of recognised, citation-based, and widely read scientific journals. SCI contains high-quality published research output and citations,[12] and is indexed on the basis of certain strict citation criteria, which assists in reliable analyses. However, it should be noted that ISI does not index all South African journals in the natural sciences, nor, for that matter, does any other database.

The data were processed in several successive stages before being used for the present analysis. In the first stage, data for relevant periods were chosen. No papers by South African scholars published between 1945 and 1965, irrespective of discipline, were stored in the ISI database. This absence, as Sooryamoorthy[13] reported, could be either because South African authors did not publish during these years or because South African journals did not yet appear in the SCI database. Until 1971, there were only a few publications, but later on the number began to increase. In this scenario, the year 1975 emerged as the appropriate starting point for analysis, followed by another sample year for every 5 years thereafter. In order to have a fairly long period of analysis, the data for a three-decade period with seven representative years – 1975, 1980, 1985, 1990, 1995, 2000 and 2005 – were chosen.

Only publications grouped as 'articles' and 'reviews' for the selected years were retrieved, provided they had at least one South African author. Among the total of 18 466 such publications by South African authors and their collaborators in all seven selected years, there were 5966 within the field of natural sciences. The natural sciences comprise astronomy, astrophysics, chemistry, environmental sciences, ecology, food sciences, geochemistry, geography, geology, mathematics, meteorology, microscopy, palaeontology, physics, statistics, and water resources. In the subsequent phase, all the available information about every record was extracted from the database and entered manually into the statistical software program SPSS.

Analysis and results

The specific characteristics of the publications which appeared in the ISI database for the seven selected years analysed were: the number of publication records, the number of authors involved in the production of these publications, partnering countries, the affiliation sector of authors and their partners, collaboration categories in the production of publications, and the regional origin of international partners. Wherever necessary, the basic characteristics of the publications in the natural sciences were compared with those of publications by South Africans in 'all subjects'.

Publications in the natural sciences

As the sample study shows, South Africa produced 5966 ISI-indexed publications in the natural sciences in the last three decades. When this figure was compared with the total number of publications in 'all subjects', it was 32% of the total South African output (1975–2005). The growth from 415 records in 1975 to 1416 in 2005 was about threefold (341%) in the natural sciences. The year-on-year change, that is, the difference between the current year and the immediate previous year, ranged between 21% and 74%, with the highest percentage of 74% occurring in 2005. Specifically, these changes were 21% in 1980, 45% in 1985%, 40% in 1990, 28% in 1995 and 32% in 2000. A drop in the publication count was seen in 1995, but it recovered in the following years. On average, ISI-indexed natural science publications by South Africans increased at a rate of 40% for every 5-year period of the analysis (Table 1).

Of the 18 466 publications in 'all subjects', 1212 were published in 1975 and 4161 in 2005. The increment between 1975 and 2005 was, as in the case of the natural sciences, threefold. 'All subjects' expanded to 343% of the number for the base year 1975. The year-on-year change for 'all subjects' ranged between 4% (in 1995) and 66% (in 2005). The average of these was 41%, which was just 1% over that of the natural sciences. A fall in publications was reported in 1995, for both the natural sciences and 'all subjects'. This fall was faster for 'all subjects' (4%) than for the natural sciences (28%). The F-test (F=0.026) showed that the variation

Table 1: Characteristics of publications in the natural sciences from South Africa, 1975–2005

Publication characteristics	YEAR														ANOVA		
	1975		1980		1985		1990		1995		2000		2005		All		F	Sig
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
No. of publications	415		504		691		858		974		1108		1416		5966			
No. of authors per publication	2.24	1.48	2.27	1.99	2.56	4.33	2.67	1.76	3.11	4.67	3.45	5.27	5.11	11.80	3.39	6.77	23.629	0.0
Fractional count of publication	0.6	0.30	0.62	0.30	0.58	0.30	0.50	0.28	0.50	0.28	0.45	0.27	0.39	0.25	0.49	0.29	75.137	0.0
Countries per publication	1.12	0.38	1.16	0.51	1.20	0.53	1.24	0.59	1.43	1.00	1.59	1.04	1.89	1.52	1.47	1.05	74.565	0.0
Countries per publication in international collaboration	2.13	0.467	2.23	0.79	2.18	0.70	2.27	0.71	2.45	1.32	2.45	1.21	2.78	1.76	2.53	1.40	7.435	0.0
Citations per publication	22.31	138.91	16.03	25.09	16.14	29.40	14.97	30.95	11.83	21.35	8.81	16.46	2.76	5.71	11.15	42.37	18.849	0.0
Affiliation sector of author																		
University	1.29	1.24	0.95	0.93	1.05	0.92	1.48	1.15	1.58	1.10	2.00	1.06	2.19	1.09	1.65	1.16	160.732	0.0
Research institute	0.16	0.53	0.21	0.48	0.31	0.67	0.23	0.52	0.18	0.46	0.35	0.76	0.44	0.86	0.30	0.68	23.256	0.0
Government	0.48	0.91	0.31	0.63	0.14	0.38	0.15	0.48	0.20	0.52	0.04	0.21	0.03	0.21	0.15	0.47	75.714	0.0
Industry	0.02	0.15	0.04	0.20	0.05	0.23	0.04	0.26	0.05	0.22	0.04	0.29	0.05	0.30	0.04	0.26	0.631	0.7
Hospital	0.06	0.35	0.03	0.27	0.01	0.10	0.00	0.07	0.01	0.09	0.02	0.18	0.01	0.10	0.01	0.16	8.232	0.0
Type of publication[†]	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	104.310	0.0
South African journal	85	20.5	127	25.20	188	27.20	153	17.80	102	10.50	199	18.00	216	15.30	1070	17.90		
Non-South African journal	330	79.5	377	74.80	503	72.80	705	82.20	872	89.50	909	82.00	1200	84.70	4896	82.10		

[†]*Analysed using Chi-squared tests.*

between the number of publications in the natural sciences and in 'all subjects' was unequal, supporting the finding that the growth trail for the natural sciences was not different from that of the 'all subjects' (Figures 1 and 2).

The average number of authors who worked together in producing publications rose from 2.24 per publication in 1975 to 5.11 in 2005, with an aggregate average of 3.39 for the entire period of analysis. In 1995, the number rose to 138% of the 1975 value, followed by 154% in 2000 and reached an all-time high of 228%. Further analysis revealed that 21% of the papers were the efforts of single authors, 31% of two authors, 22% of three authors, 12% of four authors, 6% of five authors, and the remainder were the work of six or more authors. The proportion of sole-authored papers in 2005 was smaller than that for the entire period of analysis (11% against 21%). A quarter of the publications in 2005 were written by two authors, another 24% by three authors, 17% by four authors, and the remaining 23% by five or more authors. The median value of authors for 2005 was three (Table 2).

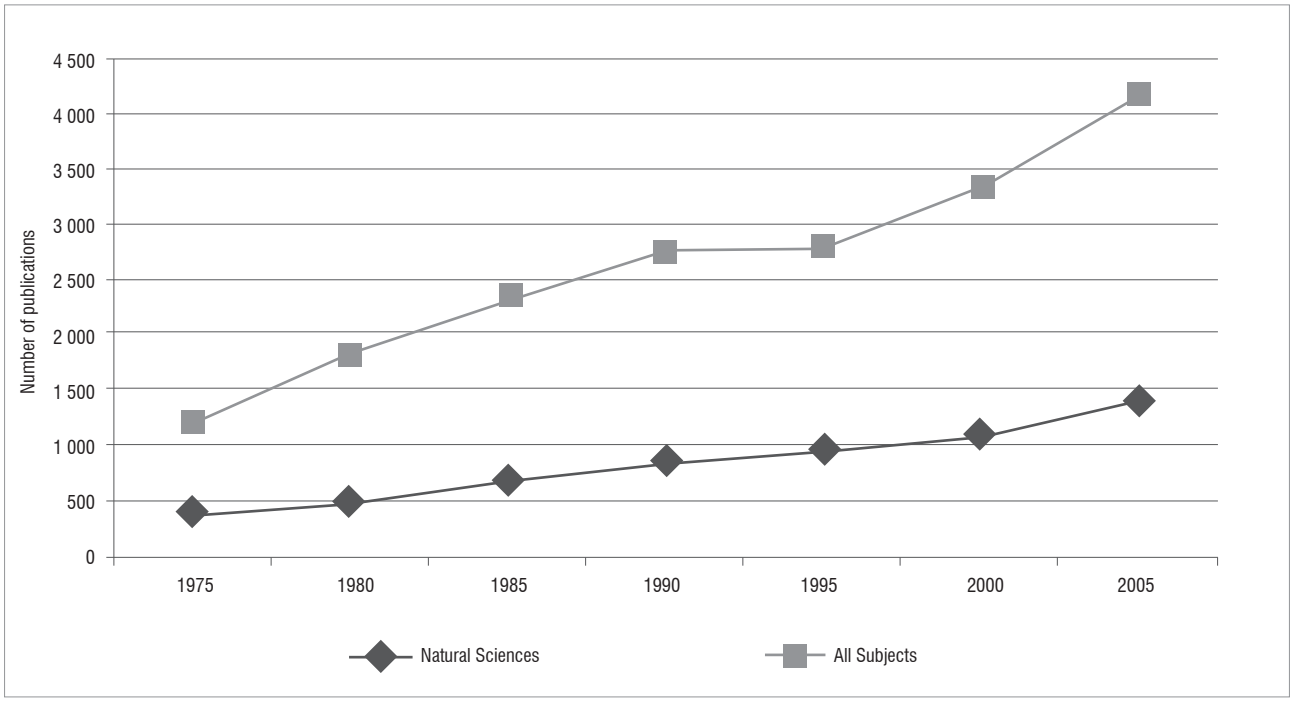

Figure 1: Growth of publications in the natural sciences and in 'all subjects' in South Africa, 1975–2005.

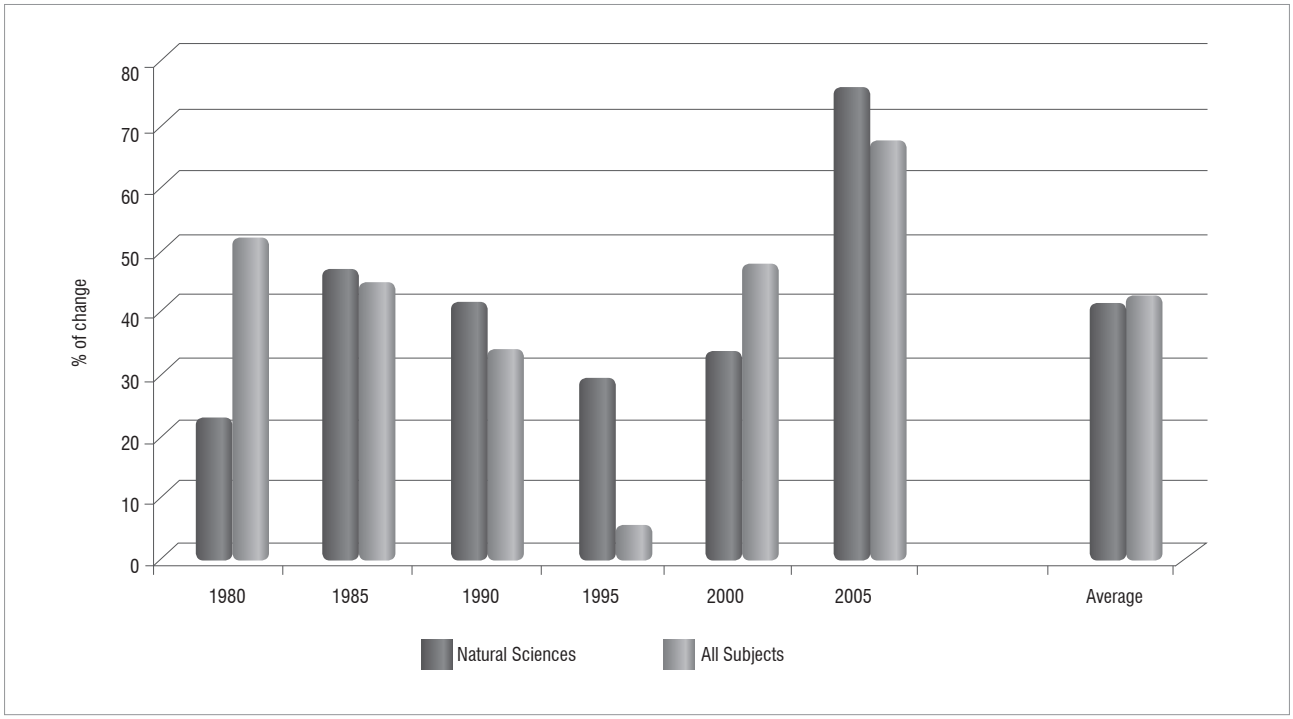

Figure 2: Year-on-year change in the production of publications in the natural sciences and in 'all subjects'.

Table 2: Co-authorship and collaboration in natural science publications from South Africa, 1975–2005

Publication records	Year															
	1975		1980		1985		1990		1995		2000		2005		All	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
Authorship																
Sole authored papers***	143	34.5	189	37.5	216	31.3	182	21.2	202	20.7	181	16.3	160	11.3	1273	21.3
Co-authored papers***	272	65.5	315	62.5	475	68.7	676	78.8	772	79.3	927	83.7	1256	88.7	4693	78.7
All authors South African***	229	55.2	250	49.6	358	51.8	512	59.7	485	49.8	650	58.7	707	49.9	3292	53.5
Collaboration types[†]																
Any collaboration	272	65.5	315	62.5	475	68.7	676	78.8	772	79.3	927	83.7	1256	88.7	4693	78.7
Domestic collaboration	233	85.7	248	78.7	363	76.4	539	79.7	514	66.6	560	60.4	682	54.3	3139	66.9
Internal-institutional collaboration (within domestic collaboration)	197	84.5	207	83.1	284	78.2	401	74.1	368	71.5	388	68.8	465	67.7	2310	73.3
External-institutional collaboration(within domestic collaboration)	40	17.2	45	18.1	82	22.6	146	27.0	151	29.3	193	34.2	262	38.1	919	29.2
International collaboration	45	16.5	69	21.9	115	24.2	163	24.1	288	37.3	442	47.7	702	55.9	1824	38.9
Multi-country international collaboration (within international collaboration)[‡]	4	8.9	8	11.6	12	10.4	30	18.4	66	22.9	111	25.1	228	32.5	459	12.5
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Degree of collaboration	0.69	0.54	0.65	0.54	0.71	0.52	0.86	0.53	0.90	0.57	1.02	0.60	1.17	0.65	0.92	0.61
Degree of collaborators of collaborated papers	1.05	0.25	1.04	0.24	1.04	0.22	1.09	0.32	1.13	0.38	1.22	0.44	1.32	0.54	1.17	0.42

****p<0.001; Chi-squared test*

[†]percentage of collaborative papers; single-authored papers are not applicable under this classification

[‡]percentage of international collaborative papers

The number of countries associated with South African scientists can be analysed from two standpoints. The first is the number of countries per publication for the whole sample, and the second is the number of countries per publication for those works resulting from international collaboration. The second standpoint provides a more precise picture than the first. When all papers were taken into consideration, the average number of countries that participated in the production of publications in the natural sciences was 1.49. In 1975, the average number of countries which participated in the production of papers in the natural sciences in South Africa was 1.12, which rose to 1.89 in 2005. Considering 1975 as the base year, the increase in the number of countries was 169%. Here again, 1995 marked the beginning of a sizable increase of 128%. Compared to these figures, there were 1.4 countries per publication in 'all subjects' during the period, which was smaller than that of the natural sciences by 0.09 points. However, this difference did not recur between 1975 and 2005 for 'all subjects'. The change in growth of 166% for 'all subjects' was close to the 169% for the natural sciences.

In 1975, there were 2.13 countries that participated in the production of international collaborative papers. By 2005, this number had risen to 2.78, amounting to 131% of the 1975 figure. The average change over the seven selected years was 6%. About 75% of the internationally collaborative papers had brought in scholars from two countries, while 16% brought three countries together, and the remaining 9% brought together four or more countries.

'All subjects' had a participation of 2.56 countries per every internationally produced publication, more than the natural sciences. Between 1975 and 2005, the increase was 130%, about the same as the 134% increase for the natural sciences. The year-on-year average change was also the same for 'all subjects' – 5%. The count of countries per publication remained the same for 'all subjects': 74% with two countries, 16% with three, and 10% with four or more countries.

The ISI-indexed publications in the natural sciences by South African researchers and their partners attracted an average of 11.15 citations per item. The highest average – 22.31 citations per publication – was reported in 1975. By 2000, the count had declined significantly to 8.81, which was only 40% of the citations received in 1975. The citation count in the natural sciences deteriorated from year to year, with an average change between the chosen years of 60%, a loss of 40%. For 'all subjects', the average citation per publication for the period of analysis was 10.53, 0.62 points less than that for the natural sciences. For 'all subjects', the number of citations was 17.26 in 1975 but declined to 9.74 in 2000. The year-on-year change, on average, was 69%, about 9% more than that for the natural sciences.

Sectors of South African authors in the natural sciences

Authors of publications in the natural sciences belong to five major sectors: universities, research institutes, government departments, industries and hospitals. In view of the manageability of records, this analysis focused on the affiliation sectors of up to five authors, the first five South African authors, and the first five international partners.

Most of the authors came from universities, followed by research institutes, government departments, industry and hospitals. As seen in Table 1, the university sector emerged with the highest mean value of 1.65 for the three-decade period. The research institute sector was second with a mean value of 0.30 – less than one-fifth of the university sector. The government sector contributed half of what research institutes had produced in terms of the number of authors. The industry and hospital sectors were poorly represented. The number of scholars coming from universities rose after 1990 to a value of 70% over that of the 1975 value. The contribution of universities in both 1980 and 1985 declined since 1975 by 26% and 17%, respectively.

Research institutes in South Africa formed the second major sector after the university sector. Research councils are included in the category of research institutes. The mean number of authors from research institutes improved by 275% from 0.16 in 1975 to 0.44 in 2005. However, in 1995, the mean number of authors from research institutes dropped slightly,

but not below the 1975 level. The expansion of this sector year after year was consistent, and compared well with the university sector. As opposed to universities, the number of authors from research institutes augmented at a faster rate during 1975–2005. While the university sector fell below the mean value of 1975 in both 1980 and 1985, the research institute sector gained in both these years, by 31% and 94%, respectively (Figure 3).

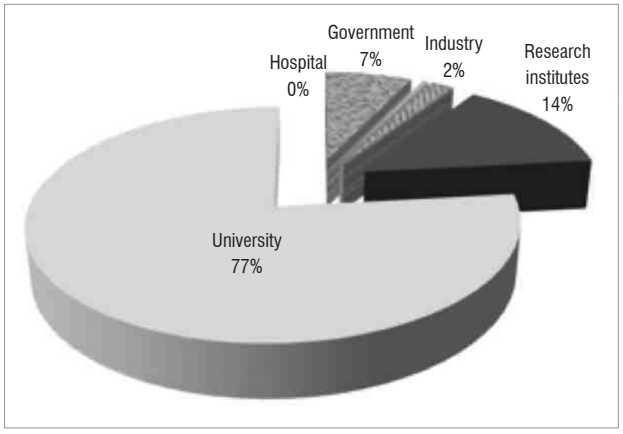

Figure 3: Sectoral share of authors in the natural sciences, 1975–2005.

The third major sector was government, which is comprised of departments, parks, museums and gardens. In 1975, this sector had a mean number of authors of 0.48, which by 2005 had reduced to 0.03. This decline was a loss of 94% of the original value reported in 1975 and was gradual until 1990, i.e. 65% in 1980, 29% in 1985, 31% in 1990 and 42% in 1990. After 2000 the fall was sudden. In 2000, authors representing the government sector consisted of just 8% of what the value had been in 1975 and declined further to 6% in 2005. Industries and hospitals did not make a significant contribution to the supply of authors in the natural sciences.

Personnel in government departments and industries are not expected to produce scientific publications the way academics in universities and researchers in research institutes are. However, the availability of and access to data encourages some to publish material. These authors are self-motivated people who are interested in publicising the findings of key issues for the public.

Authorship and collaboration

About one-fifth of the publications between 1975 and 2005 were produced by single authors while the majority were authored jointly. In the past 30 years, the share of single-author publications has contracted from 38% to 11%. In 2005, the proportion of single-authored papers was reduced to one-third of what it was in 1975. Therefore the share of co-authored papers grew from 66% in 1975 to 89% in 2005. Co-authored publications appreciated to 135% of their original share in 1975, with a year-on-year average growth of 6% between the selected five years. Only in 1980, joint publications dropped to 2.5% of the previous year. A total of 54% of all authors were South African or based in South Africa at the time of publishing their research. This percentage declined to 50% by 2005.

In the natural sciences, collaboration has been increasing. The percentage of collaborative papers for the aggregate period was 79%. In 1975, 66% of papers in the natural sciences involved some form of collaboration. By 2005, this figure had expanded to 89% of all publications. Between the five years, the most significant change was seen in 1990 with 79% of all publications involving collaboration. This change was 120% of the percentage of collaborative papers published in 1975. Again in 2005, there was considerable growth in the number of collaborative papers (89%), i.e. 135% of the 1975 collaborative publications. In about 54% of the publications in the natural sciences (for the whole period), all authors were affiliated with South Africa. Year-wise data showed that in 55% of publications in 1975, all authors were from South Africa; this figure declined to 50% by 2005.

Collaboration can be analysed in a variety of ways. When authors from within a country partner, it is regarded as domestic collaboration, either internal-institutional (authors belong to the same department or institution) or external-institutional (authors belong to different departments or institutions within South Africa). International collaboration means that at least one of the collaborators is from another country. If more than one other country is involved, then it becomes a multi-country international collaboration. Collaborative publications can be domestic, international or both.

In the aggregate period, 67% of the publications were the result of research alliances that occurred within South Africa (domestic collaboration). The average percentage of domestic collaboration ranged between 86% in 1975 and 54% in 2005, showing a clear reduction in the percentage of papers generated from domestic collaborations. If the percentage for 1975 was the benchmark (1975=100), the loss in 2005 was 37%. In domestic collaboration, 73% of publications for the whole period were produced through internal-institutional collaboration, compared with 30% produced through external-institutional collaboration. In between the years of analysis, internal-institutional collaboration manifested trends of decline from 85% in 1975 to 68% in 2005, such that by 2005 there was a reduction of 20% from the 1975 level. Only 17% of papers emerged from external-institutional alliances in 1975; a figure which rose to 38% by 2005 – more than doubling the percentage of papers.

Overall, 39% of co-authored publications were produced out of international collaborative research. In 1975, international research alliances formed only 17% of the total co-authored publications. This percentage grew steadily over the years, reaching 56% of all co-authored publications in 2005. This figure was more than 2% of the domestic collaboration for the same year. Between 1990 and 1995, the percentage of internationally co-authored papers increased rapidly from 24% to 37%.

The surge in publications during this period is attributed to the changes that occurred in South African science since the late 1980s. For political reasons relating to the apartheid regime, circumstances for scientific growth, publications and co-publications were not conducive until the late 1980s.[10] This 'closed off' period was when the South African scientific community was isolated from the international scientific fraternity as a result of a scientific boycott.[5] It is only since the early 1990s that, because of democratisation in the post-1994 period resulting in political stability, the conditions for the movement of scientists from abroad began to ease and a collaborative approach towards South Africa by the international scientific community became evident. South African scientists also gained access to international resources including publication opportunities and association with their international peers.[14] With the end of the period of isolation, international journals began to accept the contributions of South African scientists which resulted in an increase in the publications of South African scientists.[5,11]

Another potential factor that influenced the growth of publications in general was the influential funding policies of the government.[15] Notably, the number of potential researchers, which in 2006 was 16 000, has also been increasing since 1990.[16]

Within international collaboration another pattern – multi-country collaboration – has evolved. Multi-country international collaboration made up a good share of the internationally co-authored papers between 1975 and 2005. There has been a significant increase in multi-country international collaboration from 4 papers in 1975 to 228 in 2005. About 13% of internationally authored papers for the whole period involved the participation of more than one other country. Of the multi-country collaborative papers, 64% included the involvement of two other countries, 17% of three other countries, 6% of four other countries, and the remaining 15% of five or more other countries, with an average number of 3.1 countries per every multi-country publication. One paper was authored by researchers from 15 foreign countries – the highest number in collaborative research in the natural sciences during the period of analysis.

In this analysis, the degree of collaboration in the natural sciences was measured using the indicators of collaboration – domestic and its types, international, and multi-country collaboration. As per the definition, the presence of all types of collaboration will give a maximum index of four (internal-institutional, external-institutional, international and multi-country international). The mean degrees of collaboration for all papers and collaborative papers for the period of analysis were 0.92 and 1.17, respectively. It is clear from these figures that the presence of collaboration is widespread. In the case of co-authored papers, the index was higher at 1.17. Between the years of analysis the index advanced progressively from 1.04 to 1.32. As for the number of papers with any form of collaboration, the highest collaboration index was in 2005.

Partners of South African authors and their regional origins

Table 3 presents the regional background of the overseas collaborators of South African researchers in the natural sciences. Collaborators were from all regions: Europe, North America, Australasia, Asia, Africa, the Middle East, Latin America and Eastern Europe.

The order in terms of the mean number of representative regions was Europe, North America, Australasia, Asia, Eastern Europe, Latin America, the Middle East and Africa. The greatest number of partners was from European and North American countries. Australasia was represented in only about one-fourth of North America's share. Asia and Eastern Europe had about half the number of that of Australasia. Latin America contributed half of the Eastern Europe figure. The Middle East and Africa had the lowest representations.

European scholars who worked with South African counterparts increased in number more than sevenfold: 1.5 times in 1995, 1.6 times in 2000 and 2.6 times in 2005. North American collaboration was not as high as European collaboration. Compared with the mean value of 0.241 for Europe it was 0.151 for North America. North American collaboration with South Africa expanded threefold of what it was in 1975, with the most remarkable expansion occurring in 1990 and thereafter.

The average level of Asian collaboration for the entire period was below that of Australasian collaboration. This difference was balanced out in 2005 when Asian collaboration gained a slight edge over Australasia. Collaboration with other African countries was consistently insignificant.

Individual countries of overseas partners

The partners of South African researchers in the natural sciences originated from 54 countries, representing all continents (Table 4). Half of the total collaborations were carried out with three countries – USA, England and Germany – and 80% was conducted with 11 countries – the USA, England, Germany, France, Australia, Canada, Italy, the Netherlands, Belgium, Japan and Spain – mostly European and North American countries. The largest contribution – 25% – belonged to the USA, followed by England and Germany (12% each). The African countries with which South African scholars worked constituted only 1% of the total collaboration. These countries (in descending order of the share of collaboration) were: Zimbabwe, Ethiopia, Botswana, Namibia, Egypt, Malawi, Swaziland, Tanzania and Zambia. Inter-African collaboration in the natural sciences was mostly evident in environmental sciences/ecology (43% of the total African collaboration) and chemistry (13%). Another 26% was classified by ISI as 'multidisciplinary'.

Collaboration with Asian countries (Japan, China, India, Taiwan, South Korea, Hong Kong and Indonesia) constituted 6% of the whole. In this Asian–South African alliance, Japan, China and India were more prominent with 5% of the contribution. The BRIC countries – Brazil, Russia, India and China – with whom South Africa has established economic collaboration, contributed 19% 39%, 28% and 14% of the total of the four countries, respectively. Collaborations with these countries were mainly in the areas of physics, chemistry, astronomy, geochemistry and geology.

Table 3: Regional and sectoral representation of foreign partners of South African authors in the natural sciences, 1975–2005

Region and sector	Year														ANOVA			
	1975 (*N*=415)		1980 (*N*=504)		1985 (*N*=691)		1990 (*N*=858)		1995 (*N*=974)		2000 (*N*=1108)		2005 (*N*=1416)		All (*N*=5966)		F	Sig
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Region of partners																		
Europe	0.062	0.257	0.079	0.385	0.109	0.362	0.117	0.416	0.205	0.565	0.304	0.694	0.466	0.978	0.241	0.669	21.591	0.000
North America	0.080	0.429	0.085	0.365	0.081	0.330	0.100	0.379	0.140	0.440	0.190	0.572	0.239	0.645	0.151	0.502	15.146	0.000
Australasia	0.010	0.085	0.010	0.118	0.010	0.100	0.030	0.185	0.040	0.319	0.050	0.248	0.060	0.302	0.040	0.240	6.878	0.000
Asia	0.000	0.000	0.000	0.000	0.006	0.093	0.012	0.136	0.019	0.135	0.035	0.228	0.068	0.360	0.028	0.218	13.019	0.000
Eastern Europe	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001	0.037	0.006	0.034	0.006	0.026	0.004	0.018	0.001	10.423	0.000
Latin America	0.000	0.000	0.000	0.000	0.001	0.038	0.008	0.090	0.013	0.131	0.004	0.060	0.020	0.164	0.009	0.106	5.200	0.000
Middle East	0.002	0.049	0.002	0.044	0.007	0.084	0.005	0.068	0.009	0.095	0.007	0.112	0.004	0.070	0.006	0.082	0.859	0.524
Africa	0.000	0.000	0.004	0.062	0.003	0.053	0.008	0.113	0.006	0.110	0.005	0.067	0.007	0.084	0.005	0.083	0.697	0.652
Sector of partners																		
University	0.110	0.440	0.100	0.345	0.140	0.402	0.190	0.539	0.320	0.653	0.530	0.863	0.720	1.006	0.380	0.766	103.610	0.000
Research institute	0.020	0.146	0.030	0.193	0.030	0.191	0.060	0.254	0.080	0.316	0.140	0.485	0.250	0.679	0.110	0.442	40.450	0.000
Industry	0.000	0.049	0.000	0.045	0.000	0.056	0.010	0.076	0.010	0.101	0.010	0.095	0.010	0.095	0.010	0.085	0.801	0.569
Government	0.010	0.120	0.040	0.293	0.020	0.160	0.030	0.185	0.070	0.333	0.010	0.099	0.010	0.088	0.010	0.196	11.361	0.000
Hospital	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.003	0.010	0.003	0.010	0.002	0.000	0.001	2.203	0.040
Other	0.010	0.120	0.040	0.293	0.020	0.146	0.030	0.179	0.060	0.330	0.000	0.079	0.000	0.053	0.020	0.188	13.445	0.000

Table 4: Countries of South African partners in natural sciences research, 1975–2005

Country	Partner 1		Partner 2		Partner 3		Partner 4		Partner 5		Total	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%	*N*	%
USA	451	26.21	183	27.56	71	24.32	40	23.81	28	25.00	773	26.14
England	210	12.20	87	13.10	31	10.62	17	10.12	16	14.29	361	12.21
Germany	227	13.19	61	9.19	32	10.96	23	13.69	11	9.82	354	11.97
France	92	5.35	48	7.23	33	11.30	11	6.55	9	8.04	193	6.53
Australia	109	6.33	49	7.38	16	5.48	10	5.95	8	7.14	192	6.49
Canada	87	5.06	24	3.61	8	2.74	8	4.76	3	2.68	130	4.40
Italy	55	3.20	25	3.77	12	4.11	10	5.95	3	2.68	105	3.55
Netherlands	39	2.27	17	2.56	5	1.71	5	2.98	6	5.36	72	2.43
Belgium	44	2.56	12	1.81	4	1.37	3	1.79	3	2.68	66	2.23
Japan	30	1.74	13	1.96	9	3.08	6	3.57	4	3.57	62	2.10
Spain	28	1.63	15	2.26	7	2.40	3	1.79	4	3.57	57	1.93
Russia	34	1.98	12	1.81	3	1.03	1	0.60	1	0.89	51	1.72
Poland	31	1.80	11	1.66	4	1.37		0.00	5	4.46	51	1.72
China	24	1.39	16	2.41	7	2.40	1	0.60	1	0.89	49	1.66
Switzerland	28	1.63	9	1.36	3	1.03	2	1.19	2	1.79	44	1.49
Sweden	24	1.39	11	1.66	3	1.03	3	1.79	2	1.79	43	1.45
India	26	1.51	10	1.51	5	1.71		0.00		0.00	41	1.39
Scotland	23	1.34	7	1.05	6	2.05	2	1.19		0.00	38	1.29
Austria	18	1.05	7	1.05	3	1.03	3	1.79		0.00	31	1.05
Israel	18	1.05	4	0.60	1	0.34	5	2.98	2	1.79	30	1.01
New Zealand	18	1.05	2	0.30	3	1.03	4	2.38	1	0.89	28	0.95
Brazil	12	0.70	8	1.20	3	1.03		0.00	1	0.89	24	0.81
Denmark	9	0.52	4	0.60	6	2.05	2	1.19		0.00	21	0.71
Ireland	11	0.64	3	0.45	2	0.68		0.00		0.00	16	0.54
Argentina	3	0.17	1	0.15	7	2.40	4	2.38		0.00	15	0.51
Greece	11	0.64	1	0.15		0.00	1	0.60		0.00	13	0.44
Chile	6	0.35	4	0.60	1	0.34		0.00	1	0.89	12	0.41
Zimbabwe	11	0.64		0.00		0.00		0.00		0.00	11	0.37
Wales	5	0.29	3	0.45	1	0.34		0.00	1	0.89	10	0.34
Portugal	2	0.12	3	0.45	2	0.68	2	1.19		0.00	9	0.30
Taiwan	5	0.29	2	0.30		0.00		0.00		0.00	7	0.24
Ethiopia	6	0.35		0.00		0.00		0.00		0.00	6	0.20
Botswana	3	0.17	1	0.15	1	0.34	1	0.60		0.00	6	0.20
South Korea	3	0.17	2	0.30		0.00		0.00		0.00	5	0.17
Namibia	3	0.17		0.00		0.00	1	0.60		0.00	4	0.14
Saudi Arabia	1	0.06	2	0.30		0.00		0.00		0.00	3	0.10
Hong Kong	3	0.17		0.00		0.00		0.00		0.00	3	0.10
Ukraine	3	0.17		0.00		0.00		0.00		0.00	3	0.10
Finland	1	0.06		0.00	1	0.34		0.00		0.00	2	0.07
Mexico	2	0.12		0.00		0.00		0.00		0.00	2	0.07
Croatia	2	0.12		0.00		0.00		0.00		0.00	2	0.07
Czechoslovakia			2	0.30		0.00		0.00		0.00	2	0.07
Egypt	1	0.06		0.00		0.00		0.00		0.00	1	0.03
Uruguay	1	0.06		0.00		0.00		0.00		0.00	1	0.03
Malawi	1	0.06		0.00		0.00		0.00		0.00	1	0.03
Indonesia	1	0.06		0.00		0.00		0.00		0.00	1	0.03
Swaziland			1	0.15		0.00		0.00		0.00	1	0.03
Norway			1	0.15		0.00		0.00		0.00	1	0.03
Hungary			1	0.15		0.00		0.00		0.00	1	0.03
Bulgaria			1	0.15		0.00		0.00		0.00	1	0.03
Tanzania			1	0.15		0.00		0.00		0.00	1	0.03
Yugoslavia				0.00	1	0.34		0.00		0.00	1	0.03
Zambia				0.00	1	0.34		0.00		0.00	1	0.03
Ukraine				0.00		0.00		0.00		0.00	0	0.00
Total	1721	100	664	100	292	100	168	100	112	100	2957	100

With regard to South African collaboration with the global North and the global South, it was evident that most collaborations involved countries in the North rather than in the South. Of the total collaboration, 86% was with scholars in European and North American countries.

Relation between collaboration and production of publications

The data in Table 5 show the association between the number of ISI-indexed publications and collaborative authorship; the question is whether collaboration has a direct or inverse relationship with publication number.

The average year-on-year change in collaborative papers was 40% during 1975–2005. There were 4693 collaborative papers amongst these publications, which rose to 462% by 2005, with an average year-on-year change of 60% – higher than the average of the total number of publications. The number of papers that were a product of domestic collaboration was 3139, which rose by 293% in 2005. The year-on-year average for internationally collaborative papers was 1824 in total, which registered a higher level of increase in percentile terms. The number grew 15-fold from 1975 to 2005, with an average year-on-year change of 243%. Although small in number, multi-country collaborations resulted in the production of 459 papers and showed the greatest growth. In 2005, multi-country collaboration reached 57 times that of the 1975 figure, with an average year-on-year change of 933%. Co-authored papers – including all three forms of domestic, international and multi-country collaborative papers – registered a higher level of growth than that for all papers. If co-authored papers only were compared with all publications, the year-on-year difference was over 50% (60% and 40%, respectively). This trend suggests that collaboration exerted an influence on the production of papers in the natural sciences. In other words, collaboration led to the generation of more papers than could be generated individually in the discipline in South Africa.

As there is evidence of association between collaboration and publication, the variables that affect collaboration were examined. Table 6 presents the Pearson's correlation coefficients of relevant variables. The degree of collaboration, measured on an additive scale that counted all the existing levels of internal-institutional, external-institutional, international and multi-country collaborations, seemingly correlates with the year of publication, the number of authors, the exclusivity of only South African authors in publications, South African authors within the same organisation, citation count, and the number of foreign countries involved in the production of publications.

The degree of collaboration was positively (and significantly) correlated with the year of publication, the number of citations and the number of other countries. The number of publications in local South African journals was negatively correlated with the degree of collaboration, which may positively affect the number of publications in overseas journals. Depending on the number of other countries involved in the output of publications, a positive change in the degree of collaboration can be envisaged.

Table 5: Collaborations and publications of scientists in the natural sciences in South Africa, 1975–2005

	Publications in the natural sciences			Collaborative publications			Domestic collaborative publications			International collaborative publications			Multi-country collaborative publications		
Year	***N***	**% of 1975**	**Change**	***N***	**% of 1975**	**Change**	***N***	**% of 1975**	**Change**	***N***	**% of 1975**	**Change**	***N***	**% of 1975**	**Change**
1975	415	100.00		272	100.00		233	100.00		45	100.00		4	100.00	
1980	504	121.45	21.45	315	115.81	15.81	248	106.44	6.44	69	153.33	53.33	8	200.00	100.00
1985	691	166.51	45.06	475	174.63	58.82	363	155.79	49.36	115	255.56	102.22	12	300.00	100.00
1990	858	206.75	40.24	676	248.53	73.90	539	231.33	75.54	163	362.22	106.67	30	750.00	450.00
1995	974	234.70	27.95	772	283.82	35.29	514	220.60	-10.73	288	640.00	277.78	66	1650.00	900.00
2000	1108	266.99	32.29	927	340.81	56.99	560	240.34	19.74	442	982.22	342.22	111	2775.00	1125.00
2005	1416	341.20	74.22	1256	461.76	120.96	682	292.70	52.36	702	1560.00	577.78	228	5700.00	2925.00
Average		205.37	40.20		246.48	60.29		192.46	32.12		579.05	243.33		1639.29	933.33

Table 6: Correlation matrix of degree of collaboration in the natural sciences and other variables

	Degree of collaboration		Year of publication		Log no. of authors		South African authors		South African authors in the same organisation		Log no. of citations		Non-local journal		No. of other countries
Degree of collaboration	1														
Year of publication	0.286	***	1.000												
Log no. of authors	-0.741	***	0.262	***	1.000										
South African authors	-0.461	***	-0.230	***	-0.377	***	1.000								
South African authors in the same organisation	-0.219	***	0.093	***	-0.117	***	-0.158	***	1.000						
Log no. of citations	0.054	***	-0.335	***	0.103	***	-0.092	***	-0.071	***	1.000				
South African journal	-0.057	***	-0.082	***	-0.066	***	0.070	***	-0.031	***	-0.134	***	1.000		
No. of other countries	0.533		0.249	***	0.643	***	-0.652	***	0.111	***	0.095	***	-0.053	***	1.000

****p<0.001*

Discussion

The growth trends in the production of scientific knowledge in the natural sciences in South Africa for the last three decades were similar to those in 'all subjects'. The steady increase in the average number of authors per publication in the natural sciences, juxtaposed with those for 'all subjects', conveys several points. Firstly, it denotes a declining tendency to produce knowledge individually (in sole-authored publications). Secondly, it explains the increasingly collaborative preferences of authors in the production of scientific knowledge. Thirdly, it denotes the increasing number of authors (from 2.24 to 5.11 authors per paper) working together in the production of research publications. Fourthly, it shows an ascending pattern in the participation of countries in internationally collaborative papers, which was not significantly different from that seen in 'all subjects' for South Africa.

Citation trends of the publications in the natural sciences did not provide evidence that the knowledge produced by South African scholars is being used by the academic community as much as the knowledge created in 'all subjects' in South Africa. In their analysis covering 30 countries, Glänzel and Lange[17] noted that the observed, expected, and relative citations of papers in biomedical research and chemistry produced higher rates of citations, more so in the case of papers that were the results of multi-country research projects. Another citation analysis of South African publications indicated that the citation count was also dependent on the type of collaboration that led to the production of the publication.[18]

The large majority of authors were from universities while the research institutes were the second major player in the production of publications. Pouris'[19] ranking of South African universities based on research output has also revealed the significant role of universities in research. Like South African researchers in the natural sciences, foreign partners originated mostly from universities and research institutes. The only difference between South African authors and their foreign partners affiliated to universities was that South African researchers had partners from government and industry, but, for foreign partners, government and industry partnerships were relatively negligible. This aspect of the leading role of universities in research has been reported in previous research.[4] Pouris[3] observed that the higher education sector was responsible for 80% of the publication outputs of South Africans. What was striking in this analysis was the great difference between these two sectors (universities and research institutes) in the production of knowledge in the natural sciences. Research institutes produced only one-fifth of that of the universities, government less than one-tenth and industry only about 3% of the university sector.

Shrinking internal-institutional collaboration and expanding external-institutional collaboration point to significant trends in the disciplines in the natural sciences. South African researchers are looking outwardly rather than remaining within the limited confines of their own departments and institutions. This outlook was very clear in regard to international collaboration, which has in recent years exceeded domestic collaboration. More recently, international collaboration involving several countries has been expanding in the natural sciences. Mouton[20] found that inter-institutional and inter-sectoral collaboration are relatively low in South Africa.

Collaboration with foreign scientists is a feature that is remarkable in the natural sciences in South Africa. This finding corroborates that of other recent studies that reported an increase in international collaboration over national collaboration.[6] Jacobs[6] also found that South Africans collaborate more frequently than their counterparts in the USA and the UK.

South Africans collaborate most with authors from developed countries in the global North – European and North American countries – while research alliances with countries in the global South are dismally few. Schubert and Sooryamoorthy[21] also noted this feature of South African collaboration. For Boshoff[22], this scenario is an unequal and unbalanced partnership in North–South collaboration. Flemish researchers in the natural sciences also have shown similar interest in associating with international colleagues. Luwel[23] reported that about half of the total papers produced by Flemish natural science researchers in 1980–1996 were joint publications with foreign scientists. In Canadian research collaborations, as Larivière et al.[2] found, factors such as language and geographical proximity play an influential role. Jappe[24] also noted the influence of geographical locations on collaboration in earth and environmental sciences. A high level of collaboration, for a period of 23 years (1980–2002), was apparent in the natural sciences and engineering subjects in Canada.[2] Larivière et al.[2] reported that almost all papers were joint authored and the predominant form of collaboration was international rather than inter-institutional. Braun et al.[25] underlined the vigorous character of physics for international co-operation. As Davenport and Cronin[26] reported, joint authorships tend to vary according to disciplines and fields and the 'honorific' authorship phenomenon is common in the biomedical community.

Although causality cannot be established it is obvious from the data that the number of publications and collaboration are related. The likelihood of a publication produced through collaboration is more than that for the total number of publications. This finding suggests that increasing levels of collaboration – international over domestic – have an influential role in the production of publications in the natural sciences. This analysis has also highlighted the relationship between the degree of collaboration and some key variables including number of citations, the year of publication, publications in overseas journals, and the number of countries involved.

The above analysis and findings based on bibliographic records need to be viewed against the background of certain other factors that have influenced the production of publications in science in general and in the natural sciences in particular.

The analysis showed some trends in the production of publications. South African science was not free from the political environment. South Africa suffered a period of academic boycott on the activities conducted by South African researchers as a result of the apartheid policies of the government. International journals joined in this boycott and refused to accept South African contributions and avoided South African participants in conferences.[12] This 'closed off' period from the mid-1980s to 1994 caused a decline in the publication productivity of South African scientists[5,6,14,11]; publication was possible only in South African journals. Since 1994, there has been a positive change in the production of scientific publications, marking a favourable approach from the international community to collaborate with South African researchers.[14,15] As noted before, changing funding policies also facilitated an increase in publications.[16] Along with these, there has been an increase in the opportunities for scholars to publish their research, as new commercialised outlets have arisen.

Introduced in 1987, the funding system for universities made an impact on research and research output in South Africa.[10] The funding formulae included a subsidy per research output in approved publications, and is still followed today with amendments. There were three formulae – the Holloway formula, the Van Wyk de Vries formula and the SAPSE (South African Post Secondary Education) formula – employed. The second and third formulae retained major components of the first and brought new features and parameters to suit the changing academic environment in South Africa. The SAPSE formula was later revised in the late 1980s and early 1990s.[27] Scientists and academics were encouraged to publish in national and international journals. As early as the 1960s, scientific publications became the sole criterion for appointments and promotions,[28] which naturally increased the number of publications by South African scientists.

Drawing on the experiences of similar institutions elsewhere in the world and adopting their best features, the South African Council for Scientific and Industrial Research (CSIR) was established. A major step in scientific research in the country, the CSIR paved the way for further growth in the crucial sectors of science and technology. It was an aim of the CSIR to provide both the government and industry with basic facilities of research through the creation of well-equipped national laboratories for fundamental and applied research across the country. The effects

of these initiatives were seen in the coming years in the production of scientific papers, including publications in the natural sciences.

Funding agencies that support research opt for inter-regional or international collaborative projects rather than individual projects located in a single institution or in a single country. Governmental agencies and private foundations formulate policies that aim at accelerating inter-institutional collaboration.[29]

In South African higher learning institutions, publication productivity is valued and an incentive system operates effectively to encourage it. By way of granting productivity units, the incentive system brings in research money to researchers. Since the introduction of a formula in 1984, research money is paid out to the university academics and scientists who publish papers in SAPSE-approved peer-reviewed journals that are on the list of the Department of Higher Education and Training. This process is the basis on which universities in South Africa obtain government funding.

There are already several policy initiatives that encourage collaboration.[30,31] Quite clear in a number of policy documents is the emphasis on collaborative efforts within and outside the country. The Innovation Fund of the Department of Arts, Culture, Science and Technology has as its objective the advancement of transdisciplinary collaboration across sectors in South Africa.[32] Centres of excellence, research teams, research centres and work groups are funded to facilitate and support collaborative efforts between disciplines, universities, industries, other institutions, regions and countries. As argued in a policy document,[33] South Africa has to open its doors widely for a strong and steady inflow of ideas and scientists. Also heard is the call for policies and programmes to promote unimpeded movement of scientific and technical information to the national and international systems and encourage South African scientists to participate in national, regional and international collaborative ventures.[31,34] The existing networks within SADC (Southern African Development Community) and NEPAD (New Partnership for African Development) have turned out to be unsustainable for want of resources,[30] preventing effective collaboration with member countries.

Neglected in this discourse is the value and worth of the scientific data and knowledge that the developed countries acquire from the developing countries through such alliances. Quite evident from successful instances of collaboration is the balance in the collaboration configuration, such as when Africans provide access to local communities and non-Africans provide needed equipment and training.[35] Collaborative activities function well when the partners recognise the reality that the source of funds is equivalent to the source of resources; none is superior to the other. It is true that for scientists in many developing countries (except for a few prestigious institutions within them), in contrast to those in developed countries, the cost of collaboration is at a premium. Basic essentials for conducting research – phone calls, postage, the Internet, email, stationery, printing and copying, library and database searches, assistance and local travel, not to mention equipment and laboratory material – are not always at the disposal of scientists in poorer countries. These are structural hurdles in materialising alliances, at least in the conceiving phase before funds are actually released.

The publication record of the natural sciences in South Africa for the last three decades does not indicate that natural science publications, collectively, compared with 'all subjects', have fared particularly well. A real growth in these can, however, be achieved if appropriate and sustained measures from multiple sources are initiated. Producing young and new researchers is one such means to this end.

Acknowledgement

The National Research Foundation of South Africa is acknowledged for supporting this analysis.

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