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A DECADE OF DEVELOPMENT IN SUB-SAHARAN AFRICAN SCIENCE, TECHNOLOGY, ENGINEERING & MATHEMATICS RESEARCH

A REPORT BY THE WORLD BANK
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In March 2014, several African governments' ministers agreed on a Joint Call for Action in Kigali to adopt a strategy that uses strategic investments in science and technology to accelerate Africa toward a developed knowledge-based society within one generation. The represented governments are part of the Partnership for Applied Science, Engineering and Technology (PASET), an initiative of the World Bank that supports efforts by African governments and their partners to strengthen the role of applied science, engineering, and technology in the development agenda. The ministers unanimously acknowledged the need for specific measures to improve relevance, quality and excellence in learning, and research in higher education. Which specific measures should be taken? Answering this question requires new analyses based on credible data and public debate on the findings. This report is part of a broader, on-going effort to provide more evidence and analysis on the supply of and demand for skills, education and research within Science, Technology, Engineering and Mathematics (STEM) for Africa's socio-economic transformation and poverty reduction under the aegis of the PASET.

The World Bank and Elsevier are partnering on this report to examine the research enterprise over a decade from 2003 to 2012 of three different geographies in sub-Saharan Africa (SSA): West & Central Africa (WC), East Africa (EA), Southern Africa (SA). The research performance of these regions is compared to that of South Africa (ZA), Malaysia, and Vietnam; the latter two countries had a comparable research base to the SSA regions at the beginning of the period of analysis. The report analyzes all science disciplines, but with a special emphasis on research in the Physical Sciences & Science, Technology, Engineering, and Mathematics (STEM).

"Higher education is now front and center of the development debate – and with good reason. More than 50 percent of the population of sub-Saharan Africa is younger than 25 years of age, and every year for the next decade, we expect 11 million youth to enter the job market. This so-called demographic dividend offers a tremendous opportunity for Africa to build a valuable base of human capital that will serve as the engine for the economic transformation of our continent. … To be more competitive, expand trade, and remove barriers to enter new markets, Africa must expand knowledge and expertise in science and technology. From increased agricultural productivity to higher energy production, from more efficient and broadly available ICT services to better employability around the extractive industries, building human capital in science and technology is critical to empower Africa to take advantage of its strengths."

MAKHTAR DIOP
World Bank's Vice President for the Africa Region

High-level Forum on Higher Education, Science, and Technology in Africa
March 13, 2014 in Kigali

The report focuses on research output and citation impact, important indicators of the strength of a region's research enterprise. These indicators are correlated with the region's long-term development and important drivers of economic success. Moreover, research is a key ingredient for quality higher education. Given the shortcomings of reliable statistics on education and research in Africa, we hope the information contained in a bibliometric database will shed light on regional collaboration within Africa, academia-business collaboration, and STEM capacity.

When reading the report, we encourage the reader to not only consider the findings on research performance from the narrow sense of academic knowledge generation, but also see research patterns as predictors of the sub-continent's future ability to train knowledge workers within specific domains and sectors. As such, the patterns revealed through this report constitute a crystal ball to assess the future ability SSA's scientific and educational ability to solve its development challenges through its own capacity.

Methodology

This report uses the Scopus abstract and citation database to evaluate trends in research growth in SSA. While the report recognizes that indicators on peer-reviewed research outputs do not fully capture all research activity in SSA, this is the most systematic and objective foundation for analysis currently available. Although previous studies have also analyzed research output trends in SSA, this is the first report that provides comprehensive policy analysis and recommendations at a regional level and builds an analytical foundation for stakeholder dialogue in driving the STEM agenda.

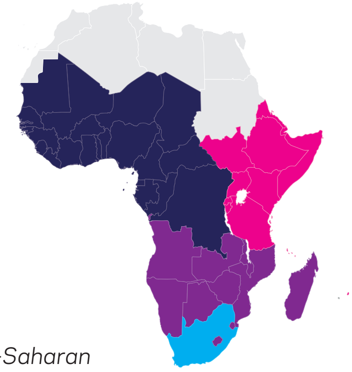

Figure E.0 *— Map of sub-Saharan Africa regions analyzed in this report.*

Key Findings and Policy Recommendations

This report presents four main developments over the past decade in research in SSA.

1) Sub-Saharan Africa has greatly increased both the quantity and quality of its research output.

- All three SSA regions more than doubled their yearly research output from 2003 to 2012.
- SSA's share of global research has increased from 0.44% to 0.72% during the decade examined.
- Citations to SSA articles comprise a small but growing share of global citations, increasing from 0.06%-0.16% for each of the regions to 0.12%-0.28%.
- All regions improved the relative citation impact of their research, with East Africa and Southern Africa raising their impact above the world average between 2003 and 2012.
- The percentages of each of SSA region's total output that are highly cited have grown steadily over time.

However, SSA still accounts for less than 1 percent of the world's research output, which remains a far cry from its share of global population at 12 percent. In addition, despite the regions' strong growth, countries with comparable levels of research output in 2003 such as Malaysia and Vietnam grew even faster over the same period. Furthermore, SSA's output growth has overwhelmingly been driven by advances in Health Sciences research (approximately 4 percent annual growth), which now accounts for 45% of all SSA research. The progress in the Health Sciences is great and much welcome news for two reasons. First, due to the tremendous health challenges the continent faces, improved Africa-relevant health research and well-trained health workers will have a great impact on health outcomes. Second, the impressive improvement in SSA's research capacity in the Health Sciences demonstrates that persistent support and funding from development partners and governments pays off. There is clearly a large scientific talent base in Africa, but this needs to be trained and nurtured.

The World Bank recommends that African governments and development partners accelerate support to research and research-based education in Africa to build the necessary human capital to further increase research on solving African problems by Africans for Africans.

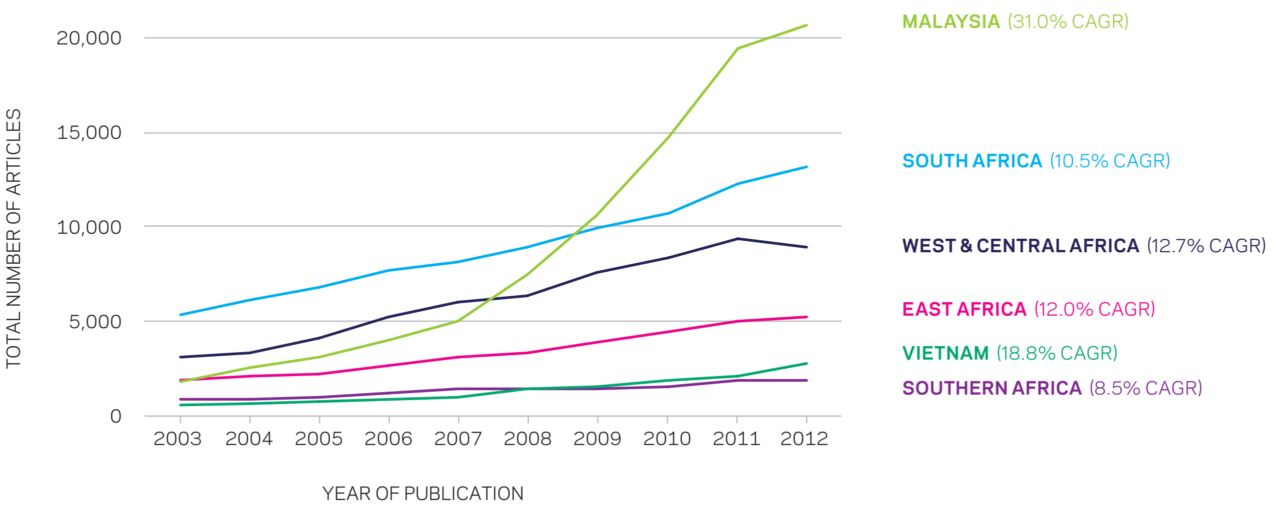

Figure E.1 *— Overall number of articles and Compound Annual Growth Rate (CAGR) for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

2) SSA research output in Science, Technology, Engineering, and Mathematics (STEM) lags that of other subject areas significantly. This is evident by the following indicators:

- Research in the Physical Sciences & STEM makes up only 29% of all research in SSA excluding South Africa, as shown in Figure E.2. In contrast, STEM constitute the largest share of Malaysia and Vietnam's total output (an average of 68%), and that share continues to grow.
- The share of STEM research in SSA has marginally declined by 0.2% annually since 2002. In comparison, the share of STEM research has declined 0.1% annually in South Africa and grew 2% annually in Malaysia and Vietnam.
- In 2012, the quality of STEM research in SSA, as measured by relative citation impact, was 0.68 (32 percent below the global average). This is below that of all disciplines in SSA (0.92) and the global average (1.00), and it has virtually stayed the same since 2003. In contrast, STEM research in Malaysia, Vietnam and South Africa in 2012 was slightly above the world average (1.02) and has improved 15% since 2003.

These findings indicate that research in STEM in SSA is lagging in terms of research quantity and citation quality. Capacity within other sciences, in particular health, is improving substantially more than STEM.

Building on the empirical basis outside of this report, the World Bank suggests that this large STEM gap could be linked to several factors: the low quality of basic education in science and math within SSA; a higher education system skewed towards disciplines other than STEM such as the humanities and social sciences; international research funding – which comprises the majority of SSA research funding – prioritizing health and agricultural research.

Analyses from parallel studies suggest that to undergo an economic transformation, SSA needs more and better STEM skills and knowledge to boost value-added and productivity within key sectors, such as extractive industries, energy, transport, and light manufacturing. The World Bank recommends the following policies:

- Accelerate and persistently pursue policies to improve the quality and quantity of teaching of STEM at all levels of the education system, including for research and research-based education.
- Systematically scale up support to STEM disciplines at the higher education and research level through, for example: bilateral university collaborations, post-graduate scholarships, and encouraging international firms to contribute to the development of STEM capacity in Africa.
- Coordinate higher education strategies with development needs and rigorously implement priorities through effective funding instruments.

The box on the next page provides one example from Uganda.

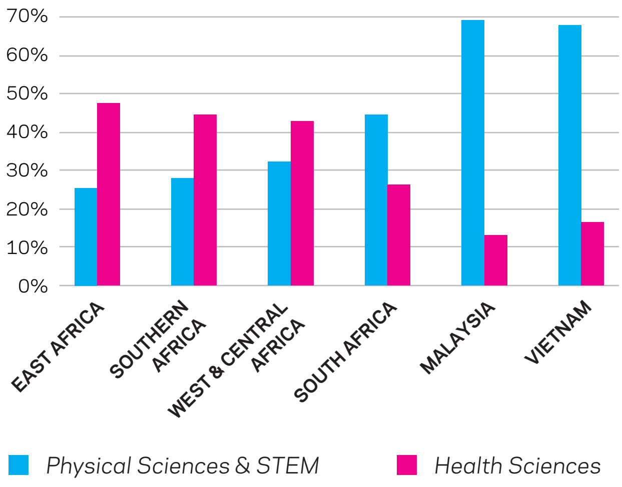

Figure E.2 *— Percentage of total article output in the Physical Sciences & STEM versus the Health Sciences for sub-Saharan Africa regions and comparator countries, 2012. Source: Scopus.*

3) SSA, especially East Africa and Southern Africa, relies heavily on international collaboration and visiting faculty for their research output.

- A very large share of SSA research is a result of international collaboration. In 2012, 79%, 70% and 45% of all research by Southern Africa, East Africa, and West & Central Africa, respectively, were produced through international collaborations. In contrast, 68%, 45%, and 32% of Vietnam, South Africa and Malaysia's research output, respectively, were produced through international collaborations.
- A large percentage of SSA researchers are non-local and transitory; that is, they spend less than 2 years at institutions in SSA. In particular, 39% and 48% of all East and Southern African researchers, respectively, fall into this category.

The high level of international collaboration testifies to the noteworthy effort and interest of academia outside of Africa to support SSA's research capacity. Moreover, international collaboration is highly instrumental in raising the citation impact of SSA' publications. At the same time, for the majority of SSA's collaboration partners, the relative citation impact of such collaborations is actually higher than those partners' overall average impact, suggesting that the collaboration is a win-win situation for Africa and the international collaborators. Furthermore, mobile researchers (those who move between institutions in the SSA and the rest of the World) tend to be more productive in terms of publications and more highly cited than those researchers who primarily stay in SSA.

However, SSA's high reliance on international collaboration for research is a concern for the World Bank; it signals a lack of internal research capacity and the critical mass to produce international quality research on its own; particu-

Supporting high quality and relevant research: Uganda Millennium Science Initiative

The Uganda MSI project (2007 – 2013) is an example of an initiative that makes use of innovative funding mechanisms such as competitive grants to enhance research capacity through teams and collaboration.

The project aimed to produce more and better qualified science and engineering graduates and higher quality and more relevant research. Component One ($ 16.7 million) of the project focused on developing research capacity through competitively awarded grants. Component Two ($16.7 million) aimed to improve public understanding and appreciation of science and strengthen the institutional capacity.

Key policy innovations include:

- *Building human capital by linking research with post-graduate education to develop the country's scientific future*
- *Building capacity of research teams for high quality scientific research*
- *Encouraging statistical and policy analysis through scientific research*
- *Project design was adopted to the Ugandan context and level of scientific development*

Major achievements include:

- *Increased human capital in STI: the number of researchers increased from 261 to 720 and the number of S&T students increased from 24 to 41 (Ph.D), from 245 to 633 (MSc), and from 3,241 to 4,892 (BSc)*
- *Established the fully functional competitive funding mechanism evaluated by Ugandan and international scientists setting a high standard*
- *Ratio of applicants to fundable proposals was 11:1 (highly competitive), with selection of high quality research proposals with strong leaderships*
- *Developed the capacity of the Uganda National Council for Science and Technology for national statistics on STI and the Uganda Industrial Research Institute, where the number of services offered increased four-fold and revenue increased from nil to UGX 67 million to enhance efficiency and self-sustainability*

Source: Uganda Millennium Science Initiative Implementation Completion and Results Report, 2013

larly within STEM. Furthermore, the transitory nature of many researchers may prevent researchers from building relationships with African firms and governments, reducing the economic impact and relevance of research. Analyzing the underlying reasons for lack of capacity goes beyond the scope of the current bibliometric analysis, but we speculate that the following are among the key reasons: shortcomings in the scale and quality of PhD programs; research funding; research equipment; and faculty time and incentives for research. To increase SSA's research capacity, the World Bank encourages stakeholders to consider an initial set of policy recommendations below:

- Continue international collaboration, and scale-up collaboration within STEM.
- Scale-up post-graduate education in Africa – possibly through regional collaboration.
- Continue scholarship funding for studies in Africa, possibly through "sandwich-programs" to ensure international exposure and include funding support to raise the quality of the African post-graduate program.

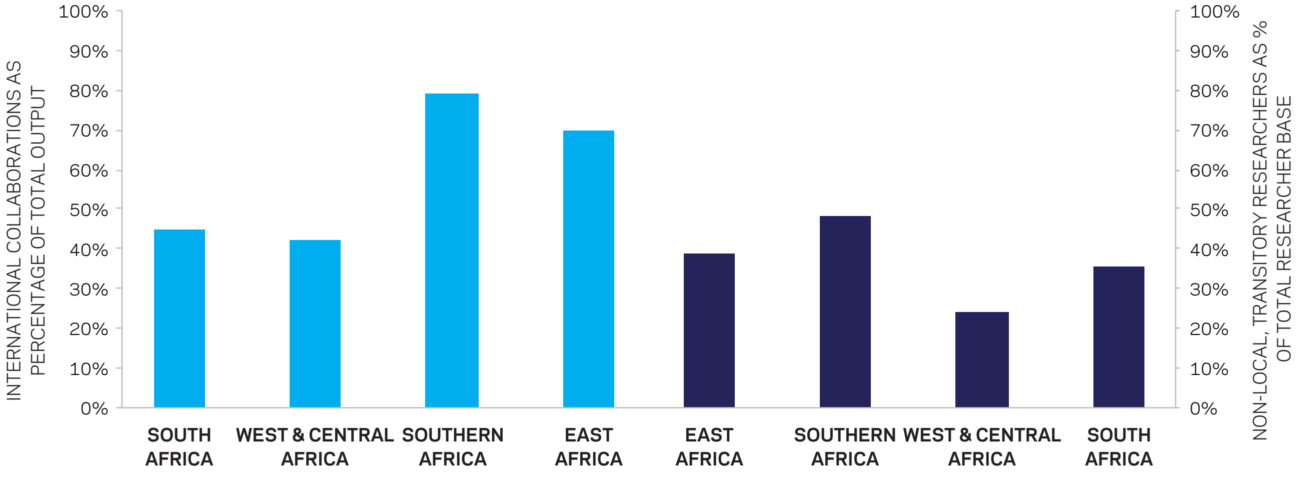

***Figure E.3** — Level of international collaboration for SSA regions (2012) and percentage of non-local, transitory researchers for SSA regions, 1996-2013. Source: Scopus.*

4) Research collaboration in Africa features a number of particular characteristics that are critical to understand for the design of successful policies

- SSA's research capacity appears fragmentized across regions, with each of the regions collaborating very little with one another. Inter-SSA collaborations (collaborations without any South-African or international collaborator) comprise just 2%, 0.9%, and 2.9% of all East African, West & Central African, and Southern African total research output.

If this observation about fragmentation is confirmed through more detailed country level analyses, national governments and regional bodies should consider regrouping researchers into larger groups either through funding incentives for team research or through institutional mergers of higher education and research institutions, which is already happening in many countries. Increasing Africa-Africa collaboration in science can also generate gains. This could be done through scaling up existing regional research and research-based education programs that stimulate regional collaboration, such the African Institute for Mathematical Sciences, the Africa Centers of Excellence, the Regional Initiative for Science Education, the Pan-African University, the Nelson Mandela Institutes for Science and Technology, and RU-FORUM.

- There appears to be little knowledge transfer and collaboration between African academics and the corporate sector, as measured by corporate downloads of and patent citations to African academic research, especially for STEM disciplines. To the extent to which such knowledge transfer occurs, it occurs within Health Sciences and through collaborations with global pharmaceutical companies. Such trends suggest that corporations do not rely much on African-generated knowledge and research for their competitiveness.

- Returning diaspora contribute significantly to raising the citation impact of SSA research, specifically in East and Southern Africa. The inflow of returnees researchers (those who originally publish from an African institution, left and published elsewhere, and then subsequently returned) make up a relatively small share of the region's total researcher base (3.6% and 2.1%, respectively), yet the relative citation impact of those returnees' publications is quite high compared to that of other SSA researchers. This empirical finding corroborates the widespread belief that the large and well-trained scientific African diaspora in Europe, North America and elsewhere should be further tapped to raise the quantity and quality of SSA research.

- West & Central Africa displays somewhat different patterns of researcher mobility and collaboration than East and Southern Africa. A higher share of West & Central African researchers is sedentary – i.e. not migrating to institutions outside of their region (44% for West & Central Africa vs. 24% and 15% for East and Southern Africa, respectively). Moreover, the share of non-African transitory researchers – i.e. visiting scholars – as a percentage of the total regional researcher base is smaller in West & Central Africa. Furthermore, there are smaller differences in the relative research productivity and impact of sedentary researchers and mobile researchers. International collaboration comprises a smaller share (42%) of West & Central Africa's total research output, and there is less research collaboration between academia and other partners (corporate, government, and medical). In contrast intra-regional collaboration is 24.7% in West and Central Africa compared to 13.6% for East Africa and 5.67% for Southern Africa. West and Central Africa is more integrated within the region as a result of institutions and researchers collaborating within the region. This report speculates that these differences could be driven by several factors, such as: a higher degree of collaboration and mobility for historical or policy reasons; a measurement bias if Francophone research is not adequately published or indexed; less donor funding for research to this part of Africa; and/or a higher share of unstable political environments.

INTER-REGIONAL COLLABORATION

0.9%-2.9%

Inter-African collaboration (without any South-African or international collaborator) comprises 2% of all East African research, 0.9% of West & Central Africa, and 2.9% of Southern Africa.

Figure E.4 *— Inter-regional collaboration between SSA regions. Source: Scopus.*

Defining national policies

The report discusses and provides a big picture of research trends at a regional level. We emphasize that this is a report rich on data, and we have only described the main findings. We recommend further analyses in three directions: examination of specific indicators at the regional level, more nuanced analysis of the factors behind the above identified developments, and particularly additional country-level analysis. Any country-level policy discussion on science, technology and innovation policy should build upon country-level analyses of research performance and its link to institutional factors and education, research, and economic policies. Moreover, given the lack of regionally and internationally comparable information on the latter topics, such exercises would be best accompanied by additional data collection on national research and research-based education sectors.

While the report calls for increased national and international funding to research and research-based education at the master and doctoral level in Africa with a strong focus on STEM, we must keep in mind the substantial opportunity costs of research funding. The estimated cost of one doctoral degree (USD 50,000) can fund 5 classrooms benefitting around 400 pupils in primary education or 25,000 textbooks in math. Therefore, it makes sense to closely tie funding for research and research-based education to African development challenges and ensure research findings and knowledge is applied towards solving these challenges. Nevertheless, with a larger share of SSA having attained or within reach of becoming middle-income countries, the regions' development will increasingly require greater scientific and technological capacity.

Following this overview, the introductory chapter introduces the underlying database and the main methodological approaches and concepts used in the report. The next chapter provides a broad overview of the research enterprise in the different regions and across different subject groupings by using a variety of metrics to examine the quantity, usage, and quality of research output. What types of knowledge and how much are being generated by SSA researchers? By whom and how much is that knowledge being used? Chapter 3 focuses on key aspects of research collaboration for the Africa regions. How frequently do researchers in the different regions co-author articles with international colleagues or colleagues in non-academic institutions? How impactful are those co-authored articles, and with which institutions do researchers collaborate the most? The final chapter focuses on the mobility of researchers to and from the different regions.

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CHAPTER 1
METHODOLOGY

1.1 Methodology

Approaches and Definition

Measuring scientific activity in low and middle-income countries

Past research studies have observed that the standards[1] used to measure and benchmark research performance in advanced nations do not necessarily translate to less developed regions. First, the infrastructure for surveying and collecting data on research and development (R&D) expenditures, number of researchers, and so forth is less developed.[2] This report eschews such data collection issues by primarily focusing on research output data captured in Scopus. Scopus is an abstract and citation database of peer-reviewed literature, covering over 50 million documents published in over 21,000 journals, book series, and conference proceedings by over 5,000 publishers. Moreover, one of the main advantages of this database is its multi-lingual and global coverage. Approximately 21% of titles in Scopus are published in languages other than English, and the database contains over 400 peer-reviewed titles from publishers based in the Middle East and Africa.[3]

Second, the overall quantity of research inputs and outputs of smaller, low-income countries are sometimes too small and noisy to be reliably tracked and analyzed over time.[4] To avoid this issue, this report aggregates research output statistics from individual institutions and countries into four major regions. Moreover, the report draws on a range of output metrics to better triangulate and verify broad sub-Saharan Africa (SSA) trends in research performance. We acknowledge, however, that the trade-off to this approach is that we cannot provide insights on country-level variations in research performance that is important for national policymaking.

Third, as Siyanbola et al. (2014) note, the usual categories of science and technology indicators often do not capture or are not useful measures for "the local realities of STI systems. Agriculture, informal economy and indigenous knowledge are three important aspects of African system that S&T indicators, to date, do not cover."[5] As the next section details more extensively, this report defines subject groupings to more closely match the relevant dimensions for SSA. More broadly, the analyses of research output data in this report are based upon recognized advanced indicators, and our base assumption is that such indicators are useful and valid, though still imperfect and partial measures. We acknowledge the limitations of drawing on publication data to capture even just research activity, let alone all scientific activity in SSA. Research activity has many outlets for dissemination, from peer-reviewed research to technical reports to policy briefs. For example, according to a recent report[6] only about 40% of the publications from the University of Dar es Salaam (UDSM) appear in serious, peer reviewed journals. Moreover, we acknowledge that a lot of other peer-reviewed research is conducted in Africa that is not published in journals or proceedings covered by Scopus, often because these sources do not meet globally accepted publication standards. Nevertheless, in focusing on peer-reviewed research, the Scopus database captures one of the most common and globally commensurable forms of research dissemination.

This report uses "article" as a shorthand to refer to the following types of peer-reviewed document types indexed in Scopus: articles, reviews, and conference proceedings. For a more detailed explanation, see Appendix B: Glossary.

Defining subject areas

Properly and consistently defining subject areas is a key concern for quantitative approaches to research assessment. Based on discussions about the most relevant schema for categorizing sub-Saharan research, article and citation data were aggregated to 5 main subject groupings: Agriculture, the Physical Sciences & STEM (Science, Technology, Engineering, and Mathematics), the Health Sciences, the Social Sciences & Humanities, and the Life Sciences. We acknowledge that there could be alternate groupings or classifications, such as combining Agriculture with the Life Sciences, and that the gains and impact of interdisciplinary sciences is not fully illustrated in the report. Nevertheless, these subject groupings are highly instrumental for the analysis.

Articles were classified in one or more of these groupings based on their underlying categorization according to the Scopus All Science Journal Classification (ASJC) codes. This classification system does not and is not intended to map onto the department, program, or school divisions of any particular university or institution. For the calculation of field-weighted citation impact, a more granular scheme encompassing more than 300 subject subfields (again, consistent with the ASJC hierarchy) was used and then aggregated to the level of the main subject groupings.

Defining SSA regions and choosing comparator countries

The choices to group SSA countries into the respective regions detailed in Figure 1.1 were based on a preliminary analysis of the respective similarities of various research indicators across those countries. For example, due to fundamental differences in the state of research infrastructure, the levels of research output, and the quality of research performance between South Africa and other Southern

Main Subject Grouping	*Scopus 27 Subject Classification*	
Agriculture	Agricultural and Biological Sciences Biochemistry, Genetics, and Molecular Biology Veterinary	
Physical Sciences & STEM	Chemical Engineering Chemistry Computer Science Earth and Planetary Science Energy Engineering Environmental Science	Materials Science Mathematics Physics and Astronomy
Health Sciences	Medicine Nursing Dentistry Health Professions	
Social Sciences & Humanities	General *(multidisciplinary journals such as Nature and Science)* Arts and Humanities Business, Management, and Accounting Decision Sciences Economics, Econometrics, and Finance Psychology Social Sciences	
Life Sciences	Immunology and Microbiology Neuroscience Pharmacology, Toxicology, and Pharmaceutics	

African countries, this report separates the former country from the latter region. In contrast, while Nigerian research comprised more than 50% of the total output in West & Central Africa between 2003 and 2012,[7] the relative citation impact of that country's research, the distribution of that country's research across different subject areas, and the relative rate of international collaboration were comparable to the larger region. As a result, although we considered treating Nigeria as a separate entity, its grouping with the larger West & Central Africa region does not distort the larger trends. Throughout the report, numbers referring to SSA as a whole exclude South Africa and refer specifically to East, West & Central and Southern Africa.

Analogously, Malaysia and Vietnam were selected as comparators for the Africa regions due to the similarity in the quantity and impact of those countries' research output with that of the Africa regions at the beginning of this report's analysis in 2003. For example, in 2003, Vietnam produced 587 research articles compared to 928 by Southern Africa, and Malaysia produced 1815 research articles compared to 1900 by East Africa. Likewise, the field-weighted citation impact (FWCI), a normalized measure of research citation impact to be explained later in this report, of Malaysian research published in 2003 was 0.67 compared to that of West & Central Africa at 0.63. Similarly, the FWCI of Vietnamese publications in 2003 was 1.02 compared to 0.88 for Southern Africa and 0.95 for East Africa. However, we acknowledge that while the research volume and citation impact of these countries and regions have similar starting points, both Malaysia and Vietnam have underlying economic differences that likely affected their capacity for scientific growth. The differences in population size, income per capita and tertiary enrollment are all key to explaining the growth patterns that are observed in the report.

We also considered using the entirety of Southeast Asia as a comparator region, but we ultimately decided against doing so for two reasons. First, as the somewhat divergent trajectories undertaken by Malaysia and Vietnam attest, there is considerably more variation in research performance across countries in that region. Second, the level of both research investment and the corresponding level of output for that region as a whole are much larger than all but South Africa.

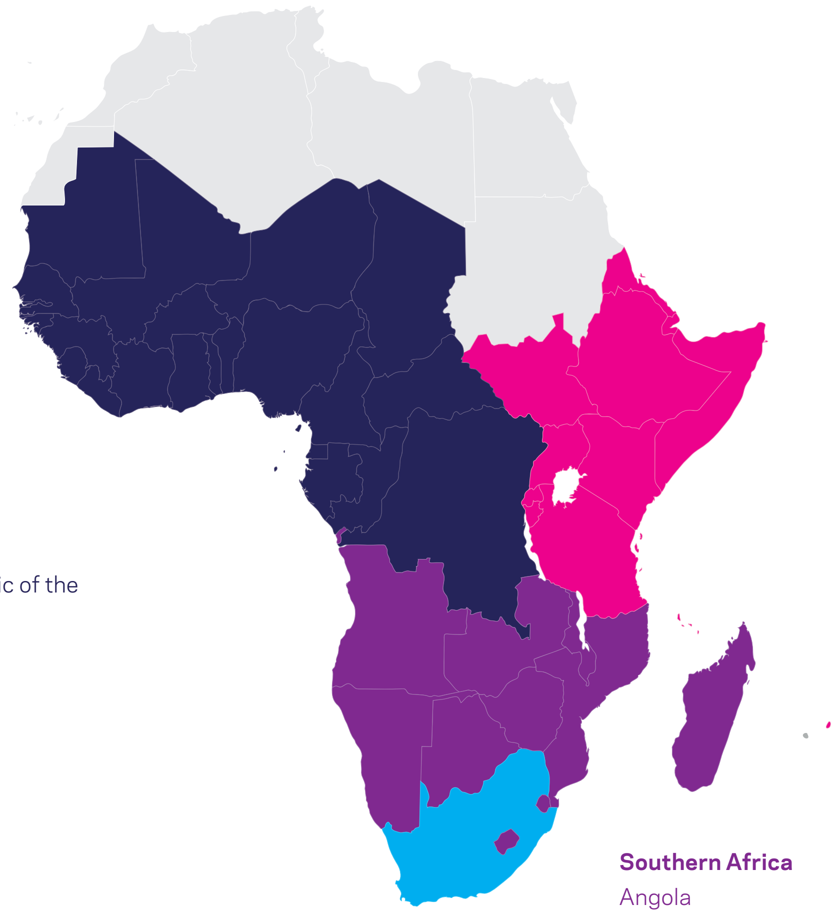

***Figure 1.1** — Map of sub-Saharan Africa regions analyzed in this report.*

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[1] The OECD's Frascati Manual is usually used as the gold standard. OECD. (2002). Proposed Standard Practice for Surveys on Research and Experimental Development: Frascati Manual. Frascati, Italy. Retrieved from http://www.oecdbookshop.org/oecd/display.asp? LANG=EN&SF1=DI&ST1=5LMQCR2K61JJ

[2] UNESCO. (2010). Measuring R&D: Challenges Faced by Developing Countries. Montreal. Retrieved from http://www.uis.unesco.org/Library/Documents/tech 5-eng.pdf

[3] For more information on Scopus, including its content coverage, please see Appendix C.

[4] Gaillard, J. (2010). Measuring Research and Development in Developing Countries: Main Characteristics and Implications for the Frascati Manual. Science Technology & Society, 15(1), 77–111. doi:10.1177/097172180901500104

[5] Siyanbola, W. O., Adeyeye, A. D., Egbetokun, A. A., Sanni, M., & Oluwatope, O. B. (2014). From indicators to policy: issues from the Nigerian research and experimental development survey. International Journal of Technology, Policy and Management, 14(1), 83. doi:10.1504/IJTPM.2014.058726

[6] Thulstrup. E, Mlama .P, & Suntinen. E (2014). Study on Higher Education and Research in Tanzania. Report from Swedish Institute for Public Administration.

[7] To put things in perspective, if South Africa were treated as part of "Southern Africa," South Africa's research output would comprise ~85% of "Southern Africa" total output.

CHAPTER 2
RESEARCH OUTPUTS & CITATION IMPACT

This chapter provides a broad overview of how much research each SSA region produces and how impactful that research is.

2.1 **Key Findings**

"Forty or fifty years ago, many people thought that simply transferring technologies from industrialized to developing countries would close the technology gap. Now we know that technologies developed in industrialized countries may not be suitable for use in other environments. They may require a particular type of infrastructure to operate. They may need specialized parts or knowledge to mend when they break down. … We now understand that innovative capacity must be built in different ways. Many developing countries can make important progress through simply adapting existing technologies. … In a globalized world, technological development is a global venture. It requires a collective and coordinated effort by government, the private sector, scientists and civil society."

UN SECRETARY-GENERAL BAN KI-MOON

January 14, 2010 at Yale University

PUBLICATION OUTPUT GROWTH, 2003-2012

> 100%

All SSA regions more than doubled their yearly research output.

SUBJECT AREA OUTPUT IN 2012

28.5%

On average for the three SSA regions, research in the Physical Sciences & STEM constituted 28.5% of their total output. In contrast, the average share of Health Sciences for the three regions was 45.2%.

HIGHLY CITED ARTICLES IN 2012

7.5%-16%

Between 7.5% and 16% of the different SSA regions' total outputs were amongst the world's top 10% most highly cited articles, but only 5.9% -10% of those same regions' total output in the Physical Sciences & STEM met that threshold.

FIELD-WEIGHTED CITATION IMPACT (FWCI)

0.92

Research output across the three SSA regions achieved a FWCI of 0.92 in 2012, meaning it was cited 8% less than the world average. However, the regions' average FWCI in the Physical Sciences & STEM was only 0.68 in 2012, and it has virtually stayed the same since 2003.

2.2 Research Output

2.2.1. Total Research Output and Growth

From 2003 to 2012, sub-Saharan Africa significantly increased the amount of peer-reviewed research it produced. As Figure 2.1 demonstrates, all three Africa regions more than doubled their total yearly article[8] output. For example, Southern Africa researchers produced 928 articles in 2003 and 1940 in 2012. West & Central Africa researchers produced 3,069 articles in 2003 and 8,978 in 2012. The compound annual growth rates (CAGRs)[9] for research output exceeded 10% for both East and West & Central Africa (Southern Africa still grew at a respectable 8.5% annually).

Despite the strong research output growth by the Africa regions, the comparator countries grew even faster over the same period. Malaysia, whose article output in 2003 was similar to that of East Africa, grew its output by 31% per year. Similarly, Vietnam, whose article output in 2003 was about two-thirds the level of Southern Africa, grew its output by 18.8% per year.

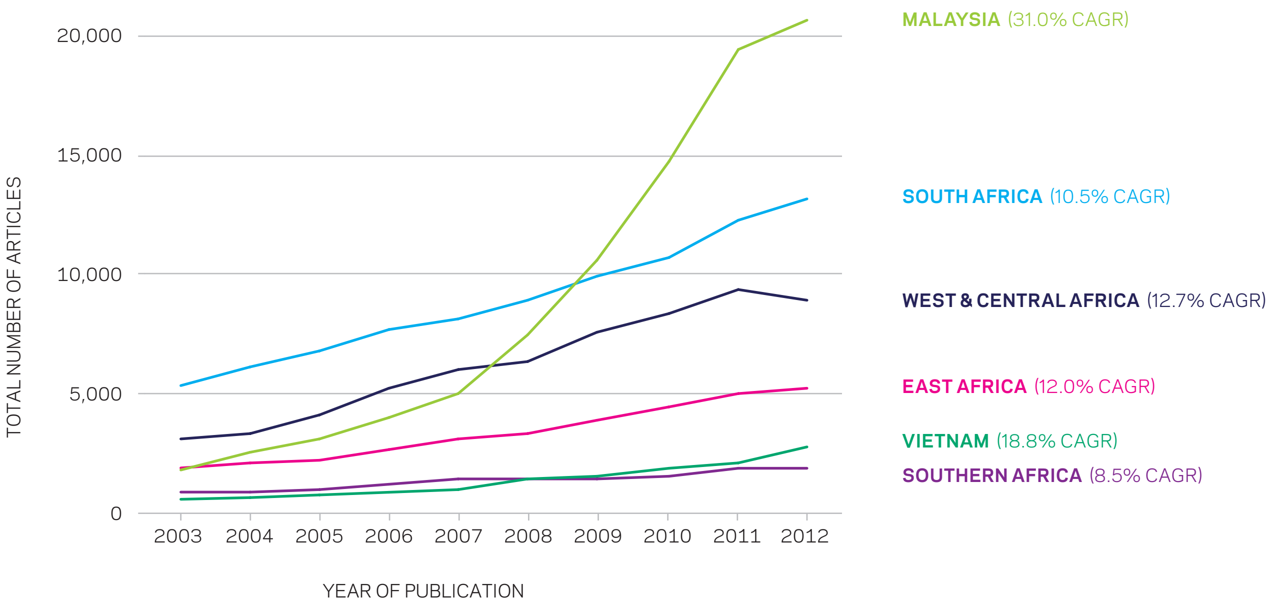


Figure 2.1 *— Overall number of articles for SSA and comparator countries, 2003-2012. Source: Scopus.*

[8] This report uses "article" as a shorthand to refer to the following types of peer-reviewed document types indexed in Scopus: articles, reviews, and conference proceedings. For a more detailed explanation, see Appendix B: Glossary.

[9] Compound Annual Growth Rate (CAGR) is the year-on-year constant growth rate over a specified period of time. Starting with the earliest value in any series and applying this rate for each time interval yields the amount in the final value of the series. The full formula for determining CAGR is provided in Appendix B: Glossary.

2.2.2. **World Article Share**

Over the past decade, the total research output of the world has also risen, and world article share[10] provides a normalized measure of the regions' growth. As Figure 2.2 shows, since every region's world publication share increased from 2003 to 2012, their output growth rates outpaced the world's overall growth. Collectively, the SSA's share of global research increased from 0.44% to 0.72%. The overall findings about sub-Saharan Africa's world publication share suggest a reversal in the trends reported in Tijssen's (2007) analysis of Africa's research output from 1980-2004,[11] which had found that "Africa's share in worldwide science has steadily declined." However, certain regions grew more quickly than others. West & Central Africa increased its world article share from 0.23% in 2003 to 0.40% in 2012, achieving a CAGR of 6.3%. In contrast, Southern Africa barely increased its share from 0.07% to 0.09%.

However, with a population of 0.9 billion, SSA accounts for 12.5% of the global population, a far cry from its less than 1% share of the world's research output. This shows a large gap in Africa's capacity to produce new knowledge in relation to its share of the world population and presents potential for rapid growth.

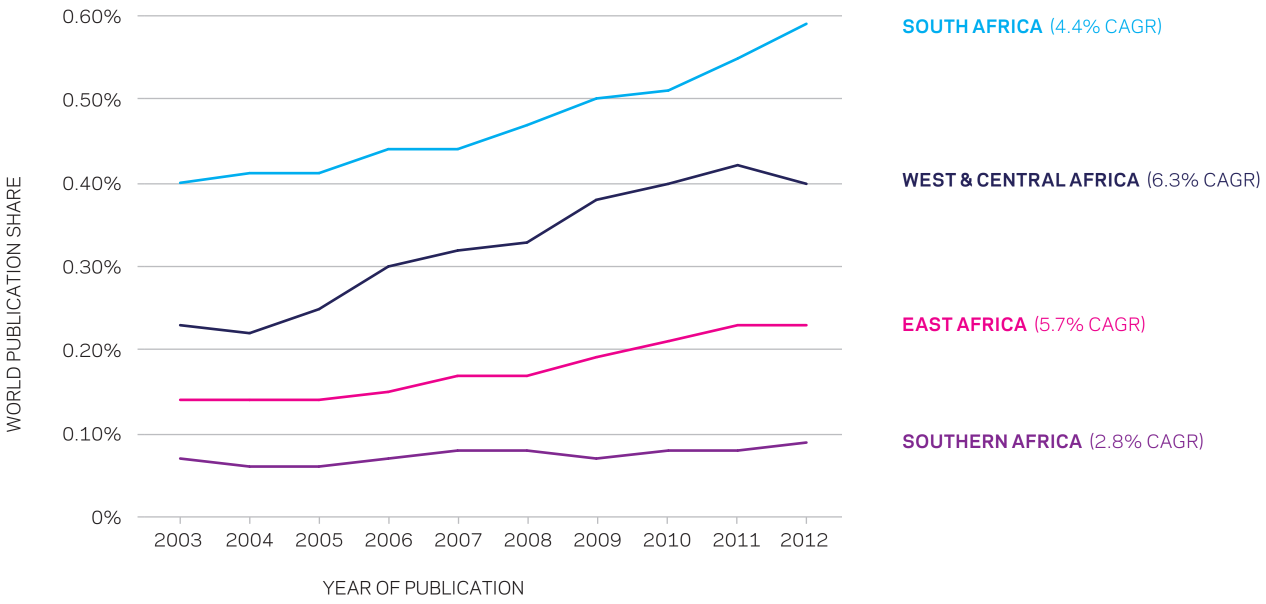


Figure 2.2 *— World publication shares for SSA and comparator countries, 2003-2012. Source: Scopus.*

[10] The share of publications for a specific region expressed as a percentage of the total world output – see Appendix B: Glossary.

[11] Tijssen, R. J. W. (2007). Africa's contribution to the worldwide research literature: New analytical perspectives, trends, and performance indicators. Scientometrics, 71(2), 303–327. doi:10.1007/s11192-007-1658-3

2.2.3. **Output and Growth by Subject Grouping**

Although overall article outputs rose for all regions from 2003 - 2012, certain subject groupings grew faster than others. As Figure 2.3 shows, in every SSA region, research in the Health Sciences comprised the highest percentage of those regions' total article output. At one extreme, research in the Health Sciences accounted for 47.8% of EA's total output in 2012. On average, research in the Health Sciences comprised 45.2% of the SSA's total research output. In contrast, the Physical Sciences & STEM has been the main area of focus for South Africa, constituting 44.7% of the country's total output in 2012. However, for the other Africa regions, the Physical Sciences & STEM comprises between only 25% and 30% of their total research output in 2012.

The Africa regions' comparator countries provide a stark contrast. As Table 2.1 reveals, over 67% of Malaysia and Vietnam's article output in 2012 was in the Physical Sciences & STEM.

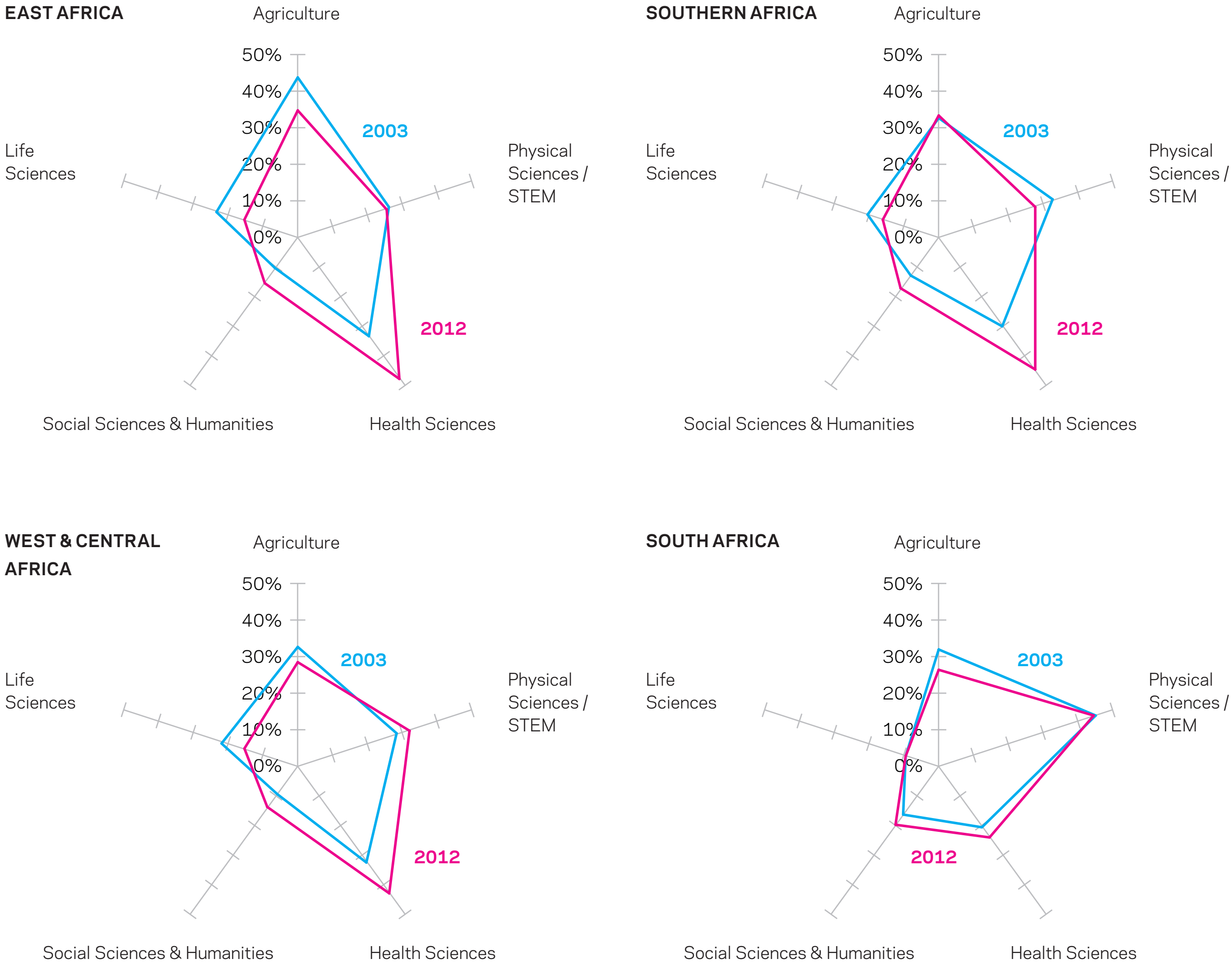


***Figure 2.3** — Percentage of total article output by subject grouping for SSA and South Africa, 2003 vs. 2012. Source: Scopus.*

Moreover, as the individual radar charts reveal and Table 2.2 details more closely, while absolute output across all subject groupings increased over time, the share of STEM research in SSA has actually marginally declined by 0.2% annually since 2003. In contrast, despite Malaysia and Vietnam's high relative output in the Physical Sciences & STEM, these comparator countries further increased their relative output in this area from 2003 to 2012, growing 2% annually. On the other hand, relative output in the Health Sciences and the Social Sciences & Humanities increased in all SSA regions.

Past research has also identified and expressed concern about the overall skew of African research toward the Health Sciences and Agriculture and away from the Physical Sciences & STEM, a trend dating back to the 1990s.[12] Pouris and Ho (2013) comment, "The continent's research emphasizes medical and natural resources disciplines to the detriment of disciplines supporting knowledge based economies and societies."[13]

Table 2.1 *— Percentage of total article output by subject groupings for Africa regions and comparator countries, 2012. For each subject area (row), the region with the highest percentage is encircled. Source: Scopus.*

	Southern Africa	East Africa	West & Central Africa	South Africa	Malaysia	Vietnam
Physical Sciences & STEM	28.0%	25.3%	32.3%	44.7%	69.2%	67.9%
Agriculture	33.4%	34.4%	28.2%	22.9%	15.3%	22.0%
Health Sciences	44.8%	47.8%	43.1%	26.5%	13.1%	16.5%
Social Sciences & Humanities	17.5%	15.4%	14.0%	21.8%	19.4%	8.4%
Life Sciences	15.7%	15.0%	15.2%	8.7%	5.1%	8.6%

Table 2.2 *— CAGR for changes in percentage of total article output by subject groupings for Africa regions and comparator countries, 2003-2012. For each subject area (row), the region with the highest CAGR is encircled. Source: Scopus*

	Southern Africa	East Africa	West & Central Africa	South Africa	Malaysia	Vietnam
Physical Sciences & STEM	-1.7%	-0.4%	1.4%	-0.1%	2.1%	1.9%
Agriculture	0.2%	-2.6%	-1.7%	-3.7%	-7.4%	-1.9%
Health Sciences	4.5%	4.1%	3.2%	2.8%	-6.1%	-2.9%
Social Sciences & Humanities	3.6%	4.4%	5.1%	3.4%	9.1%	0.3%
Life Sciences	-2.6%	-4.7%	-3.7%	-0.9%	-3.3%	-3.9%

[12] Arvanitis, R., Waast, R., & Gaillard, J. (2000). Science in Africa: A bibliometric panorama using PASCAL database. Scientometrics, 47(3), 457–473. doi: 10.1023/A:1005615816165; Chuang, K.-Y., Chuang, Y.-C., Ho, M., & Ho, Y.-S. (2011). Bibliometric analysis of public health research in Africa: The overall trend and regional comparisons. South African Journal of Science, 107(5/6). doi:10.4102/sajs.v107i5/6.309

[13] Pouris, A., & Ho, Y.-S. (2013). Research emphasis and collaboration in Africa. Scientometrics, 98(3), 2169–2184. doi:10.1007/s11192-013-1156-8

2.3 Citation Impact

2.3.1. World Citation Share

The number of citations received by an article from subsequently published articles is widely recognized as a proxy for the quality or importance of that article's research.[14] As Figure 2.4 shows, citations to articles by the SSA regions and their comparator countries comprise a small but growing share of global citations. For example, Southern Africa's share of global citations more than doubled from 0.06% in 2003 to 0.12% in 2012, a CAGR of 8%. The other regions experienced similarly strong growth rates in their world citation share, though they are modest in comparison to that of the comparator countries in Asia. For instance, Malaysia's global citation share increased more than six-fold from 0.09% to 0.56%, which is less surprising given Malaysia's corresponding increase in research output.

2.3.2. Field-Weighted Citation Impact

Although citations provide an intuitive proxy for research impact, they can be problematic for two reasons. First, citations are usually not comparable across fields. For instance, articles in the Life Sciences tend to be cited more often than those in mathematics. Second, different types of articles are cited with varying baseline frequencies. Review articles receive on average more citations than regular journal articles. A more sophisticated way of analyzing citation impact is to use field-weighted citation impact (FWCI). FWCI normalizes for differences in citation activity by subject field, article type, and publication year. This enables the comparison of citation impact across subject areas with different publication velocities and or publication type norms.

The world is indexed to a value of 1.00. A FWCI of more than 1.00 indicates that the entity's publications have been cited more than would be expected based on the global average for similar publications. For example, Southern Africa's FWCI in 2012 of 1.39 indicates that the average article from that region in that year has been cited 39% more than the world average. In contrast, Southern Africa's FWCI in 2003 of 0.88 indicates that articles from that region in that year were cited 12% less than the world average. Collectively, the SSA regions achieved of FWCI a 0.92 in 2012. For more details, please see Appendix B: Glossary.

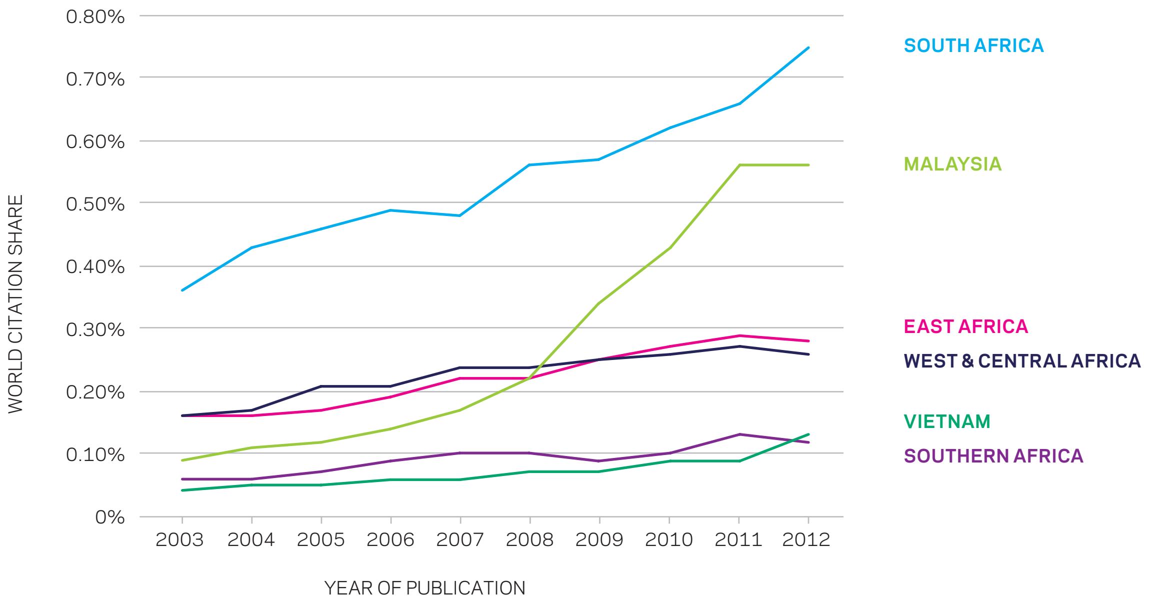


Figure 2.4 *— World citation share across all subject groupings for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

[14] Davis, P. M. (2009). Reward or persuasion? The battle to define the meaning of a citation. Association of Learned and Professional Society Publishers. doi: 10.1087/095315108X378712

Figure 2.5, which graphs the impact of research produced by the Africa regions and their comparator countries against their respective world article share over time, provides a visual contrast of the different paths that the regions took over the past decade. All three SSA regions improved the relative citation impact of their research, but there are significant variations across the regions in the baseline FWCI level and the trends in FWCI growth or stagnancy from 2003 to 2012.

Southern Africa has improved the impact of its research output the most, growing its FWCI from 0.88 in 2003 to 1.39 in 2012. However, Southern Africa did not increase its world article share much. In contrast, West & Central Africa increased the quantity of its output over time, outpacing the world's average growth to improve its world article share, but it made little gains in the overall quality of its research. Likewise, Vietnam modestly increased its world article share, but it did not significantly change its aggregate citation impact.

East Africa and South Africa developed in a hybrid manner, initially increasing their overall FWCI and then shifting toward increasing their world article share. South Africa and East Africa have also increased the impact of their research output from below the world average to above the world average. Similarly, Malaysia has increased both its world article share and its research impact, though as of 2012, it is still below the world average (0.92).

2.3.3. **Impact by Subject Groupings**

Just as the relative quantity of outputs produced by the different regions varied across subject groupings, the relative quality of said outputs also differed. Figure 2.6 to Figure 2.8 display the trends in the FWCIs in the Physical Sciences & STEM, Agriculture and Health Science versus the respective world article shares in those subject groupings from 2003-2012.

The regions' impact in the Physical Sciences & STEM is much lower than their overall average. For instance, Southern Africa's overall FWCI in 2012 was 1.39, but its FWCI in the Physical Sciences & STEM was 0.94, just below the world average. More importantly, the impact of the regions' output in the Physical Sciences & STEM has improved little over time. All three SSA regions still have subject grouping FWCIs below the world average. Although West & Central Africa's research impact in the Physical Sciences & STEM improved from 0.56 in 2003 to 0.63 in 2008, it regressed to 0.56 in 2012. In contrast, the impact of Malaysia and Vietnam's research output in the Physical Sciences & STEM have both improved significantly over the past decade.

Similarly, while the Africa regions grew the impact of their research output in Agriculture at roughly the same rate as their overall impact, the baseline impact for Agriculture was much lower. However, in contrast to the Physical Sciences & STEM, the impacts of those regions' outputs have increased over time.

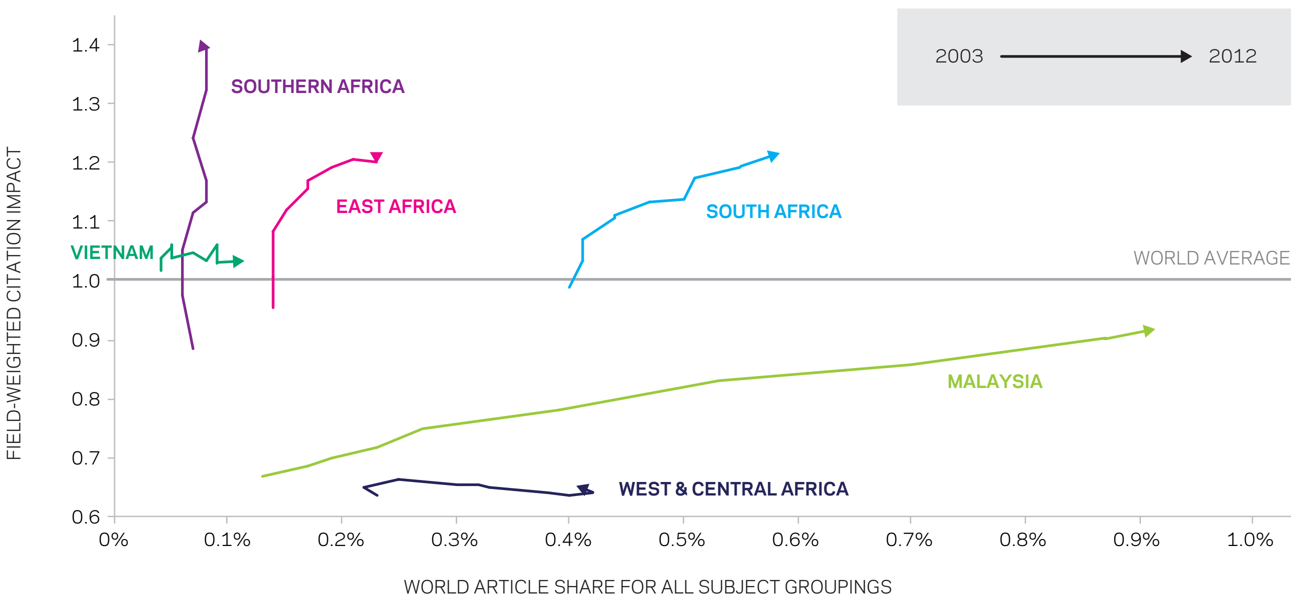


Figure 2.5 *— FWCI versus world article share for all subject groupings for SSA regions and comparator institutions, 2003-2012. Source: Scopus*

In contrast to the other subject groupings, the regions' output in the Health Sciences achieved a much higher impact than those regions' overall output. For instance, articles by Southern Africa in this subject grouping in 2012 attained a FWCI of 1.85, or nearly 85% above the world average. Similarly, East Africa and South Africa's output in 2012 attained impact levels far above their aggregate regional average. Even West & Central Africa, whose FWCI in the Health Sciences was still below the world average (0.77), outperformed its overall FWCI (0.66).

The contrast between the trends in Figure 2.6 and Figure 2.8 provide another perspective on the regions' divergent subject grouping trajectories. While all three SSA regions increased both the quantity and quality of their output in the Health Sciences, progress in the Physical Sciences & STEM has been more limited. Health Sciences has driven the regions' overall research growth.

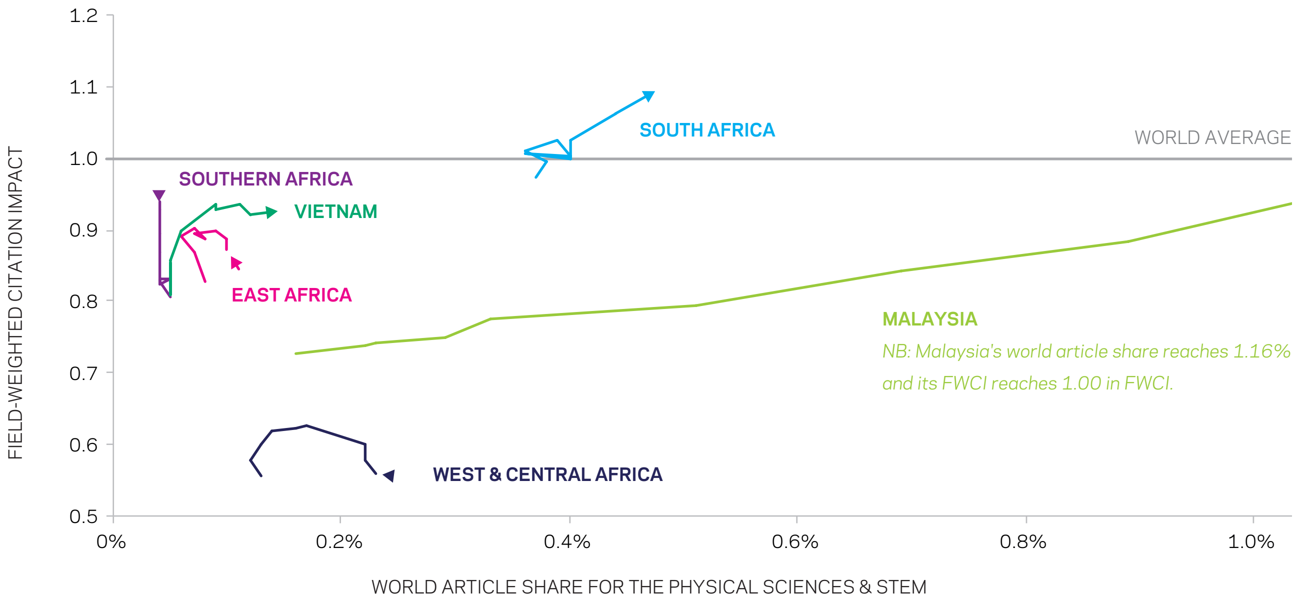


Figure 2.6 *— Field-weighted citation impact versus world article share for the Physical Sciences & STEM for SSA regions and comparator countries, 2003-2012. Source: Scopus*

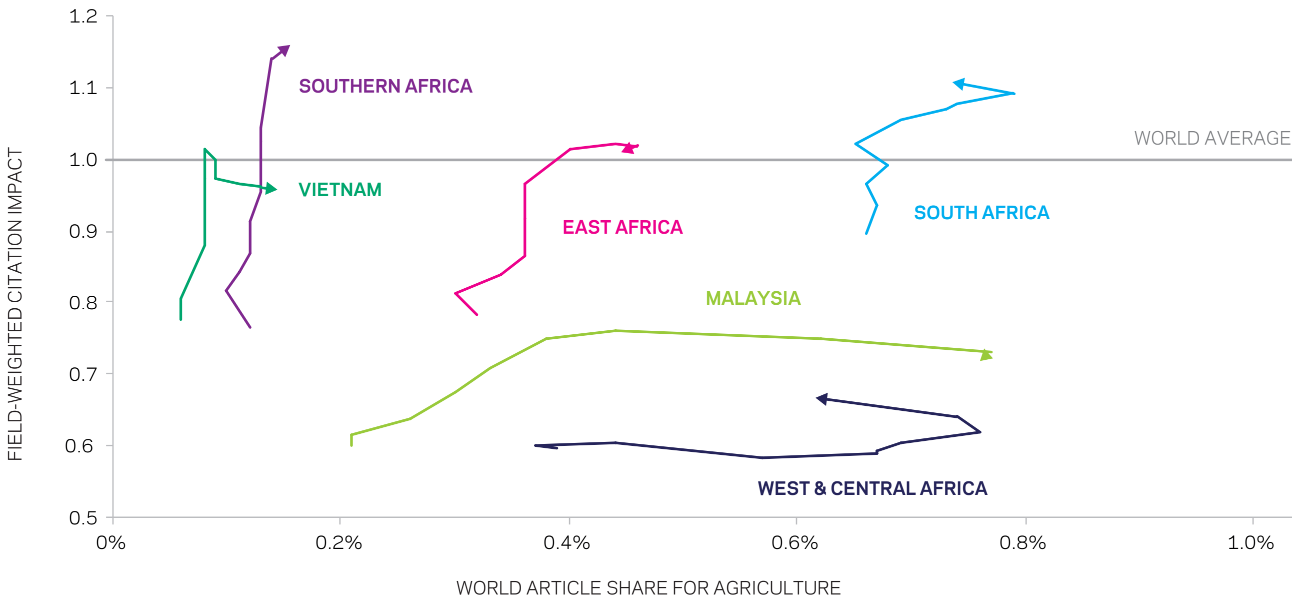


Figure 2.7 *— Field-weighted citation impact versus world article share for Agriculture for SSA regions and comparator countries, 2003-2012. Source: Scopus*

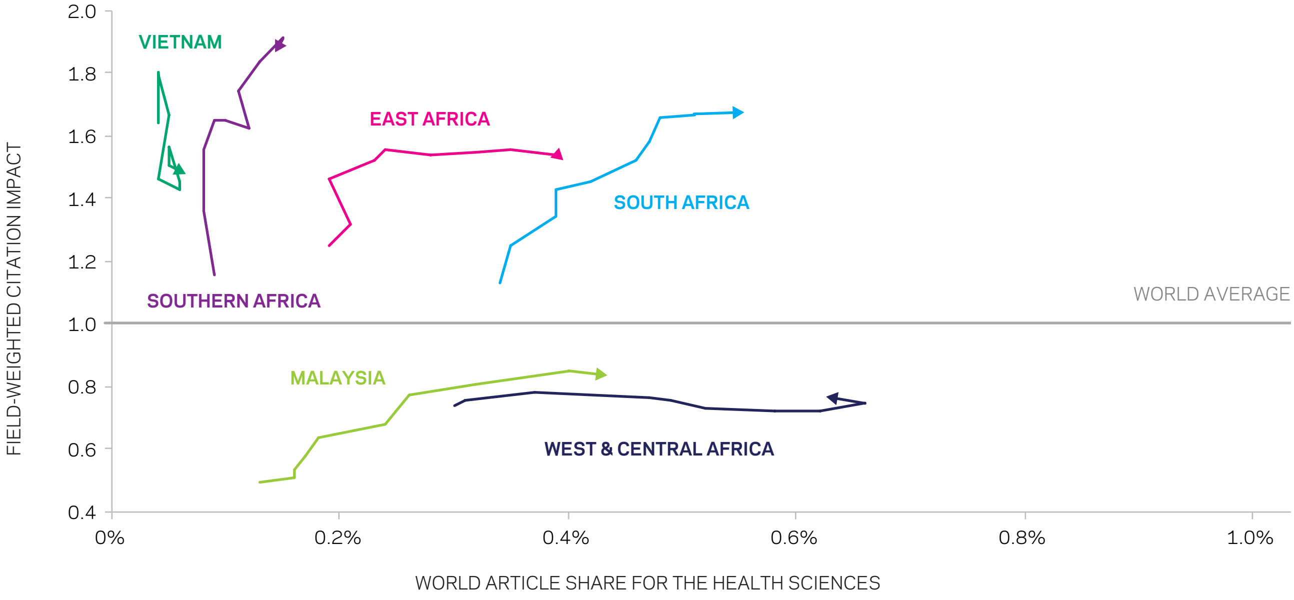


Figure 2.8 *— Field-weighted citation impact versus world article share for the Health Sciences for SSA regions and comparator countries, 2003-2012. Source: Scopus*

2.3.4. Research Excellence

Citations are not evenly distributed across articles. There is usually a strongly skewed distribution, with a small proportion of all published articles receiving the majority of the citations, a "long tail" of articles receiving the remainder, and a significant proportion of all articles never receiving a single citation.[15] Recent research suggests that not only is an examination of the small proportion of the most highly-cited articles a robust approach to research assessment,[16] it may yield insights hidden from aggregate measures.

Similar to the methodology behind FWCI, this report defines highly cited articles as those in the top X% worldwide in citation counts relative to all articles published in the same year and subject area. As Figure 2.9 shows, the percentage of each of the regions' total output that are highly cited articles – that is, articles that meet the threshold for being considered amongst the world's top 10% (e.g., those in the 90th percentile) in terms of citation count, has grown steadily over time. For instance, for East and Southern Africa, highly cited articles comprised at least 14.6% of their total output in 2012. While 8.7% of Southern Africa's outputs in 2003 were in the world's top 10%, 16.0% of that region's outputs in 2012 achieved that mark, reflecting a CAGR of 7.0% over the decade.

However, similar to the trends in FWCI, West & Central Africa lags behind the other regions in terms of its relative production of highly-cited articles. It grew its percentage of 90th percentile articles from 5.5% in 2003 to 7.5% in 2012, levels below what one would expect if the region's output matched the world average distribution.

Figure 2.10 to Figure 2.12 provide a more in-depth examination of the regions' highly cited output at the subject grouping level. South Africa consistently increased its highly cited article output in the Physical Sciences & STEM, but the trends for the other regions are less even. From 2003 to 2012, South Africa grew the percentage of its Physical Sciences & STEM output in the world's top 10% from 10.5% to 14.5%. For the other regions, the level of highly cited articles in this subject grouping increased from 2003 to 2008 but declined from 2008 to 2012. For example, the percentage of East Africa's output in the world's top 10% grew from 11.8% in 2003 to 13.4% in 2008 before falling to 9.8% in 2012.

[15] De Solla Price, D.J. (1965). "Networks of Scientific Papers". Science 149 (3683): pp. 510-515. doi: 10.1126/science.149.3683.510

[16] Bornmann, L., Leydesdorff, L., Walch-Solimena, C., & Ettl, C. (2011). Mapping excellence in the geography of science: An approach based on Scopus data. Journal of Informetrics 5(4): pp. 537-546. doi: 10.1016/j.joi.2011.05.005; Bornmann, L., & Marx, W. (2013). How good is research really? Measuring the citation impact of publications with percentiles increases correct assessments and fair comparisons. EMBO reports 14(3): pp. 226-30. doi: 10.1038/embor.2013.9

Across all three SSA regions, although the percentage of highly cited article output in Agriculture remained well below the regions' overall percentages, it increased significantly from 2003 to 2012. For example, in 2003, only 3.3% of Southern Africa's outputs in Agriculture were in the world's top 10% in terms of citation counts, but in 2012, 7.9% were.

The regions' relative output of highly cited articles in the Health Sciences has consistently increased over the past decade, with Southern Africa achieving the highest absolute percentage growth. From 2003 to 2012, Southern Africa grew its percentage of output in the world's top 10% in the Health Sciences from 10.0% to 17.3%.

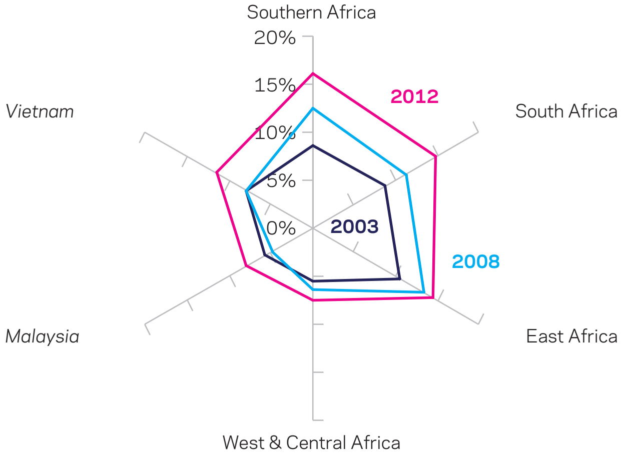


Figure 2.9 *— Percentage of total publications with citation counts in the 90th percentile worldwide for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

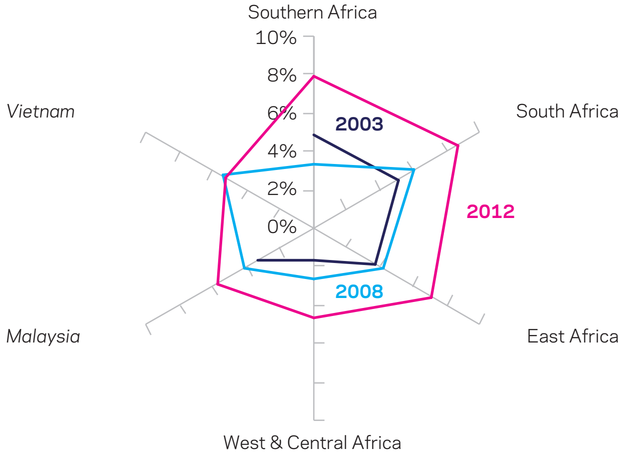


Figure 2.10 *— Comparing percentage of publications on the Physical Sciences & STEM with citation counts in the 90th percentile worldwide for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

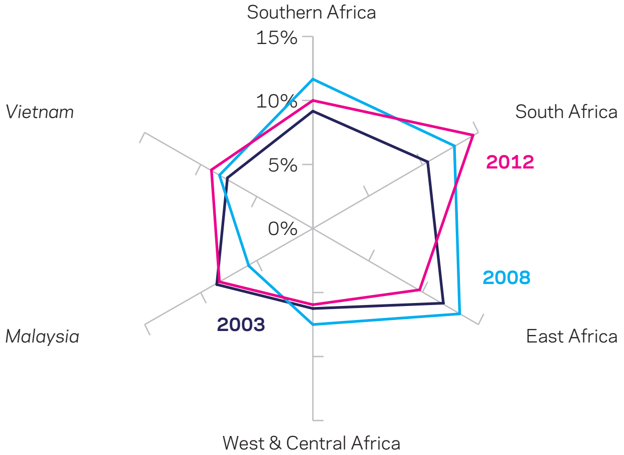


Figure 2.11 *— Comparing percentage of publications on Agriculture with citation counts in the 90th percentile world-wide for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

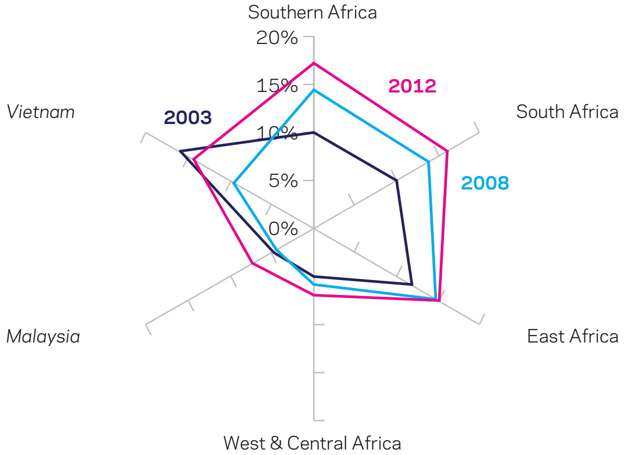


Figure 2.12 *— Comparing percentage of publications on the Health Sciences with citation counts in the 90th percentile worldwide for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

2.4 Research Per Capita

Research productivity at a national level refers to the capability of converting research inputs, such as R&D expenditures and human capital, into research outputs, such as articles and citations. Due to limitations in the data availability of more precise research inputs[17] for the Africa regions, this report draws on basic population and GDP data from the World Bank Africa Development Indicators. In contrast to previous indicators, data is available only for 2006-2011.

As Figure 2.13 shows, although South Africa's GDP (and hence capacity to invest in R&D, training human capital, and so forth) is much larger than that of the SSA regions, West & Central Africa and East Africa are slightly more productive in terms of articles per million USD$ GDP. In 2011, West & Central Africa produced 0.048 articles per million USD$, while East Africa produced 0.034 articles per million USD$.

When normalizing for population size, however, South Africa is the most productive, producing 242.6 articles per million people in 2011, an increase from 160.5 articles per million people in 2006. In contrast, the closest SSA region is West & Central Africa, which generated 47.8 articles per million people in 2011, an increase from 30.2 articles per million people in 2006.

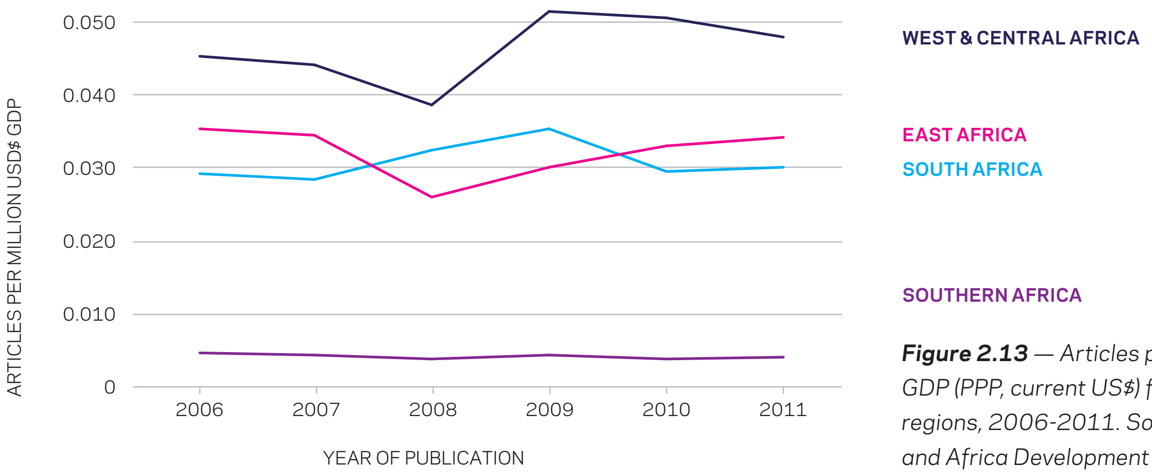


Figure 2.13 *— Articles per million GDP (PPP, current US$) for Africa regions, 2006-2011. Source: Scopus and Africa Development Indicators.*

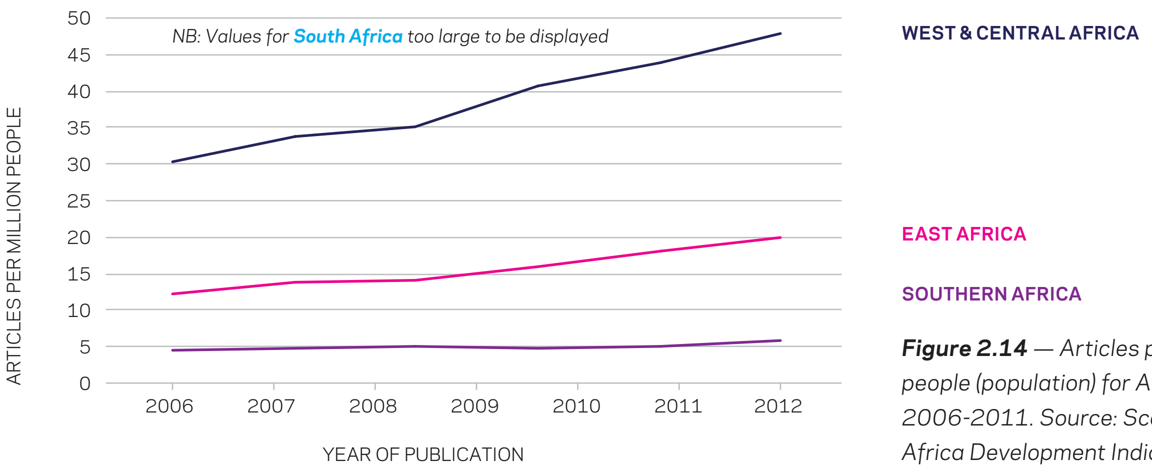


Figure 2.14 *— Articles per million people (population) for Africa regions, 2006-2011. Source: Scopus and Africa Development Indicators.*

[17] According to the UNESCO Institute of Statistics, data on gross expenditures on R&D (GERD) is available for only 11 of the 52 countries comprising the three Africa regions in 2008 and only 5 countries in 2012. Likewise, data on the number of researchers is available for only 7 of the 52 countries in 2008 and only 4 in 2012. Trend analyses are not possible but the boxes at the end of this chapter provide insights on the GERD and researcher numbers across fields. http://www.uis.unesco.org/ScienceTechnology/Pages/research-and-development-statistics.aspx

2.5 Novel Measures of Research Impact

Citations represent one path through which academic research is utilized, but it is neither meant to nor does a good job of capturing the impact of academic research outside academia. There is increasing interest in creating more and better indicators of the use and commercialization of research. Download usage and patent citations may provide new, alternative ways of understanding usage of academic research and linking academic research to larger societal impact.[18]

2.5.1. Article Downloads as Potential Predictor of Future Impact

Article downloads from online platforms are an alternative metric used as a predictor of future research impact. Measuring impact through citations is particularly difficult for recently published articles. Citation impact is by definition a lagging indicator. The accumulation of citations takes time. After publication, articles need to first be discovered and read by the relevant researchers; then, those articles might influence the next wave of studies conducted and procedures implemented. For a subset of those studies, the results are written up, peer-reviewed, and published. Only then can a citation be counted toward that initial article. Moreover, citations do not necessarily capture the full extent to which an article is being used and may systematically understate the impact of certain types of research (clinical versus basic).[19]

Since the pipeline from initial publication to receiving a citation is long and leaky, data on article downloads are an appealing alternative. When measuring downloads, one can start tracking usage immediately after the publication of an article, instead of waiting months or even years for citations to accrue. Research on publication download measurements and their implications is an emerging topic within the bibliometric community.[20]

Since full-text journal articles reside on a variety of publisher and aggregator websites, there is no central database of download statistics available for comparative analysis. Despite this, downloads are nonetheless a useful indicator of early interest in, or the emerging importance of, research. This report uses full-text article download data from Elsevier's ScienceDirect database, which provides approximately 20% of the world's published peer-reviewed journal articles, to offer an alternate perspective on how an institution's research is being used around the world.

For this report, a download is defined as either downloading a PDF of an article on ScienceDirect or looking at the full text online on ScienceDirect, without downloading the actual PDF. Views of paper abstracts are not counted. Multiple views or downloads of the same article in the same format during a user session are filtered out, in accordance with the COUNTER Code of Practice.[21] Moreover, as a proxy for the influence and impact of Africa's research on industry, this report separately analyzes the download trends of ScienceDirect users in the corporate institutions versus non-corporate ones.

[18] Bornmann, L. (2013). What is societal impact of research and how can it be assessed? a literature survey. Journal of the American Society for Information Science and Technology, 64(2), 217–233. doi:10.1002/asi.22803; Tijssen, R. J. . (2001). Global and domestic utilization of industrial relevant science: patent citation analysis of science–technology interactions and knowledge flows. Research Policy, 30(1), 35–54. doi:10.1016/S0048-7333(99)00080-3

[19] Van Eck, N. J., Waltman, L., van Raan, A. F. J., Klautz, R. J. M., & Peul, W. C. (2013). Citation analysis may severely underestimate the impact of clinical research as compared to basic research. PloS One, 8(4), e62395. doi:10.1371/journal.pone.0062395

[20] Kurtz, M.J., & Bollen, J. (2012). Usage Bibliometrics. Annual Review of Information Science and Technology Volume 44, Issue 1. doi: 10.1002/aris.2010.1440440108; Moed, H. F. (2005). Statistical relationships between downloads and citations at the level of individual documents within a single journal. Journal of the American Society for Information Science and Technology, 56(10), 1088–1097. doi:10.1002/asi.20200; Schloegl, C., & Gorraiz, J. (2010). Comparison of citation and usage indicators: the case of oncology journals. Scientometrics, 82(3), 567–580. doi:10.1007/s11192-010-0172-1; Schloegl, C., & Gorraiz, J. (2011). Global usage versus global citation metrics: The case of pharmacology journals. Journal of the American Society for Information Science and Technology, 62(1), 161–170. doi:10.1002/asi.21420; Wang, X., Wang, Z., & Xu, S. (2012). Tracing scientist's research trends realtimely. Scientometrics, 95(2), 717–729. doi:10.1007/s11192-012-0884-5

[21] http://usagereports.elsevier.com/asp/main.aspx; http://www.projectcounter.org/code_practice.html

Table 2.3 presents the average number of downloads that articles published between 2008 and 2012 by the respective regions have thus far received. The first column provides the overall average, and the next five columns provide the number of downloads per article for each of the five subject groupings. For example, East Africa has 4,231 articles on ScienceDirect, and those articles have been downloaded on average 928 times, the most of any region in this report. Moreover, across all the Africa regions' outputs in different subject groupings, East Africa's 1,376 articles in the Physical Sciences & STEM have received the most average downloads per paper at 1,086. In general, sub-Saharan research articles published between 2008 and 2012 have been downloaded on average at least 650 times.

To better benchmark and compare the relative number of downloads across subject groupings, Table 2.4 divides the downloads per article measure for each subject grouping by the overall downloads per article measure for a given region. For example, Southern Africa's output in Agriculture is downloaded on average 17% more frequently than its overall output, and Southern Africa's output in the Health Sciences is downloaded on average 9% less frequently than its overall output.

Output in Agriculture is downloaded more frequently for all three Africa regions and South Africa, and it is downloaded at an even higher relative rate for the two comparator countries (41% and 32% for Malaysia and Vietnam, respectively). Likewise, for all SSA regions, research in the Physical Sciences & STEM is downloaded at a rate higher than the overall regional average. In contrast, for all the regions, output in the Health Sciences is downloaded on average less frequently than those respective regions' overall output.

***Table 2.3** — Downloads per article by subject grouping for SSA regions and comparator countries, 2008-2012. Source: ScienceDirect.*

	All	Physical Sciences	Agriculture	Health Sciences	Social Sciences & Humanities	Life Sciences
East Africa	928	1086	991	757	1022	807
Southern Africa	884	949	1033	801	813	820
West & Central Africa	676	781	752	511	671	860
South Africa	875	816	968	956	791	1103
Malaysia	898	843	1265	803	1252	1172
Vietnam	832	763	1100	838	984	1035

***Table 2.4** — Downloads per article by subject grouping relative to regional averages for SSA regions and comparator countries, 2008-2012. Source: ScienceDirect.*

	All	Physical Sciences	Agriculture	Health Sciences	Social Sciences & Humanities	Life Sciences
East Africa	1.00	1.17	1.07	0.82	1.10	0.87
Southern Africa	1.00	1.07	1.17	0.91	0.92	0.93
West & Central Africa	1.00	1.16	1.11	0.76	0.99	1.27
South Africa	1.00	0.93	1.11	1.09	0.90	1.26
Malaysia	1.00	0.94	1.41	0.89	1.39	1.30
Vietnam	1.00	0.92	1.32	1.01	1.18	1.24

One particularly interesting audience of sub-Saharan research is international corporations. They provide both an early indicator of what types of research could attract further corporate R&D funding and a test for whether such research is more broadly applicable. Corporations, however, often have differing tastes in and uses for research than academics. As Table 2.5 exemplifies, downloads from corporate users comprises only a fraction of the total amount of usage data. For example, while East African articles from 2008-2012 were downloaded on average over 900 times, each paper was downloaded only 15.5 times on average from corporate users. More importantly, as Table 2.6 shows, the distribution of corporate interest in the different regions' subject outputs is very different from that of the academic sector. In particular, while the output in the Health Sciences received fewer downloads on average relative to that from all sectors, such output received between 27% and 87% more downloads from the corporate sector. In contrast, research in the Physical Sciences & STEM received between 9% and 30% less downloads on average.

Table 2.5 *— Corporate downloads per article by subject grouping for SSA regions and comparator institutions, 2008-2012. Source: ScienceDirect.*

	All	*Physical Sciences*	*Agriculture*	*Health Sciences*	*Social Sciences & Humanities*	*Life Sciences*
East Africa	15.5	10.9	10.5	24.4	4.5	26.0
Southern Africa	18.5	14.8	19.0	26.1	4.0	32.0
West & Central Africa	13.3	12.1	12.3	17.0	4.7	24.8
South Africa	22.3	18.7	21.7	41.6	5.5	48.6
Malaysia	16.6	14.7	27.2	32.5	6.1	37.2
Vietnam	16.2	11.1	24.1	40.6	6.9	43.4

Table 2.6 *— Corporate downloads per article by subject grouping relative to regional averages for SSA regions and comparator institutions, 2008-2012. Source: ScienceDirect.*

	All	*Physical Sciences*	*Agriculture*	*Health Sciences*	*Social Sciences & Humanities*	*Life Sciences*
East Africa	1.00	0.70	0.68	1.58	0.29	1.68
Southern Africa	1.00	0.80	1.02	1.41	0.21	1.73
West & Central Africa	1.00	0.91	0.92	1.27	0.35	1.86
South Africa	1.00	0.84	0.97	1.87	0.25	2.18
Malaysia	1.00	0.89	1.64	1.95	0.37	2.24
Vietnam	1.00	0.69	1.49	2.52	0.43	2.69

2.5.2. Patent Citations as an Alternative Measure of Impact

Past studies suggest that academic researchers and industry interact in a multitude of channels,[22] and patent citations is one of the more public lenses for understanding the linkage between academic research and intellectual property.

Intellectual property (IP) describes intangible assets, such as discoveries and inventions, for which exclusive rights may be claimed. Common types of IP include that which is codified in copyright, trademarks, patents, and designs. Typically, a patent application must include one or more claims that define the invention, and these claims should be novel and non-obvious from the prior art (i.e., from existing, publicly-available documentary sources). As such, many patent applications cite journal articles which either provide information that supports or are related to the claims but that do not constitute prior art.

Drawing on indexed patent citation data from Lexis-Nexis TotalPatent and Scopus, this section examines the percentage of each Africa region's output that is referenced by global patent applications from the World Intellectual Property Organization (WIPO). The numbers in Table 2.7 correspond to the total number of citations in patent applications from 2003-2012 to journal articles published by the respective regions (and when applicable, the respective subject groupings) between 2003 and 2012. To normalize for differences in the underlying number of publications produced by each region (and hence the number of publications that could be cited in patents), Table 2.8 presents the number of patent citations divided by the total number of publications produced by a region in a subject area.

In terms of raw numbers, given the size and maturity of South Africa's research enterprise, it is unsurprising that South Africa has attained more than twice as many patent citations overall than any SSA region (804 compared to the next closest, West & Central Africa, at 351). More surprising, however, is the disparity in the relative distribution of patent citations across subject groupings. Research in the Physical Sciences & STEM by East Africa has only been cited 32 times compared to 90 and 87 times for research in the Health Sciences and Agriculture, respectively. Southern Africa and West & Central Africa show similar trends. In contrast, for Malaysia, research in the Physical Sciences & STEM has garnered more patent citations (256) over the past decade than research in any other subject grouping.

When patent citations are normalized by the regions' total publication outputs, the disparities between the regions get smaller. For example, the ratio of patent citations to all publications was 0.60% for East Africa and 0.50% for Malaysia. However, even when patent citations are normalized by the regions' publication outputs per subject, there is still a noticeable focus amongst the SSA regions on Agriculture and Health Sciences instead of the Physical Sciences & STEM. The ratio of patent citations to all publications for West & Central Africa was 0.33% in the Physical Sciences & STEM versus 0.82% in Agriculture and 0.61% in the Health Sciences. For Malaysia and Vietnam, the ratio of patent citations to all publications in the Physical Sciences & STEM is quite low (0.42% and 0.02%) relative to that of other subject areas because of those comparator countries' high levels of output in the Physical Sciences & STEM, not necessarily because the research conducted by the countries in those subject areas is not particularly helpful to inventors.

Table 2.7 *— Patent citations to academic output in different subject groupings for SSA regions and comparator institutions, 2003-2012. Source: LexisNexis TotalPatent and Scopus.*

	All Subject Groupings	Physical Sciences & STEM	Agriculture	Health Sciences
East Africa	205	32	87	90
Southern Africa	63	8	26	26
West & Central Africa	351	60	167	151
South Africa	804	315	338	211
Malaysia	450	256	203	98
Vietnam	88	17	39	26

Table 2.8 *— Patent citations to academic output as percentage of total publication output in different subject groupings for SSA regions and comparator institutions, 2003-2012. Source: LexisNexis TotalPatent and Scopus.*

	All Subject Groupings	Physical Sciences & STEM	Agriculture	Health Sciences
East Africa	0.60%	0.38%	0.68%	0.64%
Southern Africa	0.46%	0.19%	0.61%	0.48%
West & Central Africa	0.56%	0.33%	0.82%	0.61%
South Africa	0.90%	0.79%	1.43%	0.99%
Malaysia	0.50%	0.42%	1.33%	0.77%
Vietnam	0.65%	0.20%	1.21%	1.05%

[22] D'Este, P., & Patel, P. (2007). University–industry linkages in the UK: What are the factors underlying the variety of interactions with industry? Research Policy, 36(9), 1295–1313. doi:10.1016/j.respol.2007.05.002; Schartinger, D., Rammer, C., Fischer, M. M., & Fröhlich, J. (2002). Knowledge interactions between universities and industry in Austria: sectoral patterns and determinants. Research Policy, 31, 303-328. doi: 10.1016/S0048-7333(01)00111-1

2.6 Interpretation and Discussion of Chapter Key Findings

The following section interprets the key findings on research output and impact in SSA and provides insights into the expected drivers of the key findings.

The key findings point in our view to three main interpretations:

1. Africa is rising in research. Both the quantity and quality of research performance is improving. Capacity in the African higher education and research sector has clearly progressed in the decade from 2003-2012. The improvements are primarily driven by increased research capacity in the Health Sciences. This interpretation is supported by the following key findings:

a. Research production has increased by more than 100% in SSA since 2003.

b. SSA's share of global research has increased from 0.44% in 2003 to 0.72% in 2012.

c. Between 7.5% and 16% of the different SSA's total publications were amongst the world's top 10% most highly cited articles, but only 5.9% -10% of those same region's total output in the Physical Sciences & STEM met that threshold.

d. On average for the three SSA regions, research in the Health Sciences constituted 45.2% of their total output.

2. A large gap in research capacity still exists between SSA and the rest of the world.

a. SSA's research output remains less than 1% of the world, while its share of the population is 12%.

b. Research output by comparator countries grew even faster than that of Sub-Sahara Africa. Malaysia, whose article output in 2003 was similar to that of East Africa, grew its output by 31% per year. Similarly, Vietnam, whose article output in 2003 was about two-thirds the level of Southern Africa, grew its output by 19% per year.

3. SSA research capacity within Science, Technology, Engineering and Mathematics is underdeveloped and lags significantly. This is evidenced by absolute and comparative shortcomings in the quantity and quality of STEM research.

a. STEM research makes up only 29% of all research in SSA. In contrast, STEM research constitutes the largest share of each of the comparator countries' total outputs (45% for South Africa and an average of 68% for Vietnam and Malaysia).

b. The share of STEM research in SSA has marginally declined by 0.2% annually since 2003. In comparison, the share of STEM research has declined 0.1% annually in South Africa and grew 2% annually in Malaysia and Vietnam.

c. In 2012, the quality of STEM research in SSA, as measured by relative citation impact, was 0.68 (32 percent below the global average). This is below that of all disciplines in SSA (0.92) and the global average (1.00), and it has not significantly changed since 2003. In contrast, STEM research in Malaysia, Vietnam and South Africa in 2012 was slightly above the world average and has improved significantly since 2003.

Below is a short discussion of some of the key factors that may drive the key findings of this chapter. Since the main scope of this report is research output, the following is based on factors observed in other regions and findings from other relevant, country-wise studies explaining research output in SSA. Subsequent research should further examine these explanatory factors.

- Volume of Funding: Research outputs are greatly determined by international and national funding for R&D which finances necessary salaries, equipment and other research costs. As an example, Box 1 summarizes how increased R&D expenditures in South Africa were an essential driver behind this country's growth in research outputs. Box 3 presents the latest available R&D expenditure data for SSA.
- Sectoral R&D Funding: Similarly, disciplinary allocation of R&D funding may heavily influence disciplinary research output. Box 2 presents anecdotal data for 3 countries. Although data is scarce, the research funding provided by international development partners, such as the US Government and SIDA, to health research in Africa is expected to be a major factor behind the improved research output in SSA. The increases in health R&D spending and output is encouraging and important. First, due to the tremendous health challenges the continent faces, improved Africa-relevant health research and well-trained health workers will have a great impact on health outcomes. As recent research shows, although SSA assumes the heaviest burden of major diseases such as HIV/AIDS, malaria, and tuberculosis, it is primarily Western countries that have the highest research intensities in said subjects, with the exception of South Africa.[23] Second, the impressive improvement in SSA's research capacity in the Health Sciences demonstrates that persistent support and funding from development partners and governments pays off.

On the other hand, Pouris and Ho (2013)[24] argue that Africa's heavy dependency on international scientific collaboration may be stifling research individualism and affecting the continent's research evolution and priorities. Researchers argue that Africa's dependence on international research funding implies that some of its research priorities are underfunded, STEM being a critical one. Governments and development partners could use lessons learnt from the rapid growth in health R&D to boost growth in other sciences, specifically STEM.

- Funding mechanisms: How research funding is allocated and the accountability for results equally matters for research output. Box 1 describes one example on how a change in research funding to South Africa universities fostered a marked increase in research output. The gold standard for research funding is open, transparent, competitive, and peer-reviewed research funding. Further, it is critical that institutional incentives are transferred within each institution to its faculty.
- Research infrastructure: Research in most STEM, Agricultural, Health, and Life Sciences require substantial equipment as well as access to international databases and science literature. Research infrastructure is built and depleted over time. Lack of research infrastructure in Africa is a frequent explanation espoused by researchers working in Africa. Unfortunately, no systematic data is collected on this topic.
- Number of researchers: The number of PhD holders, faculty, and post-docs and PhD students is a key determinant of research output. Similar to research infrastructure, research human capital is built and depleted over time. Box 4 provides a snapshot of available information on the sectoral composition of the number of researchers in SSA.

Box 1. R&D Funding and Funding Mechanisms Matter: The Case of South Africa

The following figures provide data on the growth of R&D in South Africa as a result of increased funding and better managed funding mechanisms. As shown in Figure A, starting from 2000, R&D funding in South Africa rose with GERD reaching $4.3 billion (in 2005 dollars) by 2008. This increase in funding volume has led to a sharp rise in research output in the past decade. The line in Figure A represents the introduction of a new funding formula for the provision of incentives by the Department of Education to universities. It is clear that this led to a sharp rise in the number of publications. Pouris (2011)[25] concludes that R&D funding and funding mechanisms matter for research output.

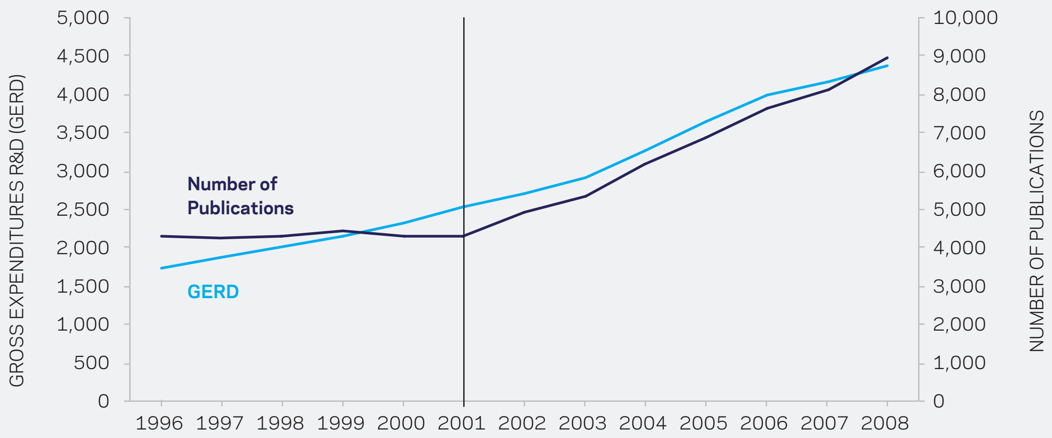


Figure A *— Trends in GERD and overall number of articles over time for South Africa, 1996-2008, with GERD in millions 2005 dollars - constant PPP. The line at 2001 notes when the new funding formula was introduced (see Pouris 2011)[26] Source: OECD Main Science and Technology Indicators and Scopus.*

[23] Huggett, S. (2009). Research supports UN millennium development goals. Research Trends (14). Retrieved from http://www.researchtrends.com/issue14-december-2009/behind-the-data/

[24] Pouris, A., & Ho, Y.-S. (2013). Research emphasis and collaboration in Africa. Scientometrics, 98(3), 2169–2184. doi:10.1007/s11192-013-1156-8

[25] Pouris, A. (2012). Science in South Africa: The dawn of a renaissance? South African Journal of Science, 108(7/8). doi:10.4102/sajs.v108i7/8.1018

[26] Ibid.

Box 2. Growth Mirrors Allocation of Resources: Learning from Health in SSA GERD by field of science

Over the years both Uganda and Mozambique have increased their funding in S&T but it remains lower than that of health. In Malaysia, the GERD in STEM is 28% while that in Health is 4%. In contrast, in 2010 the spending on STEM in Mozambique and Uganda was 15% and 12%, respectively of the total countries' expenditures on research. In Africa, Health has seen great improvements given the national priorities and presents an example that can be followed in STEM.

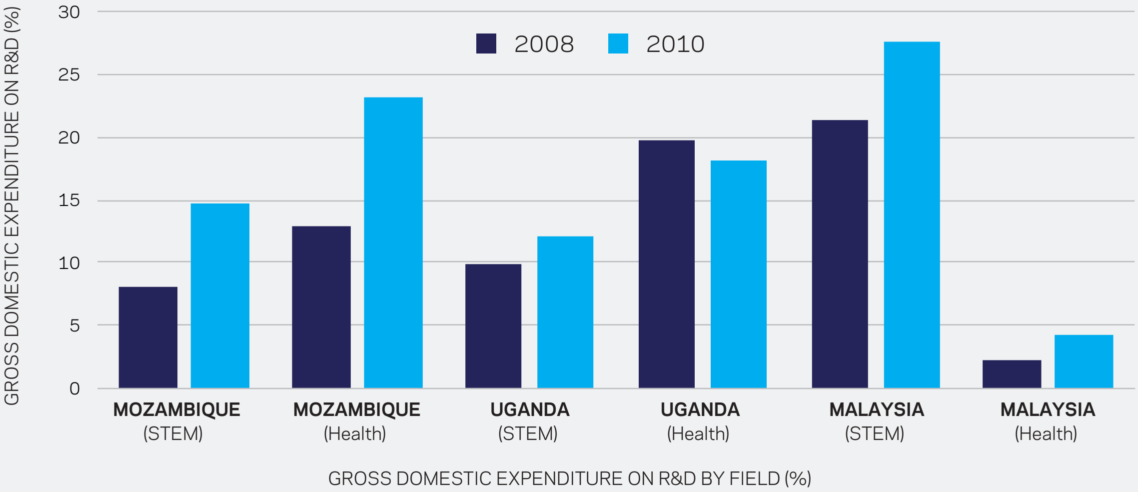


Figure B *— Gross domestic expenditure on R&D by field (%), 2008 versus 2010. Source: UNESCO Institute of Statistics.*

Box 3. Low Country Investments in R&D

Most West African countries are placing less than 0.25% of the GDP in R&D investments, while East Africa remains largely below 0.5% of the GDP.

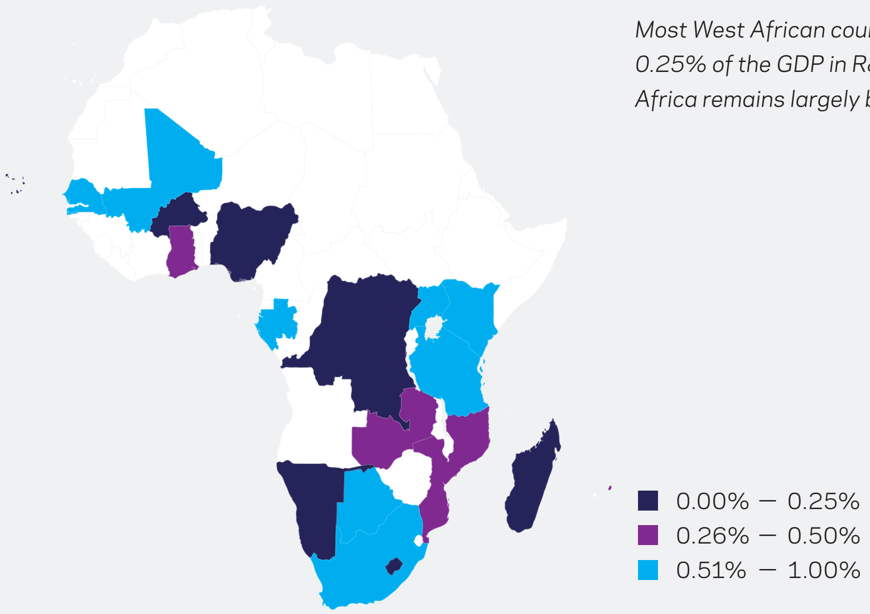


Figure C *— Gross domestic expenditure on R&D (GERD) as a percentage of GDP, 2011 or latest available year for sub-Saharan Africa. Source: UNESCO Institute of Statistics.*

Box 4. Researchers are concentrated in the field of medical and health sciences

The number of researchers mirrors the flow of resources. As shown in the figure, the share of researchers in medical science and health far exceed the share of researchers in engineering and technology, e.g. In Burkina Faso, 46% of the researchers focus on Medical & Health Sciences while in Ethiopia and Kenya, it is 21% and 25% respectively. In contrast, the percentage of researchers that focus on Engineering & Technology in those countries are 16%, 6%, and 14%, respectively.

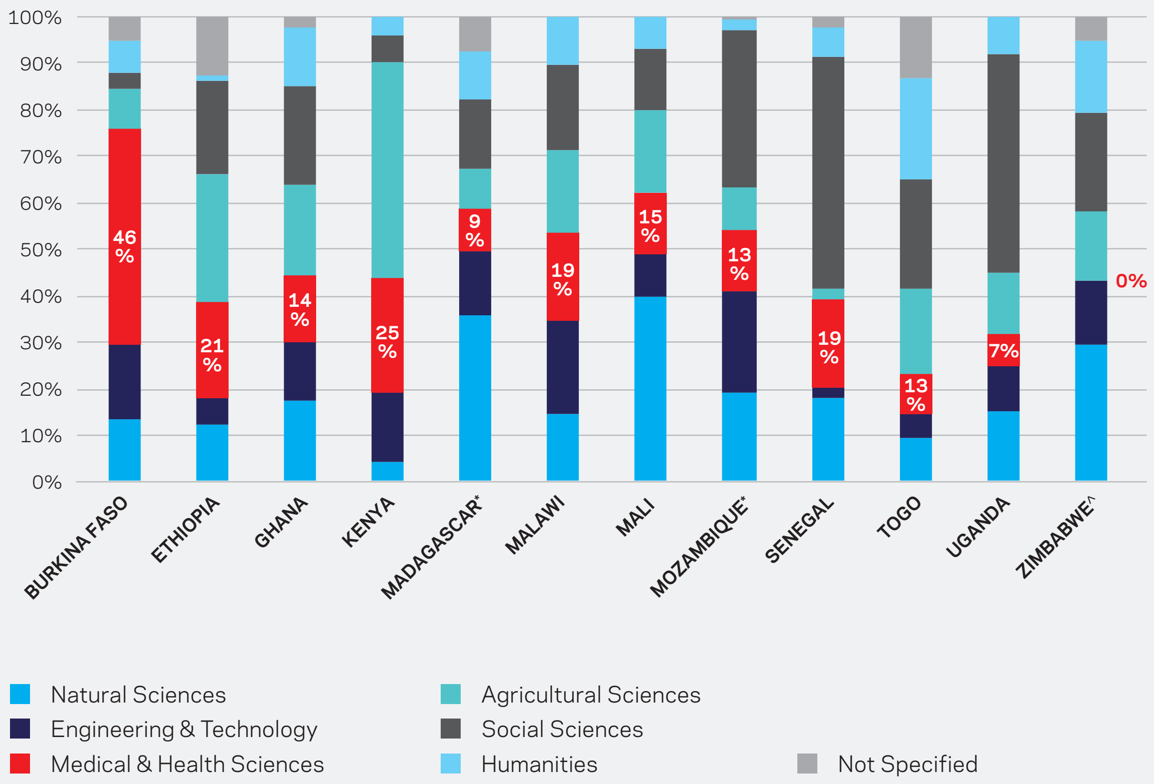


Figure D *— Percentage of researchers in different fields for select SSA countries. Note: Data in this graph are based on FTE from 2010 counts unless otherwise noted (* = data from 2011, ^ data from 2012). Source: UNESCO Institute of Statistics.*

CHAPTER 3
RESEARCH COLLABORATION

This chapter focuses on how various types of collaboration affect citation impact. It examines the levels of extra-regional (i.e. international) and intra-regional collaboration, the corresponding impact of research resulting from such collaborations, and the top institutional collaborators with each region.

3.1 Key Findings

EXTRA-REGIONAL COLLABORATION

42%-79%

In 2012, the dominant share of SSA research is a result of international collaboration (42%, 68%, and 79% of total research for West & Central, East, and Southern Africa, respectively.

INTER-REGIONAL COLLABORATION

0.9%-2.9%

Inter-African collaboration (without any South-African or international collaborator) comprises 2% of all East African research, 0.9% of West & Central Africa, and 2.9% of Southern Africa.

CROSS-SECTOR COLLABORATION

1%-2.4%

Academic-corporate collaborations comprise between 1% and 2.4% of SSA's total research output from 2003-2012.

TOP ACADEMIC COLLABORATOR

Harvard

Harvard University ranked amongst the top 10 academic collaborators for the three SSA regions.

COLLABORATION CITATION IMPACT

3.23-3.82

Extra-regional (i.e., international) collaborations for SSA regions were between 3.23 and 3.82 times as impactful as those respective regions' institutional collaborations.

CROSS-SECTOR COLLABORATION CITATION IMPACT

2.81-6.09

In 2012, West & Central Africa's academic-corporate collaborations received more than six times as many relative citations as the average article. Southern and East Africa's academic-corporate collaborations also achieved high multipliers of 3.71 and 2.81, respectively.

TOP CORPORATE COLLABORATORS

GlaxoSmithKline, Novartis

From 2003-2012, GlaxoSmithKline and Novartis were amongst the top 3 corporate collaborators for the three SSA regions.

3.2 International Collaboration

3.2.1. Methodology

As technological advances facilitate long-distance communication and low-cost travel, researchers are increasingly collaborating with international partners.[27] Moreover, past research suggests that such collaborations are quite productive. Internationally co-authored articles are associated with higher field-weighted citation impact.[28] For this report, publications are classified as single-author (self-explanatory) or into one of three, mutually-exclusive types of geographic collaboration based on the nature of co-authorship:[29] extra-regional (i.e., international), intra-regional, and institutional.

Table 3.1 *— Typology of Different Types of Geographic Collaboration.*

Type of Collaboration	*Definition*
Extra-regional (i.e., international) Collaboration	Multi-authored research outputs with authors affiliated with institutions in at least two different regions (e.g., East Africa and non-Africa, or West & Central Africa and Southern Africa)
Intra-regional Collaboration	Multi-authored research outputs with authors affiliated with more than one institution but both institutions within the same Africa region (e.g., University of Nairobi and National University of Rwanda, both in East Africa region) NB: for country comparators, regional collaboration is synonymous with national collaboration
Institutional Collaboration	Multi-authored research outputs with all authors affiliated with the same institution
Single Author	Single-authored research outputs

[27] Pan, R. K., Kaski, K., & Fortunato, S. (2012). World citation and collaboration networks: uncovering the role of geography in science. Scientific reports, 2, 902. doi: 10.1038/srep00902

[28] Science Europe & Elsevier. (2013). Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility. Retrieved from http://www.scienceeurope.org/uploads/Public documents and speeches/SE and Elsevier Report Final.pdf; The Royal Society. (2011). Knowledge, networks and nations: Global scientific collaboration in the 21st century. (J. Wilson, L. Clarke, N. Day, T. Elliot, H. Harden-Davies, T. McBride, … R. Zaman, Eds.) (p. 113). London: The Royal Society. Retrieved from http://royalsociety.org/policy/projects/knowledge-networks-nations/report/

[29] Melin, G., & Persson, O. (1996). Studying research collaboration using co-authorships. Scientometrics, 36(3), 363–377. doi:10.1007/BF02129600; Glänzel, W., & Schubert, A. (2004). Analyzing Scientific Networks through Co-Authorship. In H. F. Moed (Ed.), Handbook of Quantitative Science and Technology Research (pp. 257-276). Amsterdam: Kluwer Academic Publishers.

3.2.2. **International Collaboration**

"International" collaboration has been an especially popular topic in past studies of Africa's research performance. Since many studies have analyzed this variable at the country instead of the intra-regional level,[30] this report cannot provide a direct, apples-to-apples comparison of research measures. Instead, this report's definition of regional collaboration subsumes both co-authored publications between two institutions in the same country (e.g., University of Nairobi and Moi University in Kenya) as well as co-authored publications between institutions in different countries but the same region (University of Swaziland and Catholic University of Angola, both in the SA region). Likewise, this report's definition of international collaborations refers to collaborations between researchers inside a particular Africa region and researchers outside that region (i.e., extra-regional collaboration). Thus, the terms international and extra-regional collaboration are used interchangeably in this chapter.

Figure 3.1 presents the amount of international collaborations as the relative percentage of a region's total output. The international collaboration rate is quite high especially for Southern Africa and East Africa. Between 2003 and 2012, international collaborations as a percentage of Southern Africa's total article output increased from 60.7% to 79.1%. For Eastern Africa, international collaborations consistently comprised between 65% and 71% of the region's total output.

The figures on the next few pages provide another perspective on the degree to which the Africa regions collaborate with different types of geographic partners. Across all the regions, there is a common trend in the decline of single authorship and to a lesser extent, institutional collaborations.

In addition, with the exception of West & Central Africa, international collaborations as a percentage of total output rose for all the Africa regions. As Figure 3.2 and Figure 3.4 show, international collaboration consistently comprised over 60% of East Africa's and Southern Africa's total research outputs, with no other type of collaboration constituting more than 20% from 2003 to 2012. However, for East Africa, intra-regional collaboration has increased over time from 9.8% of its total output in 2003 to 13.6% in 2012.

As Figure 3.3 shows, international collaborations as a percentage of West & Central Africa's total output actually fell between 2003 to 2010 from 44.1% to 35.1% before rebounding to 42.2% in 2012. Nevertheless, during those years, intra-regional collaboration rose from 14.3% in 2003 to 24.7% in 2012.

Malaysia provides interesting contrasts to the Africa regions. International collaborations as a percentage of Malaysia's total output has actually fallen over time, and institutional collaborations now constitute the largest share of all Malaysian research. In contrast, Vietnam's heavy emphasis on international collaboration mirrors that of East Africa and Southern Africa.

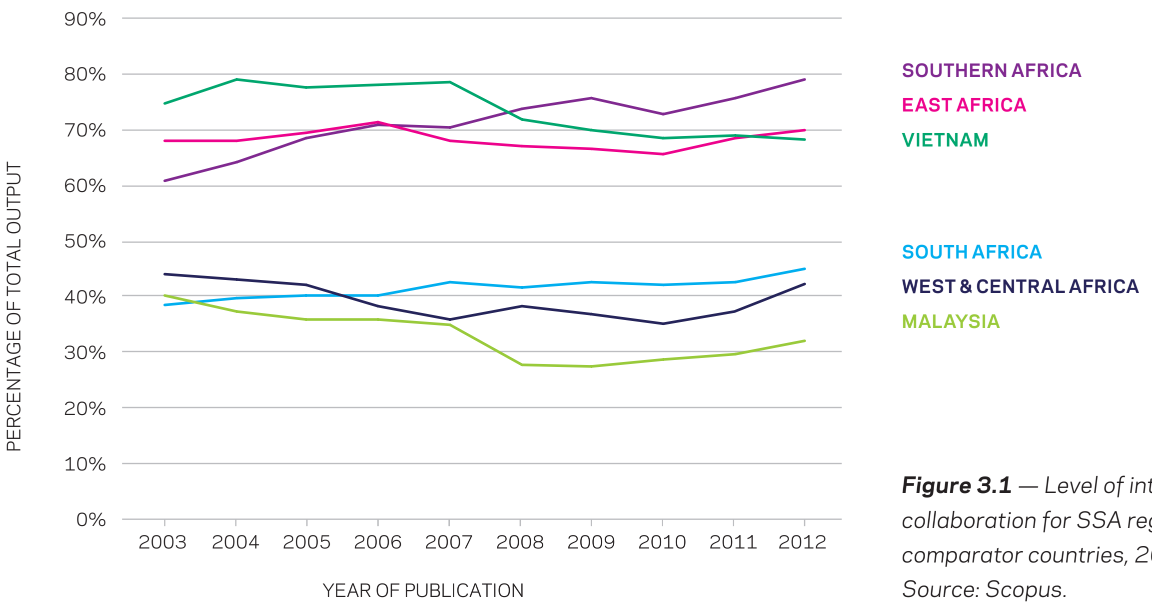


__Figure 3.1__ — Level of international collaboration for SSA regions and comparator countries, 2003-2012. Source: Scopus.

[30] Mêgnigbêto, E. (2012). Scientific publishing in Benin as seen from Scopus. Scientometrics, 94(3), 911–928. doi:10.1007/s11192-012-0843-1; Mêgnigbêto, E. (2013). Scientific publishing in West Africa: comparing Benin with Ghana and Senegal. Scientometrics, 95(3), 1113–1139. doi:10.1007/s11192-012-0948-6

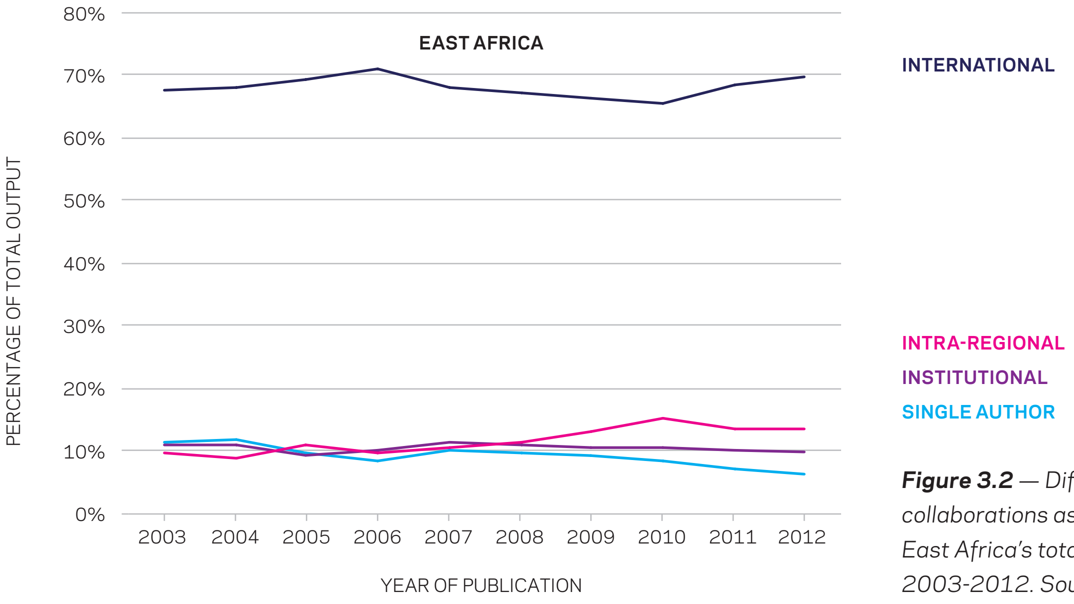


Figure 3.2 *— Different types of collaborations as percentage of East Africa's total output, 2003-2012. Source: Scopus.*

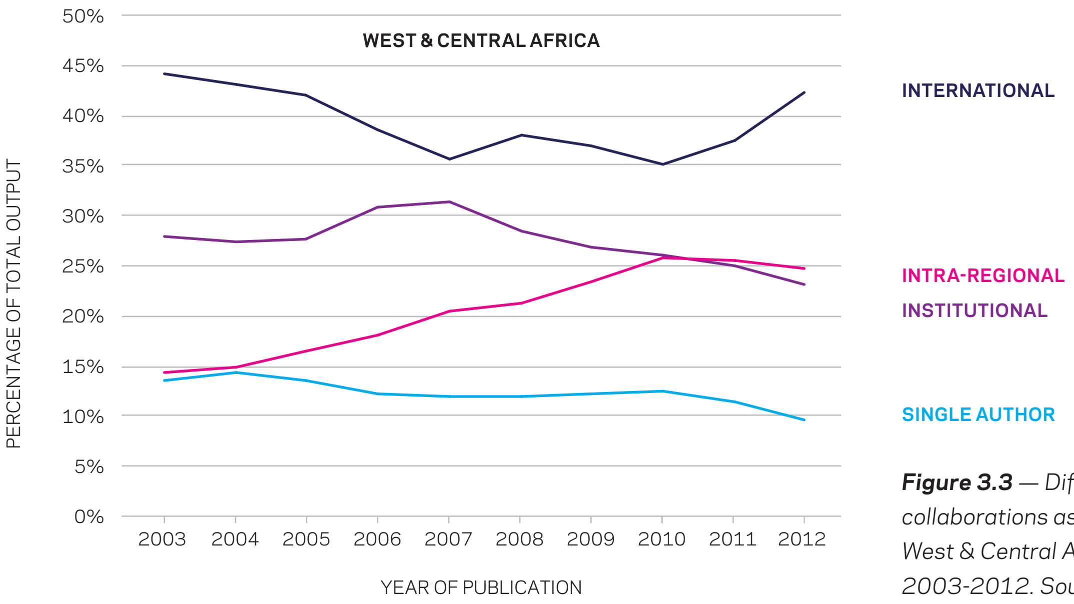


Figure 3.3 *— Different types of collaborations as percentage of West & Central Africa's total output, 2003-2012. Source: Scopus.*

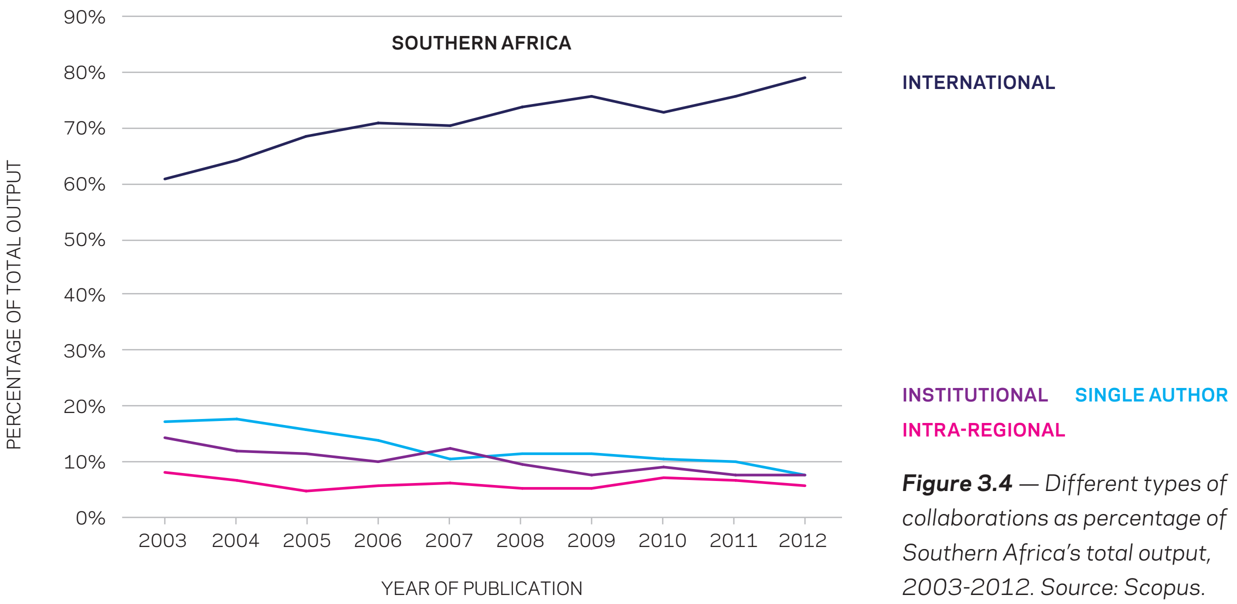


Figure 3.4 *— Different types of collaborations as percentage of Southern Africa's total output, 2003-2012. Source: Scopus.*

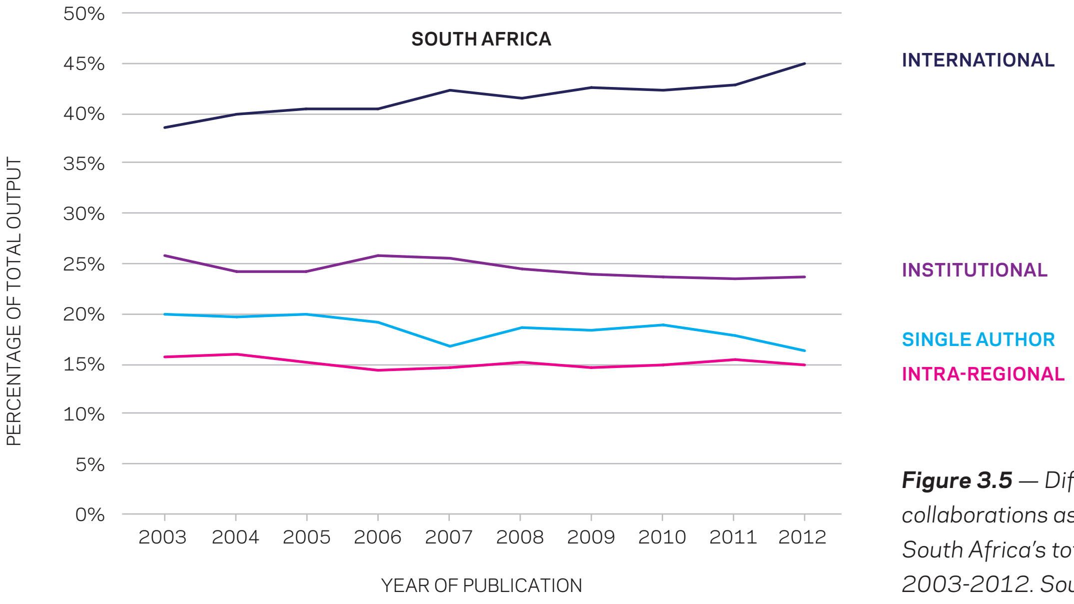


Figure 3.5 *— Different types of collaborations as percentage of South Africa's total output, 2003-2012. Source: Scopus.*

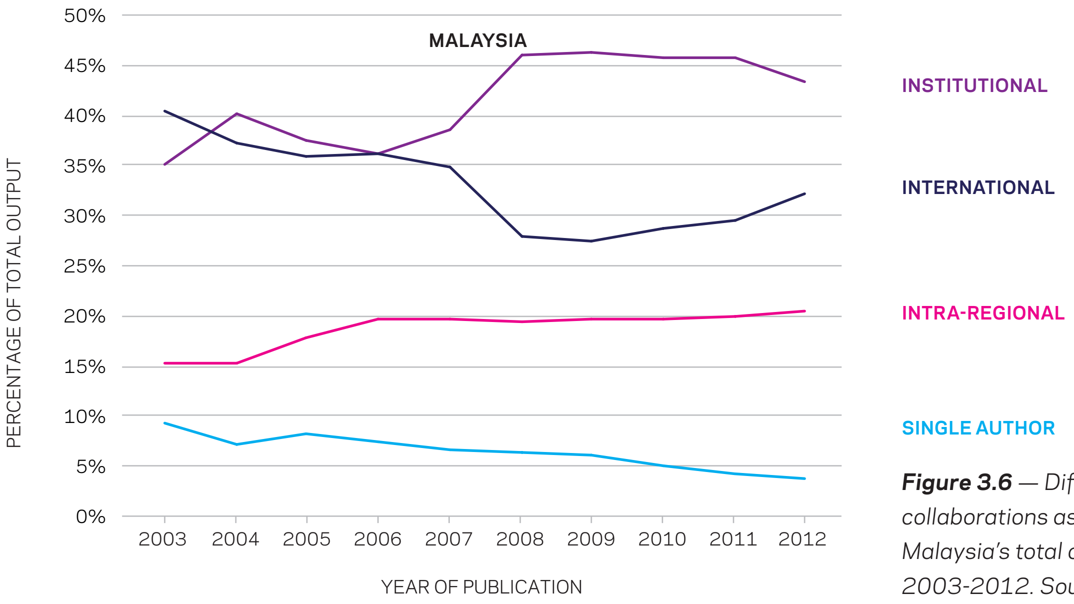


Figure 3.6 *— Different types of collaborations as percentage of Malaysia's total output, 2003-2012. Source: Scopus.*

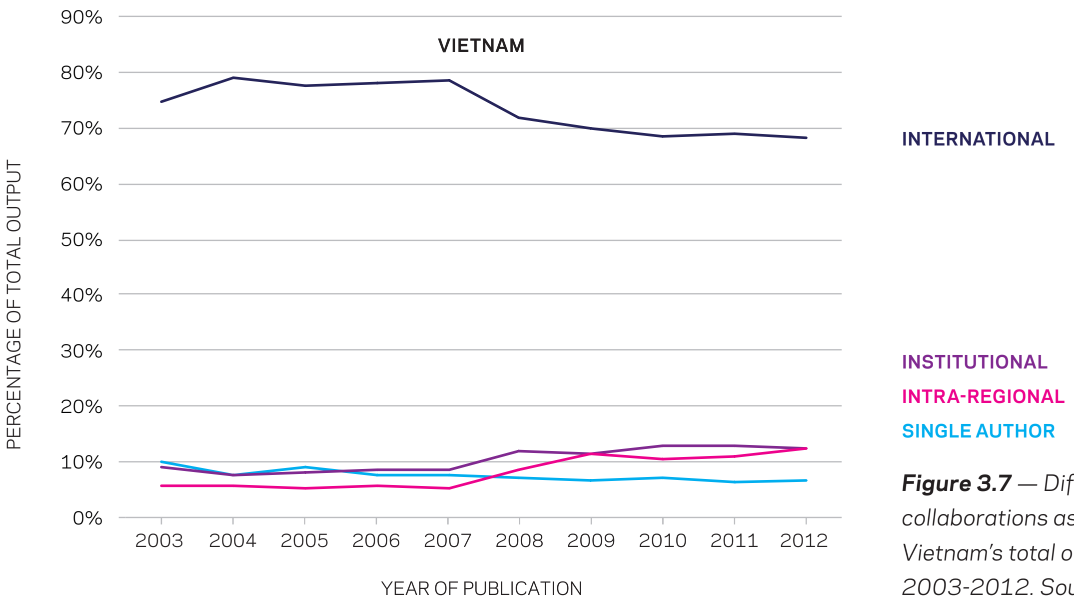


Figure 3.7 *— Different types of collaborations as percentage of Vietnam's total output, 2003-2012. Source: Scopus.*

3.2.3. **Inter-Regional Collaboration**

In addition to "international" collaboration, researchers and policymakers are particularly interested in better understanding the degree to which the different Africa regions collaborate with one another. Are there indications of the rise of a sub-Saharan research network independent from ties to European and American foci? Past studies have found low rates of both intra-regional and inter-regional collaboration.[31] For example, Boshoff's 2009 study of the Southern African Development Community (SADC) found that only 5% of all SADC papers from 2005-2008 were co-authored between a researcher in the SADC and another African researcher.[32] From their network analysis of Africa's research output that similarly demarcated the continent into three large regions (Southern-Eastern, West, and Northern), Toivanen and Ponomariov similarly found low levels of inter-regional collaboration. They argue, "So great is the heterogeneity between these three regions and so weak are the inter-regional linkages, that it raises the broader question of optimal organization of African research. Considering that African research effort and capacity are increasing rapidly, Africa as a whole stands the risk to miss synergies inherent in well integrated innovation systems and which are foundational for knowledge economy."[33]

To calculate the number of collaborations between East Africa and West & Central Africa, for example, this report counted all publications in which at least one author holds an affiliation to an East African institution and another author holds an affiliation to a West & Central African institution. Thus, the counts of inter-regional collaborations are subsets of the counts of international (i.e., extra-regional) collaborations from the previous section. Figure 3.8 displays the trends of inter-regional collaboration for East Africa vis-à-vis the other regions. The first and top three trend lines correspond to all collaborations between East Africa and West & Central Africa, Southern Africa, and South Africa respectively. The bottom three trend lines correspond specifically to collaborations in which no co-authors were affiliated with institutions in OECD countries.[34] This provides a measure of un-brokered collaborations between co-authors at institutions in two or more different Africa regions.[35]

Relative to East Africa's overall rates of international collaboration (which comprise over 60% of East Africa's total output), its level of inter-regional collaboration with other SSA regions is low, at about 2%. Yet, East Africa's collaborations with South Africa have increased considerably over time, from 3.9% in 2003 to 7.9% in 2012. This growth has been driven mostly through collaborations involving partners at institutions in developed countries. The annual growth rate of East Africa-South Africa collaborations without an OECD partner has only been 3.3%, compared to 8.2% with an OECD partner.

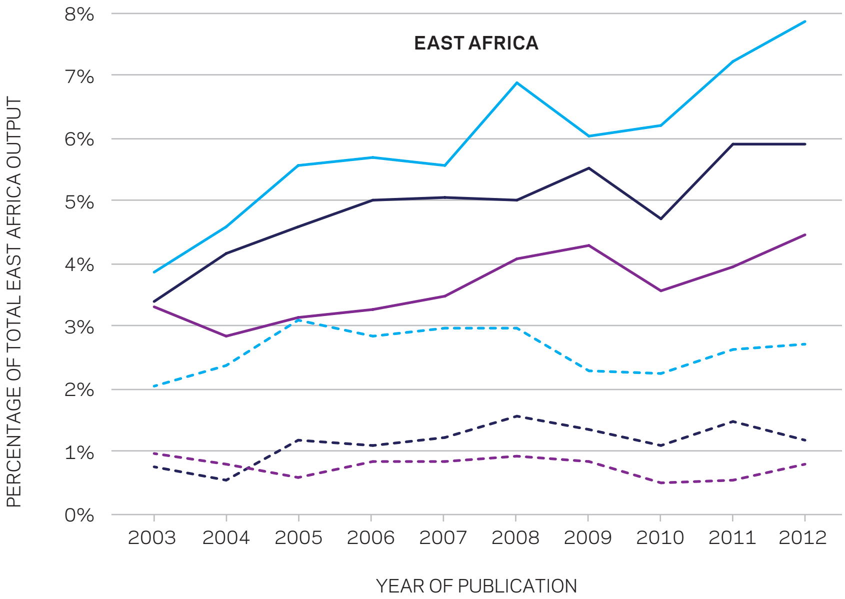
[31] Adams, J., Gurney, K., Hook, D., & Leydesdorff, L. (2013). International collaboration clusters in Africa. Scientometrics, 98(1), 547–556. doi:10.1007/s11192-013-1060-2; Onyancha, O. B., & Maluleka, J. R. (2011). Knowledge production through collaborative research in sub-Saharan Africa: how much do countries contribute to each other's knowledge output and citation impact? Scientometrics, 87(2), 315–336. doi:10.1007/s11192-010-0330-5

[32] Boshoff, N. (2009). South–South research collaboration of countries in the Southern African Development Community (SADC). Scientometrics, 84(2), 481–503. doi:10.1007/s11192-009-0120-0

[33] Toivanen, H., & Ponomariov, B. (2011). African regional innovation systems: bibliometric analysis of research collaboration patterns 2005–2009. Scientometrics, 88(2), 471–493. doi:10.1007/s11192-011-0390-1

[34] OECD member countries include: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom, and the United States.

[35] These counts may still reflect collaborations amongst two Africa regions and non-OECD countries, so they are not necessarily pure, un-brokered research collaborations.



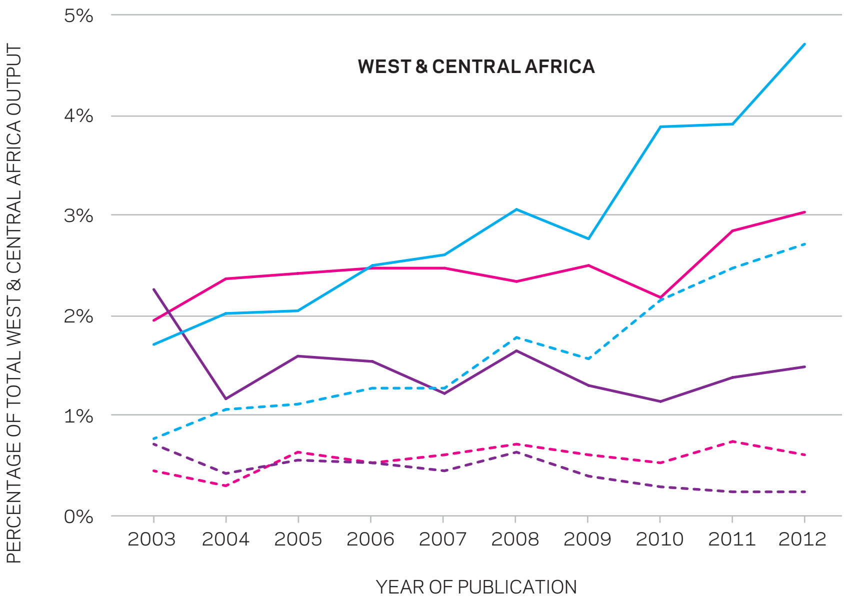
with SOUTH AFRICA

with WEST & CENTRAL AFRICA

with SOUTHERN AFRICA

with SOUTH AFRICA
with WEST & CENTRAL AFRICA
with SOUTHERN AFRICA

Figure 3.8 *— Different types of inter-regional collaborations as percentage of East Africa's total output, 2003-2012. Dashed lines refer to rates of inter-regional collaboration excluding additional OECD partners. Source: Scopus.*

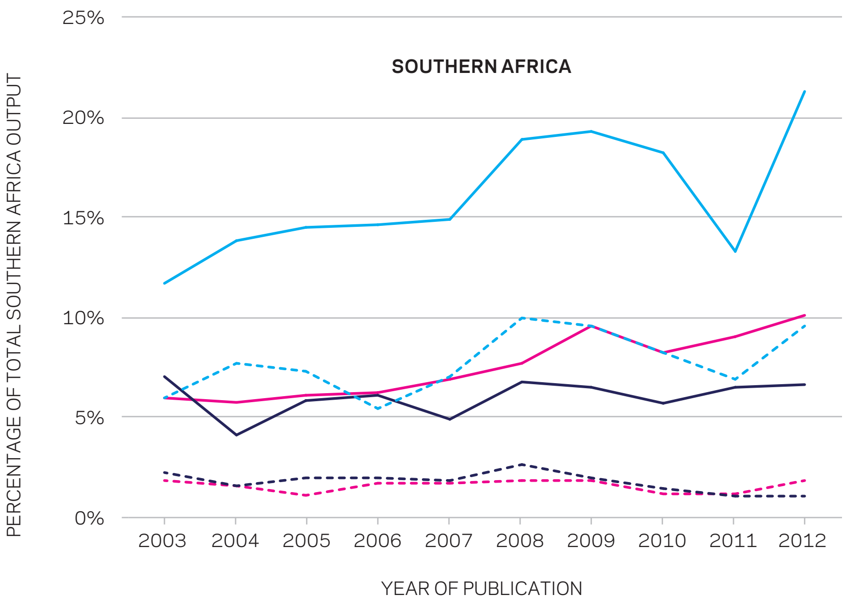


with SOUTH AFRICA

with EAST AFRICA
with SOUTH AFRICA

with SOUTHERN AFRICA
with EAST AFRICA
with SOUTHERN AFRICA

Figure 3.9 *— Different types of inter-regional collaborations as percentage of West & Central Africa's total output, 2003-2012. Dashed lines refer to rates of inter-regional collaboration excluding additional OECD partners. Source: Scopus.*



with SOUTH AFRICA

with EAST AFRICA
with SOUTH AFRICA
with WEST & CENTRAL AFRICA
with EAST AFRICA
with WEST & CENTRAL AFRICA

Figure 3.10 *— Different types of inter-regional collaborations as percentage of Southern Africa's total output, 2003-2012. Dashed lines refer to rates of inter-regional collaboration excluding additional OECD partners. Source: Scopus. Source: Scopus.*

3.3 Citation Impact of Collaboration

Previous studies suggest there exists a strong positive correlation between international collaboration and citation impact.[36] Table 3.2 shows adjusted FWCI with different types of collaboration normalized against the FWCI of institutional collaborations. For all SSA regions, the FWCI associated with international collaborations is at least 3.23 times higher than that attained by institutional collaborations. Moreover, while comparator countries Malaysia and Vietnam also have multipliers above 1, they are much lower than those values for the SSA regions.

Corroborating the results of past studies,[37] the citation impacts of intra-regional collaborations were higher than that of single-institution collaborations in East and Southern Africa. However, in contrast to past research, which suggest that single-authored publications achieve lower levels of impact than all types of collaboration,[38] in all three SSA regions, single-authored publications were actually more impactful than collaborations between researchers at the same institution.

How, if at all, have the citation impacts of the regions' international collaborations changed over time? As Figure 3.11 shows, the FWCI of Southern Africa's international collaborations increased from 1.16 in 2003 to 1.66 in 2012, reflecting a 4% CAGR. Since international collaborations comprised no less than 60% of Southern Africa's total output over this period, the rise in the impact of its overall research output can be primarily traced to the increases in the impact of its international collaborations.[39]

Paralleling the growth in the impacts of the Africa regions' collaborative outputs, Malaysia also saw the impact of its international collaborations grow from 0.89 (below world average) to 1.14 (above the world average). However, Vietnam saw little change over time in the FWCI of its international collaborations.

Table 3.2 *— Adjusted FWCI associated with different types of collaboration (e.g., FWCI for single-authored, intra-regional, and international collaboration normalized against FWCI of institutional collaboration) for SSA regions and comparator countries, 2012. Source: Scopus.*

	Single Author	*Institutional*	*Intra-regional*	*International*
East Africa	1.08	1.00	1.03	3.23
Southern Africa	1.07	1.00	1.24	3.82
West & Central Africa	1.13	1.00	0.92	3.64
South Africa	0.95	1.00	1.12	2.67
Malaysia	0.62	1.00	0.93	1.34
Vietnam	1.18	1.00	1.02	1.92

[36] Adams, J. (2013). Collaborations: The fourth age of research. Nature, 497(7451), 557–60. doi:10.1038/497557a; Franceschet, M., & Costantini, A. (2010). The effect of scholar collaboration on impact and quality of academic papers. Journal of Informetrics, 4(4), 540–553. doi:10.1016/j.joi.2010.06.003; Guerrero Bote, V. P., Olmeda-Gómez, C., & de Moya-Anegón, F. (2013). Quantifying the benefits of international scientific collaboration. Journal of the American Society for Information Science and Technology, 64(2), 392–404. doi:10.1002/asi.22754; The Royal Society, & Society, T. R. (2011). Knowledge, networks and nations: Global scientific collaboration in the 21st century (p. 113). Retrieved from http://royalsociety.org/uploadedFiles/Royal_Society_Content/policy/publications/2011/4294976134.pdf; Sooryamoorthy, R. (2009). Do types of collaboration change citation? Collaboration and citation patterns of South African science publications. Scientometrics, 81(1), 177–193. doi:10.1007/s11192-009-2126-z

[37] Apolloni, A., Rouquier, J.-B., & Jensen, P. (2013). Collaboration range: Effects of geographical proximity on article impact. The European Physical Journal Special Topics, 222(6), 1467–1478. doi:10.1140/epjst/e2013-01937-5

[38] Gazni, A., & Didegah, F. (2011). Investigating different types of research collaboration and citation impact: a case study of Harvard University's publications. Scientometrics, 87(2), 251–265. doi:10.1007/s11192-011-0343-8; Hsu, J., & Huang, D. (2010). Correlation between impact and collaboration. Scientometrics, 86(2), 317–324. doi:10.1007/s11192-010-0265-x

[39] To confirm this hypothesis, this report further analyzed the impact trends associated with Southern Africa's single author, institutional, and intra-regional collaborations. In 2012, such collaborations (or lack thereof) was relatively low and stable with FWCI from 0.45 to 0.54 and CAGRs from -1.0% to 0.9%.

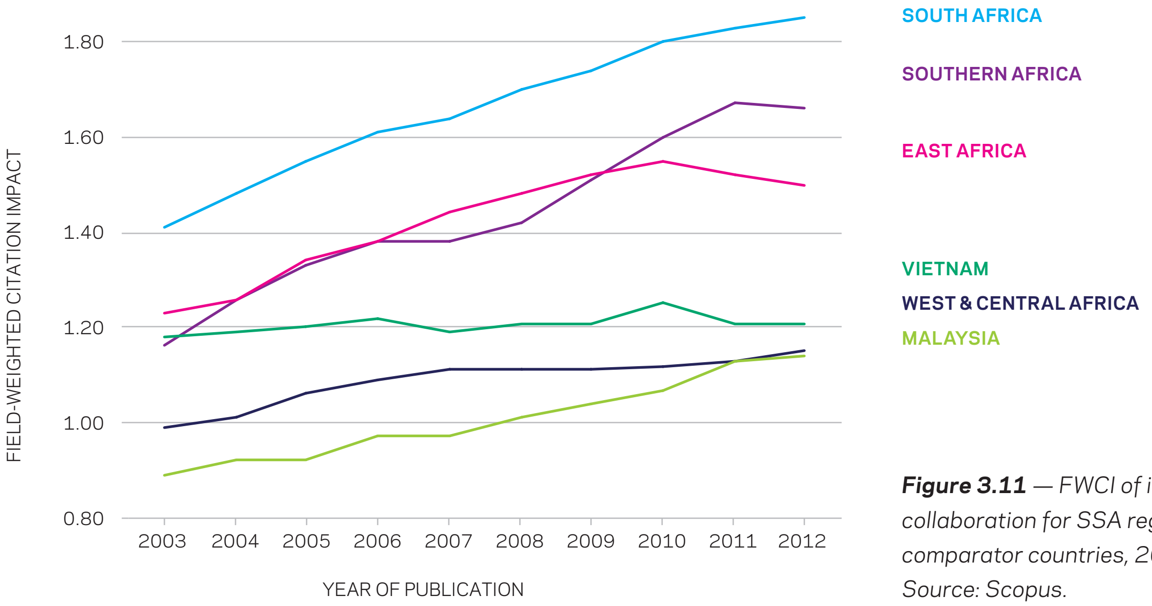


***Figure 3.11** — FWCI of international collaboration for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

3.4 Cross-sector collaboration

Cross-sector collaboration potentially provides another lens into understanding the improvement of Africa regions' research citation impact over the past decade. Much recent research focuses on the benefits of and complementarity between academic and commercially oriented research.[40] Measuring co-authored publications across sectors is one proxy for cross-sector collaboration. For this report, the affiliation of every (co-)author in an article has been assigned to one of four sectors: academic, corporate, government, or medical.[41] When an article is co-authored by authors with affiliations in different sectors, that article is added to the count of cross-sector collaboration between those sectors. This section investigates the rates at which authors collaborate across sectors within the different regions.[42]

Table 3.3 presents the amount of cross-sector collaboration as the relative percentage of each region's total output between 2003 and 2012. Across all the SSA regions, academic-government collaborations comprised the highest level of all types of cross-sector collaborations. For example, 17.4% of Southern Africa's total output over the past decade belonged to this category, a growth from 13.7% in 2003 to 19.6% in 2012 or a 4.1% annual increase. Academic-government collaborations constituted a similarly large minority of Vietnam's total output (14%) over the same period, but they made up only a small portion (3.3%) of Malaysia's total output.

Academic-corporate collaborations account for only a small percentage of each region's total output, but it has grown over time. For instance, Southern Africa published only 16 articles co-authored between an academic and a corporate institution in 2003 but 74 in 2012. Such collaborations are particularly interesting for two reasons. First, they are a signal of and proxy for deeper connections between the two sectors, which suggests a greater transfer of knowledge. Second, the academic-corporate collaborations act as a harbinger of future, alternative funding channels.

[40] Larsen, Maria Theresa (2011). The implications of academic enterprise for public science: An overview of the empirical evidence. Research Policy 40(1): pp. 6-19. doi: 10.1016/j.respol.2010.09.013

[41] The overwhelming majority of corporate research is conducted by mostly large, multinational corporations with significant R&D workforces, such as Microsoft, Merck, Boeing, General Electric, and so forth. We acknowledge that our current measures of research output and performance do not provide a good proxy for the level of collaboration and exchange between smaller African companies and their university counterparts. Please see Appendix B: Glossary on Sectors for more details on how institutions are specifically assigned to these sectors.

[42] These cross-sector counts do not distinguish between whether both institutions are located in a particular AR or, if only one of the co-authors is from the AR, to which sector that author's institution belongs. In practice, the great majority of AR institutions that engage in cross-sector collaborations are academic institutions.

For each region, Table 3.4 displays the citation impact associated with different types of cross-sector collaborations relative to the impact of all articles produced by that region in 2012. For example, the 112 articles from West & Central Africa in 2012 that were academic-corporate collaborations received more than six times as many citations on average as articles from the region overall. More importantly, academic-government collaborations received two or more times as many relative citations on average as articles from the regions overall.

The impact associated with different types of cross-sector collaborations has grown significantly over the past decade. Figure 3.12 is most relevant for understanding the influence of academic-government collaborations on the citation impact of the Africa regions' total output since academic-government collaborations comprise such a sizeable minority of those regions' output. For example, between 2003 and 2012, the impact of such collaborations for Southern Africa grew at nearly 6% per year, from 1.66 in 2003 to 2.80 in 2012.

Table 3.3 *— Cross-sector collaboration as percentage of total publications for SSA regions and comparator institutions, 2003-2012. Source: Scopus*

	Academic – Corporate	*Academic – Government*	*Academic – Medical*
East Africa	2.4%	17.2%	6.0%
Southern Africa	2.4%	17.4%	7.5%
West & Central Africa	1.0%	10.5%	4.2%
South Africa	2.8%	12.6%	3.0%
Malaysia	1.3%	3.3%	1.7%
Vietnam	2.1%	14.0%	3.8%

Table 3.4 *— Adjusted FWCI of different types of cross-sector collaboration (e.g., FWCI for cross-sector collaboration normalized against FWCI of all articles) for SSA regions and comparator countries, 2012. Source: Scopus.*[43]

	Overall	*Academic – Corporate*	*Academic – Government*	*Academic – Medical*
East Africa	1.00	2.81	2.00	2.69
Southern Africa	1.00	3.71	2.01	2.43
West & Central Africa	1.00	6.09	2.67	2.48
South Africa	1.00	2.88	2.07	3.71
Malaysia	1.00	1.90	1.64	2.03
Vietnam	1.00	3.32	1.95	2.76

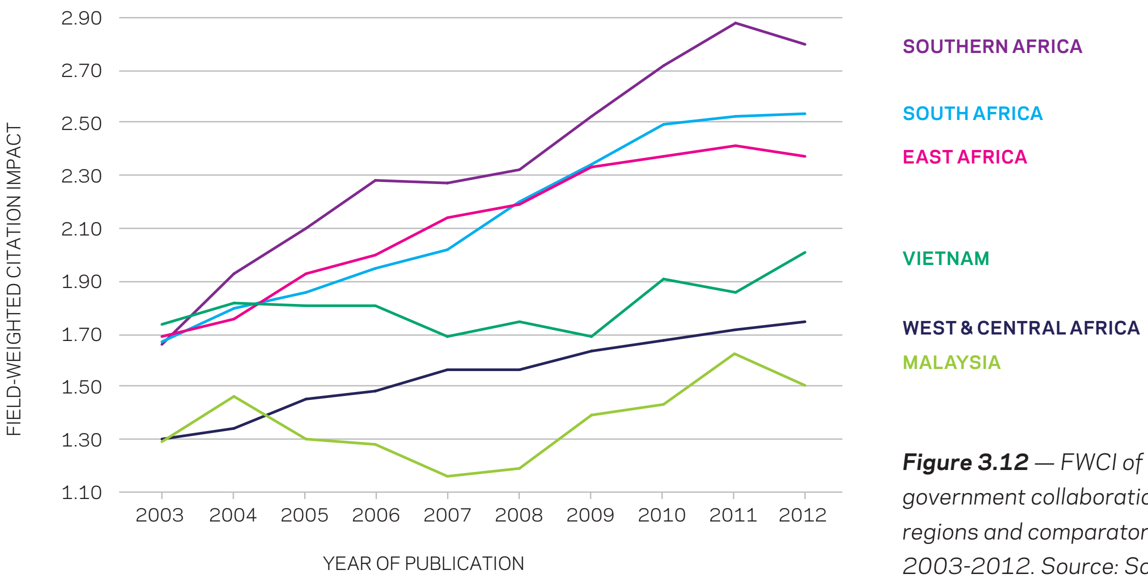


Figure 3.12 *— FWCI of academic-government collaboration for SSA regions and comparator countries, 2003-2012. Source: Scopus.*

[43] NB: There were at least 50 articles published in 2012 for each category of cross-sector collaboration in every country. This ensures that there were enough observations to draw meaningful conclusions.

3.5 Top collaborating institutions

To further investigate the trends in international and cross-sector collaboration, this section analyzes those institutions with which the different Africa regions collaborate the most and the frequency and impact of those collaborations. Jones et al.'s research (2008) suggests that the returns to collaboration in terms of citation impact depend not just on whether one collaborates but with whom one collaborates. The returns are predictably stratified by the rank or prestige of the collaborating institution.[44]

Past studies of Africa's research output from the 1990s suggest that the institutions with whom African institutions collaborate the most are from the US and Europe.[45] Moreover, the exact list of top countries with which African institutions collaborate depends on those institutions' colonial ties – for example, South Africa and other former British colonies tended to collaborate more with the UK,[46] while Francophone countries collaborated more with France, and so forth.

Figure 3.13 presents a global overview of those institutions with whom the different regions collaborate with the most, with Figure 3.14 and Figure 3.15 providing insets of the United States and Europe. The colors of the circles correspond to the specific SSA regions with whom those institutions collaborate highly, and the size denotes the number of publications that that institution has co-authored with institutions from that respective region from 2008-2012. Certain institutions appear on the list of top collaborators for multiple regions and are represented by concentric circles of the respective regional colors. Notably, Harvard University and the London School of Hygiene and Tropical Medicine rank amongst the top ten academic collaborators for all three Africa regions, while the University of Copenhagen, the University of Liverpool, and the University of Oxford are amongst the top ten academic collaborators for two of the three.

Further corroborating past studies, the top collaborating institutions for South Africa tend to be based in the UK. Given the French colonial history associated with many West & Central African countries, it is unsurprising that four of its top ten overall collaborators are French organizations (CIRAD, Institut Pasteur, and IRD).

[44] Jones, B. F., Wuchty, S., & Uzzi, B. (2008). Multi-University Research Teams: Shifting Impact, Geography, and Stratification in Science. Science, 322(5905), 1259–1262. doi:DOI 10.1126/science.1158357

[45] Narváez-Berthelemot, N., Russell, J. M., Arvanitis, R., Waast, R., & Gaillard, J. (2002). Science in Africa: An overview of mainstream scientific output. Scientometrics. doi:10.1023/A:1016033528117

[46] Sooryamoorthy, R. (2009). Collaboration and publication: How collaborative are scientists in South Africa? Scientometrics, 80(2), 419–439. doi:10.1007/s11192-008-2074-z

WORLD MAP OF SSA REGIONS' TOP COLLABORATING INSTITUTIONS

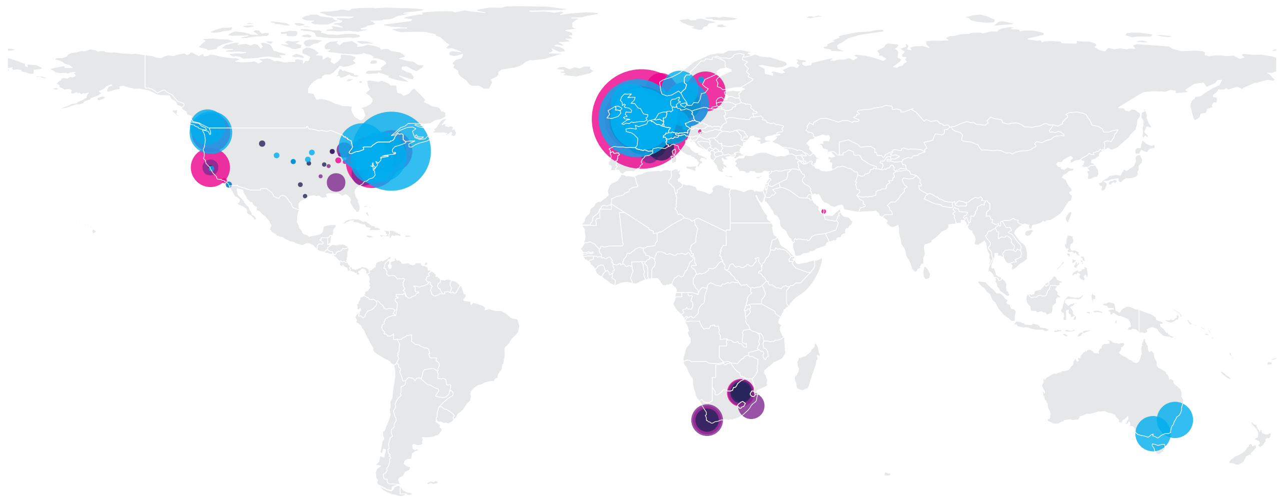


Figure 3.13 *— World map depicting top institutions collaborating with different SSA regions and South Africa, 2003-2012. Source: Scopus. Plotted using R/ggplot & rgdal, and free vector and raster map data @ naturalearthdata.com.*

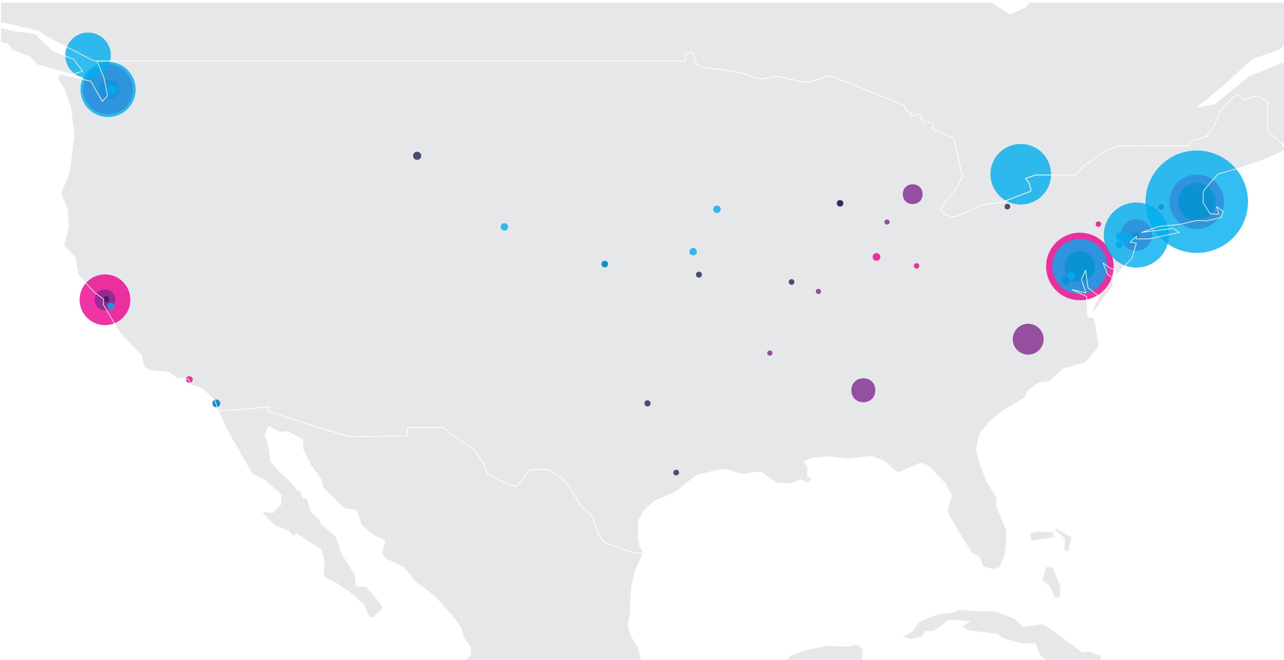


Figure 3.14 *— Inset of world map, focusing on the United States, depicting top institutions collaborating with different SSA regions and South Africa, 2003-2012. Source: Scopus. Plotted using R/ggplot & rgdal, and free vector and raster map data @ naturalearthdata.com.*

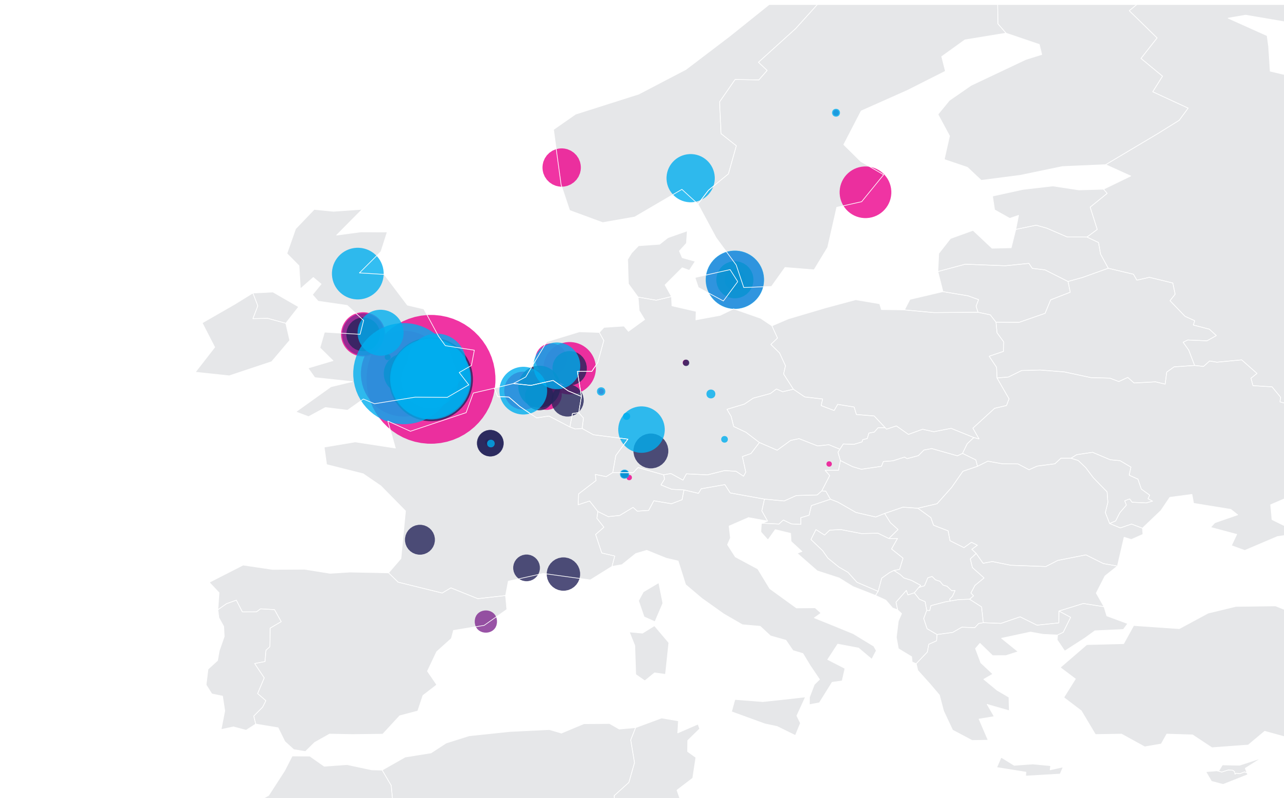


Figure 3.15 *— Inset of world map, focusing on Europe, depicting top institutions collaborating with different SSA regions and South Africa, 2003-2012. Source: Scopus. Plotted using R/ggplot & rgdal, and free vector and raster map data @ naturalearthdata.com.*

Region
- West & Central Africa
- East Africa
- Southern Africa
- South Africa

Co-publications

250 500 750 1000 1250

Past research on Africa's international research collaborations has been especially sensitive about the asymmetry of North-South partnerships. Collaborations between African institutions and those in more developed countries tend to rely on the funding of and hence be driven by the needs and research interests of the latter. The distribution of work as well as credit tends to be unequal. Moreover, rather than a mutually beneficial partnership, scholars suggest that collaboration partners in Africa receive a boost in their citation impact, while those in more developed countries experience a relative decline.[47]

For the top 10 collaborators (from any sector) for each region, Figure 3.16 graphs the relative FWCI associated with articles co-authored between that institution and an Africa region, relative to the FWCI of all internationally co-authored articles from those institutions (on the vertical axis) or from that particular region (on the horizontal axis). As with the previous figures, bubble size denotes the number of collaborations between that institution and a particular Africa region. The FWCI of co-authored articles between the regions and the great majority of their top collaborators are above the relative baselines (y=1, x=1), indicating that those collaborations were beneficial to both parties.

However, the relative impact of these top collaborations varies by region. In particular, all of South Africa's and most of Southern Africa's top collaborating institutions can be found in the top-right quadrant. About half of East Africa's top collaborating institutions are above the relative baseline, while most of West & Central Africa's top collaborating institutions are located below of the relative baseline. Thus, in contrast to previous research, these results show that institutions in more developed countries do benefit from collaborations with institutions in Africa regions, though this varies across the different regions.

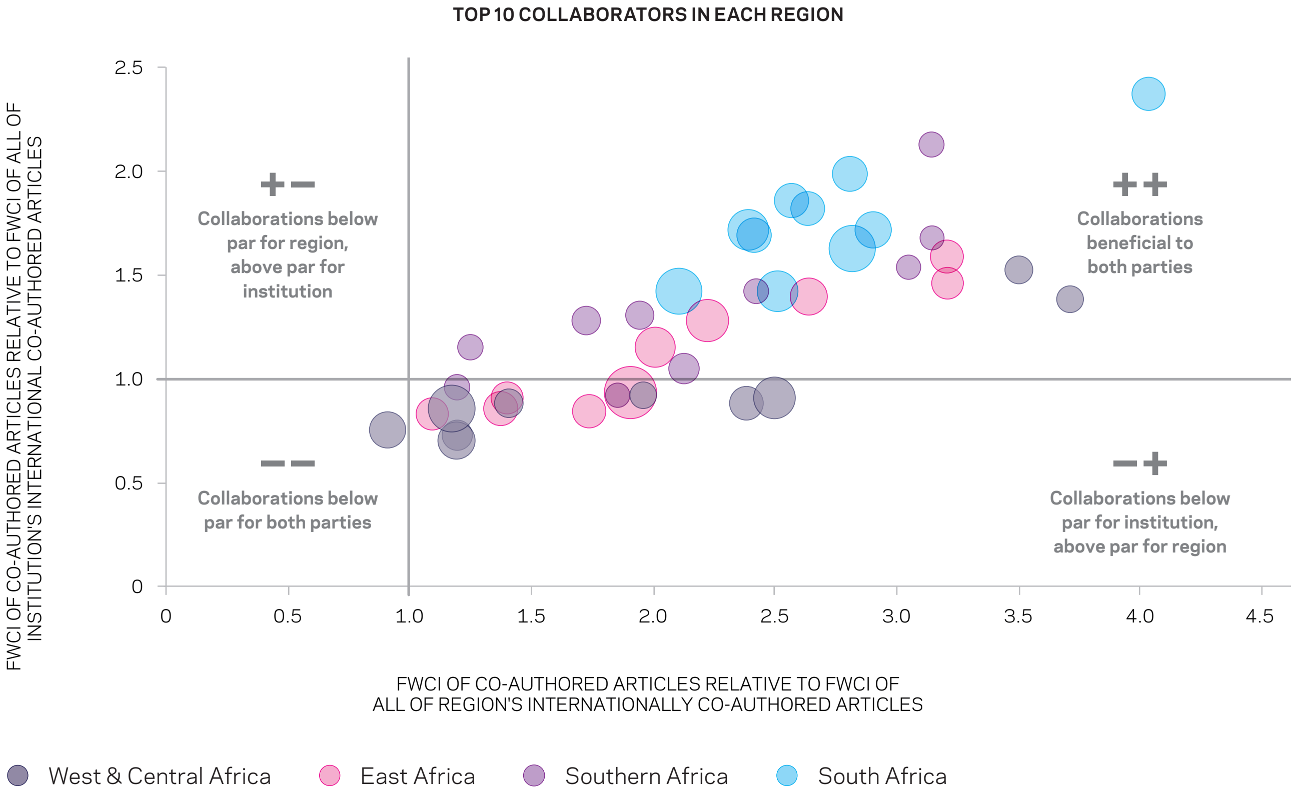


***Figure 3.16** — Top 10 collaborators with each SSA region and South Africa in terms of total co-authored publications, 2003-2012. Size of circle indicates the volume of co-authored publications between the collaborating institutions. Source: Scopus.*

[47] Boshoff, N. (2009). Neo-colonialism and research collaboration in Central Africa. Scientometrics, 81(2), 413–434. doi:10.1007/s11192-008-2211-8; Gaillard, J. F. (1994). North-South research partnership: Is collaboration possible between unequal partners? Knowledge and Policy, 7(2), 31–63. doi:10.1007/BF02692761; Jentsch, B., & Pilley, C. (2003). Research relationships between the South and the North: Cinderella and the ugly sisters? Social Science & Medicine, 57(10), 1957–1967. doi:10.1016/S0277-9536(03)00060-1

3.5.1. **Top Collaborators in Southern Africa**

Figure 3.17 provides a more granular view of Southern Africa's top ten collaborators. Given the skew of the region's output and impact in the Health Sciences, nearly all of its top collaborators are institutions that specialize in medicine and health-related research. This skew towards high levels of (and impacts associated with) collaboration in the Health Sciences is also found in the lists of top institutions for the other Africa regions, including South Africa.

Further reinforcing the dominance of Health Sciences in the regions' collaborations, past research has found that in terms of absolute publication output, public-private research collaborations are most common in the fields of medicine.[48] Unsurprisingly, the two companies that appeared in all three SSA regions' lists of top 10 corporate collaborations were GlaxoSmithKline and Novartis. Moreover, other pharmaceutical companies comprise the majority of each region's top corporate collaborator lists.

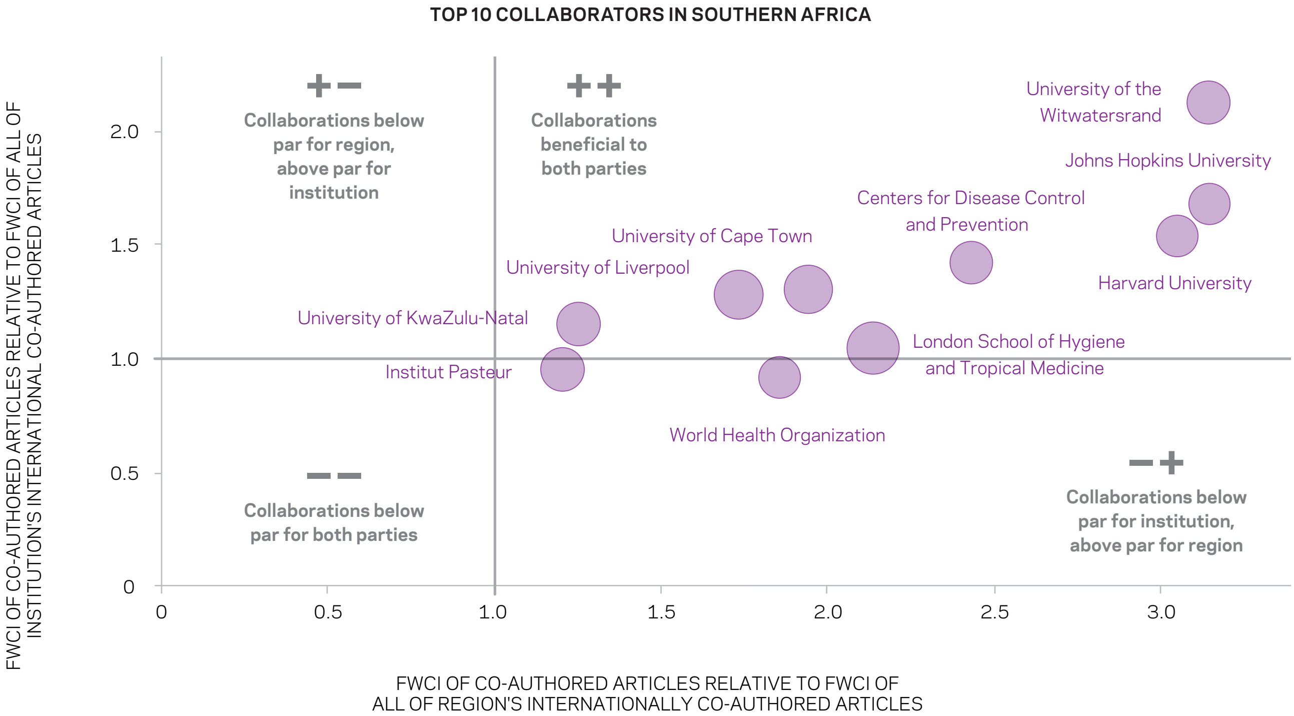


Figure 3.17 *— Top 10 Collaborators with Southern Africa in terms of total co-authored publications, 2003-2012. Source: Scopus.*

[48] Abramo, G., D'Angelo, C. A., Costa, F. Di, & Solazzi, M. (2009). University–industry collaboration in Italy: A bibliometric examination. Technovation, 29(6-7), 498–507. doi:10.1016/j.technovation.2008.11.003

3.6 Interpretation of Key Findings on Research Collaboration

The following section summarizes the findings on research collaborations in sub-Saharan Africa and suggests interpretations and background factors for the key findings.

1. A very large share of SSA research is a result of international collaboration. In 2012, 79%, 70% and 45% of all research by Southern Africa, East Africa, and West & Central Africa, respectively, were through international collaborations. In contrast, 68%, 45%, and 32% of Vietnam, South Africa, and Malaysia's research output, respectively, were international collaborations.

2. International collaboration is highly instrumental in raising the citation impact of SSA publications. Such collaborations were between 3.23 and 3.82 times as impactful as those respective regions' institutional collaborations. In contrast, the multiplying factors for South Africa, Malaysia, and Vietnam were 2.7, 1.3, and 1.9, respectively.

Although international collaboration is the major driver of African research, raising the citation impact of research in Africa, Africa today still lacks sufficient capacity and critical mass to produce international quality research on its own, in particular within STEM.

While the success of SSA's diaspora demonstrates that talent abounds on the continent, that scientific talent may be insufficiently nurtured due to shortcomings in the quality of science and math basic education, the availability of high quality post-graduate training, research infrastructure, faculty time, research funding, and incentives to pursue an academic career. In most public research institutes, the governments only cover operational costs and salaries, and the research itself is financed through collaborations. In addition, research funding often comes through international collaboration (often salaries are covered, but not operational, travel, and equipment costs). As a result, research would, independent of student training capacity, tend to be associated with international collaboration.

3. There appears to be little knowledge transfer and collaboration between African academics and the corporate sector, as measured by corporate downloads of and patent citations to African academic research, especially for STEM disciplines. To the extent such knowledge transfer occurs, it occurs within Health Sciences and through collaborations with global pharmaceutical companies. Such trends suggest that corporations do not rely much on African-generated knowledge and research for their competitiveness.

4. SSA's research capacity appears fragmented across regions, with each the regions collaborating very little with one another. Inter-African collaboration (without any South-African or international collaborator) comprises 2% of all of East Africa's research, 0.9% of West & Central Africa's, and 2.9% of Southern Africa's.

5. West & Central Africa displays somewhat different patterns of collaboration than East and Southern Africa. International collaboration comprises a smaller share (42%) of West & Central Africa's total research output, and there is less research collaboration between academia and other partners (corporate, government, and medical).

CHAPTER 4
RESEARCHER MOBILITY

This chapter examines the geographic mobility of different types of African researchers as they move to and from the larger African diaspora.

4.1 **Key Findings**

"Africa has reached a stage of development where it has become a destination for doing world-class science - a place that has individuals, facilities and institutions that attract scientists from around the world to work on the continent. ... As an example, the SKA project has resulted in a net brain gain to the region, with leading astronomers, ranging from post-doc[toral]s to research professors, choosing to work in Africa."

Professor Justin Jonas

Associate Director of South Africa's Square Kilometre Array (SKA) and Professor of Physics and Electronics at Rhodes University

Source:
http://www.bbc.com/news/science-environment-21851042

HIGHLY MOBILE RESEARCHER BASE

85.3%

85.3% of Southern Africa's researcher base has published an article while outside of Southern Africa.

VISITING SCHOLARS

57%-65%

Transitory researchers – those who spend less than 2 years in or outside the region – comprise 57% and 65% of East Africa's and Southern Africa's total researcher base.

HIGH IMPACT RESEARCHERS

Returnee Inflow

Returning diaspora contribute significantly to raising the citation impact of SSA research, specifically in East and Southern Africa. While they make up a relatively small share of the region's total researcher base (3.6% and 2.1%, respectively), the relative citation impact of those returnees' publication is quite high compared to that of other SSA researchers.

4.2 Researcher Mobility Model

Brain circulation has been a key area of interest for Africa. Although the concepts of brain drain and brain gain have traditionally been discussed in terms of losers and winners, new research and theoretical frameworks suggest that talent mobility results in win-win situations where all parties accrue benefits both in the short-term and the long-term.[49]

In the context of academic mobility, although a country or institution may lose some of its best scientific talent to elsewhere (especially for graduate training), many researchers come back with stronger skills, strengthening collaboration ties between the countries and institutions and improving the quality of their research.[50] Moreover, those that remain abroad still maintain strong ties to their place of origin, enabling the flow of ideas and providing trainee opportunities for other researchers from that country.[51] In the context of especially medical training in Africa, researchers emphasize the benefits of these positive network externalities over potential declines in the stock of local human capital.[52]

The availability of comprehensive publication databases containing articles with complete author affiliation data, such as Scopus, has enabled the development of a systematic approach to researcher mobility analysis through the use of authors' addresses listed in their published articles as a proxy for their location. The following section describes the individual components of that brain circulation model, which draws on the methodology detailed in Moed et al. (2013).[53] It shares many characteristics with the approach used in previous studies conducted to analyze the mobility of UK researchers[54] and compare European and US researchers.[55]

Measuring international researcher mobility

This report's approach uses Scopus author profile data to derive a history of active researchers[56] affiliated with institutions in the respective Africa regions, as recorded in their published articles. These are then used to assign researchers to mobility classes defined by the type and duration of observed moves.

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49 Teferra, D. (2005). Brain Circulation: Unparalleled Opportunities, Underlying Challenges, and Outmoded Presumptions. Journal of Studies in International Education, 9(3), 229–250. doi:10.1177/1028315305277619; Tung, R. L. (2008). Brain circulation, diaspora, and international competitiveness. European Management Journal, 26(5), 298–304. doi:10.1016/j.emj.2008.03.005; Ciumasu, I. M. (2010). Turning brain drain into brain networking. Science and Public Policy, 37(2), 135–146.

50 Easterly, W., & Nyarko, Y. (2009). Is the Brain Drain Good for Africa. In J. Bhagwati & G. H. Hanson (Eds.), Skilled Immigration Today: Prospects, Problems, and Policies (pp. 316–60). Oxford ; New York: Oxford University Press.; Scellato, G., Franzoni, C., & Stephan, P. (2012). Mobile Scientists and International Networks. Retrieved from http://www.nber.org/papers/w18613; Murakami, Y. (2013). Influences of return migration on international collaborative research networks: cases of Japanese scientists returning from the US. The Journal of Technology Transfer. doi: 10.1007/s10961-013-9316-9

51 In praise of the "brain drain". (2007). Nature, 446(7133), 231. doi:10.1038/446231a

52 Weinberg, B. A., Hanson, G., & Rapoport, H. (2011). Developing science: Scientific performance and brain drains in the developing world. Journal of Development Economics, 95(1), 95–104. doi:10.1016/j.jdeveco.2010.05.009; Docquier, F., & Rapoport, H. (2012). Globalization, Brain Drain, and Development. Journal of Economic Literature, 50(3), 681–730. doi:10.1257/jel.50.3.681

53 Moed, H. F., Aisati, M., & Plume, A. (2012). Studying scientific migration in Scopus. Scientometrics, 94(3), 929–942. doi:10.1007/s11192-012-0783-9

54 UK Department of Business Innovation and Skills. (2011). International Comparative Performance of the UK Research Base - 2011. (A. Plume, M. El Aisati, M. Amin, N. Gracy, N. Weertman, & N. Fowler, Eds.) (p. 88). London: Elsevier. Retrieved from http://www.bis.gov.uk/assets/BISCore/science/docs/I/11-p123-international-comparative-performance-uk-research-base-2011.pdf

55 Science Europe & Elsevier. (2013). Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility. Retrieved from http://www.scienceeurope.org/uploads/Public documents and speeches/SE and Elsevier Report Final.pdf

56 See Appendix C for more details on what constitutes an active researcher.

Mobility Classes

The model generates several main categories of researchers.

Category	*Description*
Sedentary	Researchers who have only published with affiliations to institutions within a particular region. This includes researchers who move between institutions within the same region.
Inflow	Researchers who come to the region.
Outflow	Researchers who leave the region.
Returnees (Inflow)	Researchers who first publish while at an institution in the region, leave and publish with an affiliation to an institution outside of the region for two or more years, and ultimately return to back to the region. The institutional affiliation of their return destination need not be the same as their "original institution".
Returnees (Outflow)	Researchers who first publish elsewhere, come and stay in the region for two or more two years, and then leave to publish elsewhere. The institutional affiliation of their post-region destination need not be the same as their "original institution".
Transitory	Researchers that spend less than two years at an institution in the region or an institution outside the region at any given time; within this group, this report separately analyzes those that publish the majority of their work with region-affiliations versus non-region affiliations, denoting the former as Local Transitory researchers and the latter as Non-local Transitory researchers.

Indicators

For each of the mobility classes, the analysis provides several indicators to characterize the publication profile of the sets of researchers:

Indicator	*Description*
Relative Productivity	The number of papers published per year (PPY) since the first appearance of each researcher as an author in the database during the period 1996-present, relative to all researchers in that region for the same period. The analysis calculates the relative productivity for an author's entire output of articles, not just those articles with a particular regional affiliation. Relative productivity somewhat normalizes for career length, enabling comparisons of productivity across different groups (e.g. those comprising mostly early career researchers versus those comprising mostly more senior academics). For instance, a group that has a relative productivity of 1.28 produces 28% more PPY than that institution's overall average PPY.
Relative Age	The number of years since the first appearance of each researcher as an author in the database relative to all researchers in the region in the same period. The analysis calculates relative age for the author's entire output in articles (e.g., not just those with a particular regional affiliation). Since the dataset goes as far back as 1996, reporting on relative age is right-censored (e.g., the time since a researcher's first appearance as an author has an upper limit of 17 years).
FWCI	The FWCI (see Appendix B for full definition) of all articles associated with a researcher, regardless of whether that researcher lists the given region as an affiliation on said articles.

4.3 International Mobility

4.3.1. East Africa

For conciseness, this section presents the brain circulation model of East Africa. The brain circulation models for the other regions can be found in Appendix F. The brain circulation model in Figure 4.1 is based on the movement of 8750 active East African researcher profiles. These profiles account for 87% of all articles published with an affiliation to an institution in the East African between 1996-2013. As a comparison, the FWCI of articles associated with all East African researchers over this period is 1.65, while that of articles associated with *active* East African researchers is 1.74.

The Outflow groups of East African researchers tend to be more senior, productive, and impactful. Returnees Outflow, or those researchers that spend more than 2 years in East African institutions before leaving to publish elsewhere, are amongst the most productive and impactful of all mobility classes - they produce 35% more papers per year on average than the typical East African researcher, and the average FWCI of their papers at 2.14 is well above the 1.74 average associated with all active East African researchers.

Transitory researchers comprise the great bulk of East African researchers at 57.2%. Within this group, there is a big difference between non-local transitory researchers (visiting scholars) and local transitory researchers. The former are much more productive (relative productivity of 1.38 versus 0.57), senior (relative age of 1.16 versus 0.84), and impactful (FWCI of 1.81 versus 1.42).

Relative to past studies of other regions, East Africa has a low number of sedentary researchers (24%); in contrast, 31.7% and 56.8% of US and European active researchers remain in their respective regions throughout their careers.[57] Such researchers tend to be less productive (relative productivity of 0.47) but also younger (relative age of 0.70).

[57] Science Europe, & Elsevier. (2013). Comparative Benchmarking of European and US Research Collaboration and Researcher Mobility. Retrieved from http://www.scienceeurope.org/uploads/Public documents and speeches/SE and Elsevier Report Final.pdf

BRAIN CIRCULATION MODEL
EAST AFRICA

BRAIN INFLOW

Researchers: **9.1%**
Relative Productivity: **0.75**
Relative Age: **1.18**
FWCI: **1.74**

Inflow
Researchers: **5.4%**
Relative Productivity: **0.66**
Relative Age: **1.17**
FWCI: **1.50**

Returnees Inflow
Researchers: **3.6%**
Relative Productivity: **0.89**
Relative Seniority: **1.20**
FWCI: **2.00**

TRANSITORY BRAIN MOBILITY

Researchers: **57.2%**
Relative Productivity: **1.17**
Relative Age: **1.06**
FWCI: **1.76**

Transitory (mainly East Africa)
Researchers: **18.4%**
Relative Productivity: **0.57**
Relative Age: **0.84**
FWCI: **1.42**

Transitory (mainly non-East Africa)
Researchers: **38.8%**
Relative Productivity: **1.38**
Relative Age: **1.16**
FWCI: **1.81**

BRAIN OUTFLOW

Researchers: **9.7%**
Relative Productivity: **1.09**
Relative Age: **1.22**
FWCI: **1.99**

Outflow
Researchers: **5.0%**
Relative Productivity: **0.81**
Relative Age: **1.14**
FWCI: **1.73**

Returnees Outflow
Researchers: **4.7%**
Relative Productivity: **1.35**
Relative Age: **1.31**
FWCI: **2.14**

SEDENTARY

Researchers: **24.0%**
Relative Productivity: **0.47**
Relative Age: **0.70**
FWCI: **1.13**

Figure 4.1 *— International mobility of East African researchers, 1996-2013.*

4.4 Cross-Region Comparisons

Although transitory researchers account for the largest part of each region's total researcher base, there is significant variation in the relative distribution of other researcher classes. West & Central Africa has the highest percentage of sedentary researchers at 41.8% while Southern Africa has the lowest percentage at 14.7%. In other words, 85.3% of all Southern African researchers have published an article while outside of Southern Africa. Taking together the total Outflow (5.7%) and total Inflow (8.5%), West & Central Africa has a net inflow of researchers (2.8%), while Southern Africa has a substantial net outflow (-5.6%).

Table 4.2 shows the adjusted FWCI associated with the different mobility classes, normalized against each region's overall researcher FWCI. West & Central Africa's Sedentary researchers have the lowest adjusted FWCI (0.43 compared to the next lowest region's researchers, South Africa at 0.60). In other words, while moving abroad is positively associated with the impact of researchers' outputs across all regions, the relative benefit of doing so is largest for West & Central African researchers.

Moreover, relative to the each region's overall average researcher FWCIs, West & Central Africa's Brain Outflow researchers have the highest adjusted FWCI (1.25). This suggests that while East Africa loses the most impactful researchers amongst all the regions, the relative effect of West & Central Africa's Brain Outflow is more acute.

Table 4.3 provides a more granular breakdown of the different mobility classes. Returnees outflow researchers – those who initially publish in abroad, move to an Africa region for more than two years, and then go abroad again – have the highest adjusted FWCI amongst all categories of African researchers.

Southern African researchers categorized as Returnees Inflow have the highest FWCI (2.02) associated with any regions' Returnees Inflow. However, East Africa's Returnee Inflow researchers have high adjusted FWCI and comprise the largest (though still small) percentage of the Africa region's total researcher pools at 3.6%. This suggests that, amongst all the regions, East Africa has benefited the most from academic returning migrants.

Table 4.1 *— Researcher mobility classes as percentage of total active research base for SSA regions and South Africa based on brain circulation models, 1996-2013.*

	Sedentary	*Brain Outflow*	*Transitory*	*Brain Inflow*
East Africa	24.0%	9.7%	57.2%	9.1%
South Africa	34.0%	8.0%	49.1%	8.9%
Southern Africa	14.7%	13.1%	64.7%	7.5%
West & Central Africa	41.8%	5.7%	44.1%	8.5%

Table 4.2 *— Adjusted FWCI associated with researcher mobility classes (e.g., FWCI for individual mobility classes normalized against each region's overall researcher FWCI) for SSA regions and South Africa based on brain circulation models, 1996-2013.*

	Overall	*Sedentary*	*Brain Outflow*	*Transitory*	*Brain Inflow*
East Africa	1.00	0.65	1.14	1.01	1.00
South Africa	1.00	0.60	0.94	1.10	0.92
Southern Africa	1.00	0.67	0.98	1.03	0.96
West & Central Africa	1.00	0.43	1.25	1.14	0.98

Table 4.3 *— Adjusted FWCI associated with detailed researcher mobility classes (e.g., FWCI for individual mobility classes normalized against each region's overall researcher FWCI) for SSA regions and South Africa based on brain circulation models, 1996-2013.*

	Overall	*Outflow*	*Returnees Outflow*	*Non-Local Transitory*	*Local Transitory*	*Returnees Inflow*	*Inflow*
East Africa	1.00	0.76	1.13	1.05	0.82	1.06	0.91
South Africa	1.00	0.90	0.98	1.16	0.74	0.98	0.89
Southern Africa	1.00	0.99	1.23	1.04	0.82	1.15	0.86
West & Central Africa	1.00	1.07	1.41	1.27	0.64	0.98	0.98

4.5 Interpretation of Key Findings on Researcher Mobility

The following section interprets the main findings on research mobility in SSA and make five overall suggestions for interpretation:

1. African researcher are highly mobile, particularly those from East and Southern Africa. Transitory researchers – those who spend less than 2 years in or outside the region – comprise 57.2% and 65% of East Africa's and Southern Africa's total researcher base. In contrast, 44% and 49% of West & Central Africa and South Africa's research base, respectively, are transitory researchers). Moreover, a large percentage of SSA researchers are non-local and transitory; that is, they spend less than 2 years at institutions in SSA. 39% and 48% of all East and Southern African researchers, respectively, fall into this category.

The high percentage of non-local transitory researchers is concerning. The transitory nature of many researchers may prevent researchers from building relationships with African firms and governments, reducing the economic impact and relevance of research.

Several key drivers could explain the high level of researcher mobility: inadequate research infrastructure, low African production of PhDs/researchers, shortages in funding, a high degree of international funding for international researchers, lower dynamism, incentives, and scale of research environments within the region. The interesting and unique research topics, including within health and agricultural, that Africa offers could be highly attractive to researchers from other regions and the African diaspora. This genuine commitment to support the development of African science from a large number of international academics, including diaspora, should not be underestimated.

2. The research productivity and impact of the mobile African researcher is markedly higher than those of sedentary African researchers. For the SSA regions, the latter type of researcher produces research that is between 33% and 57% less impactful than sedentary researchers. This is likely to be the results of several factors: prior, unobserved differences between the types of researchers and collaboration with international researchers, exposure to new ideas, and access to better resources internationally.

3. Returning diaspora contribute significantly to raising the citation impact of SSA research, specifically in East and Southern Africa. The inflow of returnees researchers - those who originally publish from an African institution, left and published elsewhere, and then subsequently returned – make up a relatively small share of the region's total researcher base (3.6% and 2.1%, respectively), yet the relative citation impact of those returnees' publication is quite high compared to that of other SSA researchers.

4. Visiting faculty (transitory mainly publishing at institutions outside of Africa), which also can be diaspora, contribute even more to raising the volume and impact (citations) of research. Such researchers produce research that is between 4% and 27% more impactful than the average researcher in the region.

5. West & Central Africa displays a different pattern of researcher mobility. A higher share of West & Central African researchers is sedentary – i.e. not migrating to institutions outside of their region (44% for West & Central Africa vs. 15% and 24% for Southern and East Africa, respectively).

Several particularities of West & Central Africa could explain these differences: (i) a large part of West & Central Africa is Francophone. This could reduce international scientific collaboration which is in many cases conducted in English. (ii) Another potential contributing factor is measurement bias if Francophone research is not adequately published or indexed; (ii) a higher share of unstable political environments could lower the willingness of researchers to travel to this part of Africa.

APPENDICES

APPENDIX A
AUTHOR CREDITS, ADVISORY GROUPS, & ACKNOWLEDGEMENTS

This study was commissioned by the World Bank. It was jointly conducted and written by George Lan, Dr. Judith Kamalski, Georgin Lau and Jeroen Baas at Elsevier and Andreas Blom and Mariam Adil at the World Bank.

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The study is amongst of a series of technical outputs being produced under the World Bank Partnership for Applied Sciences, Engineering and Technology (PASET) initiative. Preliminary findings from this report were presented and reviewed at a high-level forum on Higher Education for Science, Technology, and Innovation in Kigali, Rwanda in March 2014 that was co-hosted by the Government of Rwanda and the World Bank and attended by representatives from the governments of Ethiopia, Mozambique, Rwanda, Senegal, and Uganda as well as private sector participants and development partners. The findings were presented and further refined at an internal World Bank seminar in March 2014, the University of Michigan STEM-Africa Initiative Third Biennial Conference in April 2014, and a World Bank review panel in August 2014. We thank the participants at all of these events for their helpful insights and feedback.

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The report is available online at www.worldbank.org/africa/stemresearchreport

APPENDIX B
GLOSSARY

Article (unless otherwise indicated) denotes the main types of peer reviewed documents published in journals: articles, reviews, and conference papers.

Article output for an institution or region is the count of articles with at least one author from that institution (according to the affiliation listed in the authorship byline). All analyses make use of ‘whole’ rather than ‘fractional’ counting: an article representing international collaboration (with at least two different countries listed in the authorship byline) is counted once each for every institution listed.

Article share (world) is the share of publications for a specific region expressed as a percentage of the total world output. Using article share in addition to absolute numbers of article provides insight by normalizing for increases in overall growth of the world’s research enterprise.

CAGR (Compound Annual Growth Rate) is defined as the year-over-year constant growth rate over a specified period of time. Starting with the first value in any series and applying this rate for each of the time intervals yields the amount in the final value of the series.

$$\mathrm{CAGR}\,(t_0, t_n) = \left(V(t_n) / V(t_0)\right)^{\frac{1}{t_n - t_0}} - 1$$

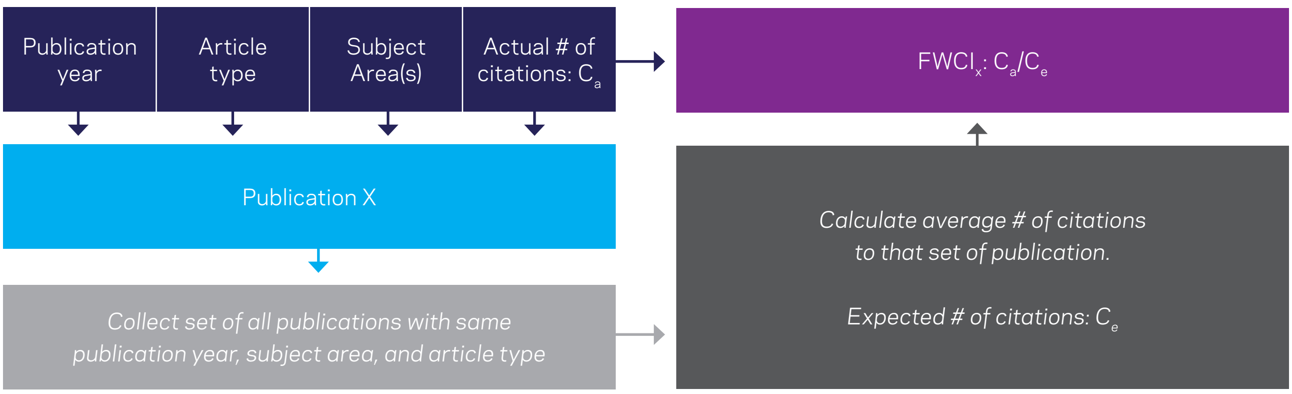
$V(t_0)$: start value
$V(t_n)$: finish value
$t_n - t_0$: number of years.

Citation is a formal reference to earlier work made in an article or patent, frequently to other journal articles. A citation is used to credit the originator of an idea or finding and is usually used to indicate that the earlier work supports the claims of the work citing it. The number of citations received by an article from subsequently-published articles is a proxy of the quality or importance of the reported research.

Downloads are defined as either downloading a PDF of an article on ScienceDirect, Elsevier’s full-text platform, or looking at the full-text online on ScienceDirect without downloading the actual PDF. Views of abstracts are not included in the definition. Multiple views or downloads of the same article in the same format during a user session will be filtered out, in accordance with the COUNTER Code of Practice Release 4.[58] ScienceDirect provides download data for approximately 16% of the articles indexed in Scopus. It is assumed that user downloading behavior across countries does not systematically differ between online platforms. Field-weighted download impact is calculated from these data according to the same principles applied to the calculation of field-weighted citation impact.

FWCI (Field-Weighted Citation Impact) is an indicator of mean citation impact, and compares the actual number of citations received by an article with the expected number of citations for articles of the same document type (article, review or conference proceeding paper), publication year and subject field. Where the article is classified in two or more subject fields, the harmonic mean of the actual and expected citation rates is used. The indicator is therefore always defined with reference to a global baseline of 1.00 and intrinsically accounts for differences in citation accrual over time, differences in citation rates for different document types (reviews typically attract more citations than research articles, for example) as well as subject-specific differences in citation frequencies overall and over time and document types. It is one of the most sophisticated indicators in the modern bibliometric toolkit.

Field-Weighted Citation Impact (FWCI)



When field-weighted citation impact is used as a snapshot, an un-weighted variable window is applied. The field-weighted citation impact value for '2008', for example, is comprised of articles published in 2008 and their field-weighted citation impact in the period 2008-12, while for '2012,' it is comprised of articles published in 2012 and their field-weighted citation impact in 2012 alone. When field-weighted citation impact is used in trend analysis, a weighted moving window is applied. The field-weighted citation impact value for '2010', for example, is comprised of the weighted average of the unweighted variable field-weighted citation impact values for 2008 and 2012 (weighted 13.3% each), 2009 and 2011 (weighted 20% each) and for 2010 (weighted 33.3%). The weighting applies in the same ratios for previous years also. However, for 2011 and 2012 it is not possible to extend the weighted average by 2 years on either side, so weightings are readjusted across the remaining available values.

Highly cited articles (unless otherwise indicated) are those in the top-cited X% of all articles published and cited in a given period.

Hypercollaboration – while no definition exists on the number of co-authors required to constitute 'hyper-collaborative' co-authorship, numbers in the hundreds or thousands seem worthy of the term. The most multi-authored research paper of all time was published in April 2010 and has 3,222 authors from 37 countries 53. As an indication of the frequency of such hypercollaborative articles, 74 articles published in 2012 had more than 3,000 authors; like the record holder, all of them reported results from the ATLAS experiment at CERN's Large Hadron Collider in Switzerland. Indeed, hypercollaborative co-authorship may be a consequence of the rise of so-called 'Big Science' – a term used to describe research that requires major capital investment and is often, but not always, international in nature.[59]

While such hypercollaborative articles may represent extreme outliers in co-authorship data, they are included in all the analyses since they remain proportionally few and because they are counted only as a single internationally co-authored article for each country represented in the article, and for each country pairing.

Intellectual property (IP) are intangible assets such as discoveries and inventions for which exclusive rights may be claimed, including that which is codified in copyright, trademarks, patents, and designs.

International Collaboration (i.e., research collaboration) in this report is indicated by articles with at least two different countries listed in the authorship byline.

Journal is a peer-reviewed periodical in which scholarship relating to a particular research field is published, and is the primary mode of dissemination of knowledge in many fields. Research findings may also be published in conference proceedings, reports, monographs and books and the significance of these as an output channel varies between fields.

R&D (Research and Development) is any creative systematic activity undertaken in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this knowledge to devise new applications. R&D includes fundamental research, applied research in such fields as agriculture, medicine, industrial chemistry, and experimental development work leading to new devices, products or processes.

Research collaboration is indicated by articles with at least two different institutions listed in the authorship byline.

Sectors in this report refer to the different organization types used to categorize institutional affiliations. The main sectors are:

Academic – universities, colleges, medical schools, and research institutes

Corporate – companies and law firms

Government – government and military organizations

Medical – hospitals

Other – non-governmental organizations, policy institutes, foundations, and other non-profit organizations

[58] http://www.projectcounter.org/r4/COPR4.pdf

[59] Hand, E. (2010). "Big science" spurs collaborative trend. Nature, 463(7279), 282. doi:10.1038/463282a

APPENDIX C
DATA SOURCES & METHODOLOGY

Data Sources

The key findings and insights discussed in this report are based on a bibliometric analysis of the relevant publication data from 2003-2012, which comes from Elsevier's search and discovery research abstract database, Scopus.[60] To augment the view of knowledge exchange, this report also draws on usage data from ScienceDirect,[61] Elsevier's full-text journal article platform, and citation-indexed patent data from LexisNexis TotalPatent and the United State Patent and Trademark Office (USPTO).

Scopus is Elsevier's abstract and citation database of peer-reviewed literature, covering 50 million documents published in over 21,000 journals, book series and conference proceedings by some 5,000 publishers. Reference lists are captured for 29 million records published from 1996 onwards, and the additional 21 million pre-1996 records reach as far back as the publication year 1823.

Scopus coverage is multi-lingual and global: approximately 21% of titles in Scopus are published in languages other than English (or published in both English and another language). In addition, more than half of Scopus content originates from outside North America, representing many countries in Europe, Latin America, Africa and the Asia Pacific region. In particular, Scopus comprises over 400 titles from publishers based in the Middle East and Africa. For more information, see http://www.elsevier.com/__data/assets/pdf_file/0019/148402/SC_Content-Coverage-Guide_July-2014.PDF

Scopus coverage is also inclusive across all major research fields, with 6,900 titles in the Physical Sciences, 6,400 in the Health Sciences, 4,150 in the Life Sciences, and 6,800 in the Social Sciences (the latter including some 4,000 Arts & Humanities related titles). Titles which are covered are predominantly serial publications (journals, trade journals, book series and conference material), but considerable numbers of conference papers are also covered from stand-alone proceedings volumes (a major dissemination mechanism, particularly in the computer sciences). Acknowledging that a great deal of important literature in all fields (but especially in the Social Sciences and Arts & Humanities) is published in books, Scopus has begun to increase book coverage in 2013, aiming to cover some 75,000 books by 2015.

For this report, a static version of the Scopus database covering the period January 1, 1996-December 1, 2013 was aggregated by country, region, and subject. Subjects were defined by ASJC subject areas (see elsewhere Appendix C for more details). When aggregating article and citation counts, an integer counting method was employed where, for example, a paper with two authors from a Rwanda (in East Africa) address and one from a South Africa address would be counted as one article for each region (i.e. 1 East Africa and 1 South Africa). This method was favored over fractional counting, in which the above paper would count as 0.67 for East Africa and 0.33 for South Africa, to maintain consistency with other reports (both public and private) we have conducted on the topic.

A body of literature is available on the limitations and caveats in the use of such 'bibliometric' data, such as the accumulation of citations over time, the skewed distribution of citations across articles, and differences in publication and citation practices between fields of research, different languages, and applicability to social sciences and humanities research. In social sciences and humanities, the bibliometric indicators presented in this report for these fields must be interpreted with caution because a reasonable proportion of research outputs in such fields take the form of books, monographs and non-textual media. As such, analyses of journal articles, their usage and citation, provides a less comprehensive view than in other fields, where journal article comprise the vast majority of research outputs.

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60 Scopus is the largest abstract and citation database of peer-reviewed literature, covering 50 million records published in over 21,000 titles including over 400 titles from publishers in the Middle East and Africa. This assuages concerns raised by researchers such as Tijssen (2007) that past bibliometric analyses have excluded a significant portion of Africa's research output placed in African-published journals. Please see Appendix C: Data Sources for more details. Tijssen, R. J. W. (2007). Africa's contribution to the worldwide research literature: New analytical perspectives, trends, and performance indicators. Scientometrics, 71(2), 303–327. doi:10.1007/s11192-007-1658-3

61 Usage is defined as full-text article downloads or full-text article views online from Elsevier's ScienceDirect database, which provides approximately 20% of the world's published journal articles. For more information on the coverage and distribution of scientific content in ScienceDirect, please see Appendix C: Measuring Article Downloads for more details.

ScienceDirect is Elsevier's full-text journal articles platform. With an invaluable and incomparable customer base, the use of scientific research on ScienceDirect.com provides a different look at performance measurement. ScienceDirect.com is used by more than 12,000 institutes worldwide, with more than 11 million active users and over 700 million full-text article downloads in 2012. The average click through to full-text per month is nearly 60 million. More info can be found on http://www.elsevier.com/online-tools/sciencedirect

LexisNexis is a leader in comprehensive and authoritative legal, news and business information and tailored applications. LexisNexis® is a member of Reed Elsevier Group plc. Patents are obtained via a partnership with LexisNexis and include those from the United States Patent and Trademark Office (USPTO), the European Patent Office (EPO), the Japanese Patent Office (JPO), the Patent Cooperation Treaty (PCT) of the World Intellectual Property Organization (WIPO) and the UK Intellectual Property Office (UKIPO).

World Bank Africa Development Indicators is a collection of development indicators compiled from officially recognized international sources, presenting the most current and accurate global development data available. This study particularly draws on data about SSA GDP and population size to calculate research output per capita. More info can be found on http://data.worldbank.org/data-catalog/africa-development-indicators

Changes in measures over time

The main data sources used in this report (Scopus, ScienceDirect usage data, LexisNexis patent citations index based on USPTO data) represent dynamic databases that are regularly updated throughout the year. The indicators are therefore a snapshot taken from the data at a point in time. For instance, the citation counts associated with South Africa's publications will increase over time. In some cases, the most recent values may be provisional as earlier data may be revised as a result of initiatives to expand data completeness. For example, in Scopus, a significant expansion of journal coverage in the Arts & Humanities beginning in 2009 has resulted in a more robust view of journal articles and related output indicators in that area. This report used data from a December 1, 2013 snapshot of the aforementioned data sources.

Time lags between inputs and outputs

In the input-output model of research & development (R&D) evaluation[62], inputs such as R&D expenditure or human capital must precede outputs such as journal articles and citations. The results of a research grant awarded in 2010 may not be published in the peer-reviewed literature for several years, and a patent application may follow after an even longer delay.[63] Such lags vary by indicator and subject fields, and they may even change in magnitude over time. Given the complexities of determining and accounting for the time lags between input and output, this report does not attempt to directly link the two. Readers are welcome to further interpret this report's findings from a productivity perspective, such as normalizing article output and citation counts by a region's population, per-unit R&D expenditure, or researcher headcount. However, such measures are more meaningful in a comparative rather than absolute sense.

Methodology and Rationale

Our methodology is based on the theoretical principles and best practices developed in the field of quantitative science and technology studies, particularly in science and technology (S&T) indicators research. The Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems (Moed, Glänzel and Schmoch, 2004)[64] gives a good overview of this field and is based on the pioneering work of Derek de Solla Price (1978)[65], Eugene Garfield (1979)[66] and Francis Narin (1976)[67] in the USA, and Christopher Freeman, Ben Martin and John Irvine in the UK (1981, 1987)[68], and in several European institutions including the Centre for Science and Technology Studies at Leiden University, the Netherlands, and the Library of the Academy of Sciences in Budapest, Hungary.

The analyses of research output data in this report are based upon recognized advanced indicators (e.g., the concept of relative citation impact rates). Our base assumption is that such indicators are useful and valid, though imperfect and partial measures, in the sense that their numerical values are determined by research performance and related concepts, but also by other, influencing factors that may cause systematic biases. In the past decade, the field of indicators research has developed a best practices which state how indicator results should be interpreted and which influencing factors should be taken into account. Our methodology builds on these practices.

Article Types

For all research output analyses, only the following, peer-reviewed document types are considered:

- Article (ar)
- Review (re)
- Conference Proceeding (cp)

Article Counting and Deduplication

All analyses make use of whole counting rather than fractional counting. For example, if a paper has been co-authored by one author from East Africa and one author from Southern Africa, then that paper counts towards both the publication count of East Africa as well as the publication count of Southern Africa. Total counts for each region are the unique counts of publications.

An article can be counted in more than one subject grouping. However, it is calculated only once toward the count of a region's total publications. For example, a West & Central Africa publication on the impact of increased corn production on pricing may be counted once each toward the totals of that region's research output in Agricultural & Biological Sciences and Economics, Econometrics, & Finance. However, this publication counts only once toward the aggregate entity of all West & Central Africa's publications.

Deduplication in the calculation of measures
All analyses make use of whole counting rather than fractional counting of articles. For example, if an article has been co-authored by one author from East Africa and one author from Southern Africa, then that article is added towards both the output of East Africa, as well as the output of Southern Africa. Total counts for each region are the unique count of articles.

The same article may be part of multiple smaller component entities, such as the calculation of article counts in subject groupings. However, this report deduplicates all articles within an aggregate entity. For example, an article from Southern Africa on the impact of increased corn production on pricing may be counted once each toward the totals of that region's output in Agriculture and the Social Sciences & Humanities. However, the article is counted only once toward the aggregate total of all articles from that region.

Citation Counting and Self-Citations
Self-citations are those by which an entity refers to its previous work in new publications. Self-citing is normal and expected academic behavior, and it is an author's responsibility to make sure their readers are aware of related, relevant work. For this report, self-citations are included in citation counts and the calculation of FWCI.

Measuring International Researcher Mobility

The approach presented here uses Scopus author profile data to derive a history of active author affiliations recorded in their published articles and to assign them to mobility classes defined by the type and duration of observed moves.

How are individual researchers unambiguously identified in Scopus?
Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements associated with the article (such as affiliation, subject area, co-authors, and so on).

The Scopus algorithm favors accuracy and only groups together publications when the confidence level that they belong together – the precision of matching – is at least 99% (that is, in a group of 100 papers, 99 will be correctly assigned). This level of accuracy results in a recall of 95% across the database: if an author has published 100 papers, on average, 95 of them will be grouped together by Scopus. These precision and recall figures are accurate across the entire Scopus database. There are situations where the concentration of similar names increases the fragmentation of publications between Author Profiles, such as in the well-known example of Chinese authors. Equally there are instances where a high level of distinction in names results in a lower level of fragmentation, such as in Western countries.

The matching algorithm can never be 100% correct because the data it is using to make the assignments are not 100% complete or consistent. The algorithm is therefore enriched with manual, author-supplied feedback, both directly through Scopus and also via Scopus' direct links with ORCID (Open Researcher & Contributor ID[69]).

What determines whether an author is an "East African researcher" or an analogous researcher from the other sub-Saharan regions?
To define the initial population for study, East African authors were defined as those that had listed an affiliation with an East African institution on at least one publication (articles, reviews and conference papers) published across the sources included in Scopus during the period 1996–2013.

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What is an 'active researcher'?

The total authors identified for this reports' analysis include a large proportion with relatively few articles over the entire ten-year period of analysis. As such, it was assumed that they are not likely to represent career researchers, but individuals who have left the research system. A productivity filter was therefore implemented to restrict the analysis to those authors with at least 1 article in the most recent 5-year period 2009–2013 and at least 10 articles in the entire period 1996-present, or those with fewer than 10 articles in 1996-present, and at least 4 articles in 2009-2013. For instance, after applying the productivity filter on the initial set of 58,293 researchers identified as being affiliated with institutions in West & Central Africa, a set of 15,019 active researchers was defined and formed the basis of the study.

How are mobility classes defined?

The measurement of international researcher mobility by co-authorship in the published literature is complicated by the difficulties involved in teasing out long-term mobility from short-term mobility (such as doctoral research visits, sabbaticals, secondments, etc.), which might be deemed instead to reflect a form of collaboration. In this study, stays overseas of 2 years or more were considered migratory and were further subdivided into those where the researcher remained abroad or where they subsequently returned to their original institution. Stays of less than 2 years were deemed transitory, and were also further subdivided into those who mostly published under an ego-region or a non—ego-region affiliation. Since author nationality is not captured in article or author data, authors are assumed to be from the institution where they first published (for migratory mobility) or from the institution where they published the majority of their articles (for transitory mobility). In individual cases, these criteria may result in authors being assigned migratory patterns that may not accurately reflect the real situation, but such errors may be assumed to be evenly distributed across the groups and so the overall pattern remains valid. Researchers without any apparent mobility based on their published affiliations were considered sedentary.

Migratory

- *Outflow:* active researchers whose Scopus author data for the period 1996-2013 indicates that they have migrated from institution(s) in the region to institution(s) outside of the region for at least 2 years without returning to the respective region.
- *Returnees Outflow:* active researchers whose Scopus author profile data for the period 1996-2013 indicates that they have migrated from institution(s) outside the region to institution(s) in the region for at least 2 years, and then subsequently migrated back to institution(s) outside the Africa region.
- *Total Outflow:* the sum of Outflow and Returnee Outflow groups.
- *Inflow:* active researchers whose Scopus author data for the period 1996-2013 indicate that they have migrated from institution(s) outside of the region to institution(s) in the region for at least 2 years without leaving that region.
- *Returnees Inflow:* active researchers whose Scopus author data for the period 1996-2013 indicates that they have migrated from institution(s) in the region to institution(s) outside the region for at least 2 years, and then subsequently migrated back to institution(s) in the region for at least 2 years.
- *Total Inflow:* the sum of Inflow and Returnee Inflow groups.

Transitory

- *Transitory (mainly non-Africa region):* active Africa region researchers whose Scopus author data for the period 1996-2013 indicates that they were based in institution(s) in the Africa region for less than 2 years at a time and have been predominantly based in institution(s) outside the Africa region.
- *Transitory (mainly Africa region):* active Africa region researchers whose Scopus author data for the period 1996-2013 indicates that they are based in institution(s) outside the Africa region for less than 2 years at a time and have been predominantly based in institution(s) in the Africa region.
- *Total Transitory:* the sum of Transitory (mainly non-Africa region) and Transitory (mainly Africa region) groups.

Sedentary

- *Sedentary:* active Africa region researchers whose Scopus author data for the period 1996-2013 indicates that they have not published outside institution(s) in the Africa region.

What indicators are used to characterize each mobility group?

To better understand the composition of each group defined on the map, three aggregate indicators were calculated for each to represent the productivity and seniority of the researchers they contain, and the field-weighted citation impact of their articles.

- *Relative Productivity* represents a measure of the articles per year since the first appearance of each researcher as an author during the period 1996-2013, relative to all Africa region researchers in the same period.
- *Relative Seniority* represents years since the first appearance of each researcher as an author during the period 1996-2013, relative to all Africa region researchers in the same period.

- *Field-weighted citation impact* is calculated for all articles in each mobility class. All three indicators are calculated for each author's entire output in the period (i.e., not just those articles listing a corresponding address for that author).

Measuring Article Downloads

Citation impact is by definition a lagging indicator: newly-published articles need to be read, after which they might influence studies that will be carried out, which are then written up in manuscript form, peer-reviewed, published and finally included in a citation index such as Scopus. Only after these steps are completed can citations to the earlier article be systematically counted. For this reason, investigating downloads has become an appealing alternative, since it is possible to start counting downloads of full text articles immediately upon online publication and to derive robust indicators over windows of months rather than years.

While there is a considerable body of literature on the meaning of citations and indicators derived from them,[70] the relatively recent advent of download derived indicators means that there is no clear consensus on the nature of the phenomenon that is measured by download counts.[71] A small body of research has concluded however that download counts may be a weak predictor of subsequent citation counts at the article level.[72]

In this report, a download is defined as the event where a user views the full-text HTML of an article or downloads the full-text PDF of an article from ScienceDirect, Elsevier's full-text journal article platform; views of an article abstract alone, and multiple full-text HTML views or PDF downloads of the same article during the same user session, are not included in accordance with the COUNTER Code of Practice[73]. ScienceDirect provides download data for approximately 20% of the articles indexed in Scopus; it is assumed that user downloading behavior across countries does not systematically differ between online platforms. Field-weighted download impact is calculated from these data according to the same principles applied to the calculation of field-weighted citation impact.

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[73] http://usagereports.elsevier.com/asp/main.aspx; http://www.projectcounter.org/code_practice.html

APPENDIX D
AFRICA REGION CLASSIFICATION

Country	ISO 3-Character Code	East Africa	West & Central Africa	Southern Africa	South Africa	Comparator Country
Angola	AGO			●		
Benin	BEN		●			
Botswana	BWA			●		
Burkina Faso	BFA		●			
Burundi	BDI	●				
Cameroon	CMR		●			
Cape Verde	CPV		●			
Central African Republic	CAF		●			
Chad	TCD		●			
Comoros	COM	●				
Congo, Dem. Rep.	ZAR		●			
Congo, Rep.	COG		●			
Cote d'Ivoire	CIV		●			
Djibouti	DJI	●				
Equatorial Guinea	GNQ		●			
Eritrea	ERI	●				
Ethiopia	ETH	●				
Gabon	GAB		●			
Gambia, The	GMB		●			
Ghana	GHA		●			
Guinea	GIN		●			
Guinea-Bissau	GNB		●			
Kenya	KEN	●				
Lesotho	LSO			●		
Liberia	LBR		●			
Madagascar	MDG			●		
Malawi	MWI			●		
Malaysia	MYS					●
Mali	MLI		●			
Mauritania	MRT		●			
Mauritius	MUS	●				
Mayotte	MYT	●				
Mozambique	MOZ			●		
Namibia	NAM			●		
Niger	NER		●			
Nigeria	NGA		●			
Rwanda	RWA	●				
Saint Helena, Ascension and Tristan da Cunha	SHN		●			
Sao Tome and Principe	STP		●			

Country	ISO 3-Character Code	East Africa	West & Central Africa	Southern Africa	South Africa	Comparator Country
Senegal	SEN		●			
Seychelles	SYC	●				
Sierra Leone	SLE		●			
Somalia	SOM	●				
South Africa	ZAF				●	
South Sudan	SSD	●				
Swaziland	SWZ			●		
Tanzania	TZA	●				
Togo	TGO		●			
Uganda	UGA	●				
Vietnam	VNM					●
Zambia	ZMB			●		
Zimbabwe	ZWE			●		

APPENDIX E **SUBJECT CLASSIFICATION**

Background on Scopus All Science Classification System (ASJC)

Titles in Scopus are classified under four broad subject clusters (life sciences, physical sciences, health sciences and social sciences & humanities) which are further divided into 27 major subject areas and 300+ minor subject areas. Titles may belong to more than one subject area. For a complete list of titles associated with these subject areas, please see http://www.elsevier.com/online-tools/scopus/content-overview

For this report, these 27 subject areas are then aggregated into five major subject groupings: Agriculture; Physical Sciences & STEM, Health Sciences, Social Sciences & Humanities, and the Life Sciences. The main foci of the report are Agriculture, the Physical Sciences & STEM, and the Health Sciences.

APPENDIX F
INTERNATIONAL RESEARCHER MOBILITY MAPS

BRAIN CIRCULATION MODEL
SOUTHERN AFRICA

BRAIN INFLOW

Researchers: **7.5%**
Relative Productivity: **0.77**
Relative Age: **1.06**
FWCI: **1.82**

Inflow
Researchers: **5.4%**
Relative Productivity: **0.73**
Relative Age: **1.06**
FWCI: **1.73**

Returnees Inflow
Researchers: **2.1%**
Relative Productivity: **0.88**
Relative Seniority: **1.05**
FWCI: **2.02**

TRANSITORY BRAIN MOBILITY

Researchers: **64.7%**
Relative Productivity: **1.13**
Relative Age: **1.03**
FWCI: **1.96**

Transitory (mainly Southern Africa)
Researchers: **16.3%**
Relative Productivity: **0.48**
Relative Age: **0.77**
FWCI: **1.56**

Transitory (mainly non-Southern Africa)
Researchers: **48.3%**
Relative Productivity: **1.28**
Relative Age: **1.11**
FWCI: **1.99**

BRAIN OUTFLOW

Researchers: **13.1%**
Relative Productivity: **0.93**
Relative Age: **1.21**
FWCI: **1.86**

Outflow
Researchers: **7.5%**
Relative Productivity: **0.71**
Relative Age: **1.17**
FWCI: **1.45**

Returnees Outflow
Researchers: **5.6%**
Relative Productivity: **1.21**
Relative Age: **1.27**
FWCI: **2.15**

SEDENTARY

Researchers: **14.7%**
Relative Productivity: **0.43**
Relative Age: **0.67**
FWCI: **1.28**

Figure F.1 *— International mobility of Southern African researchers, 1996-2013.*

BRAIN CIRCULATION MODEL
SOUTH AFRICA

BRAIN INFLOW

Researchers: **8.9%**
Relative Productivity: **0.96**
Relative Age: **1.14**
FWCI: **1.60**

Inflow
Researchers: **6.5%**
Relative Productivity: **0.89**
Relative Age: **1.11**
FWCI: **1.54**

Returnees Inflow
Researchers: **2.4%**
Relative Productivity: **1.13**
Relative Seniority: **1.23**
FWCI: **1.71**

TRANSITORY BRAIN MOBILITY

Researchers: **49.1%**
Relative Productivity: **1.27**
Relative Age: **1.10**
FWCI: **1.91**

Transitory (mainly South Africa)
Researchers: **13.6%**
Relative Productivity: **0.57**
Relative Age: **0.98**
FWCI: **1.28**

Transitory (mainly non-South Africa)
Researchers: **35.5%**
Relative Productivity: **1.44**
Relative Age: **1.14**
FWCI: **2.02**

BRAIN OUTFLOW

Researchers: **8.0%**
Relative Productivity: **0.88**
Relative Age: **1.18**
FWCI: **1.63**

Outflow
Researchers: **4.9%**
Relative Productivity: **0.77**
Relative Age: **1.16**
FWCI: **1.57**

Returnees Outflow
Researchers: **3.1%**
Relative Productivity: **1.05**
Relative Age: **1.31**
FWCI: **1.70**

SEDENTARY

Researchers: **34.0%**
Relative Productivity: **0.50**
Relative Age: **0.78**
FWCI: **1.04**

Figure F.2 *— International mobility of South African researchers, 1996-2013.*

BRAIN CIRCULATION MODEL
WEST & CENTRAL AFRICA

BRAIN INFLOW

Researchers: **8.5%**
Relative Productivity: **0.94**
Relative Age: **1.26**
FWCI: **1.21**

Inflow
Researchers: **5.0%**
Relative Productivity: **0.85**
Relative Age: **1.24**
FWCI: **1.21**

Returnees Inflow
Researchers: **3.5%**
Relative Productivity: **1.07**
Relative Seniority: **1.30**
FWCI: **1.20**

TRANSITORY BRAIN MOBILITY

Researchers: **44.1%**
Relative Productivity: **1.27**
Relative Age: **1.12**
FWCI: **1.40**

Transitory (mainly West & Central Africa)
Researchers: **19.7%**
Relative Productivity: **0.65**
Relative Age: **0.98**
FWCI: **0.79**

Transitory (mainly non-West & Central Africa)
Researchers: **24.3%**
Relative Productivity: **1.67**
Relative Age: **1.23**
FWCI: **1.56**

BRAIN OUTFLOW

Researchers: **5.7%**
Relative Productivity: **1.19**
Relative Age: **1.33**
FWCI: **1.54**

Outflow
Researchers: **3.5%**
Relative Productivity: **0.97**
Relative Age: **1.28**
FWCI: **1.32**

Returnees Outflow
Researchers: **2.2%**
Relative Productivity: **1.50**
Relative Age: **1.42**
FWCI: **1.74**

SEDENTARY

Researchers: **41.8%**
Relative Productivity: **0.57**
Relative Age: **0.78**
FWCI: **0.53**

Figure F.3 — *International mobility of West & Central African researchers, 1996-2013.*

Notes

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