SCHOOL OF ECONOMICS & MANAGEMENT LISBON

MESTRADO EM

ECONOMIA E GESTÃO DA CIÊNCIA, TECNOLOGIA E INOVAÇÃO

TRABALHO FINAL DE MESTRADO

DISSERTAÇÃO

SCIENCE AND TECHNOLOGY IN AFRICA: A BIBLIOMETRIC AND PATENT ANALYSIS

HUGO JOÃO FIALHO COSTA CONFRARIA

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ORIENTAÇÃO:

PROFESSOR DOUTOR MANUEL MIRA GODINHO

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AGRADECIMENTOS

Este trabalho não seria possível sem a ajuda de algumas pessoas fantásticas.

Em primeiro lugar, estou muito agradecido ao meu orientador, Professor Manuel Mira Godinho, pelos ensinamentos, opiniões, recomendações e disponibilidade, que foram vitais para o meu desenvolvimento durante todo o mestrado.

Em segundo lugar, queria agradecer ao Rui Cartaxo, Ido Alon e Ramiro Oliveira pelos comentários críticos feitos a este texto. O documento melhorou muito com a vossa ajuda.

Gostaria também de gratular todos os meus professores e colegas do ISEG, que partilharam comigo ideias e conhecimento durante o mestrado. Sem eles, o meu interesse por certas matérias seria certamente menor.

Quero também deixar uma palavra particular de agradecimento à Professora Ana Moutinho e à Universidade de Lisboa por me terem permitido usar a ferramenta de análise bibliométrica *InCites/Thomson Reuters*.

Finalmente, quero agradecer especialmente à minha Mãe pelo apoio incondicional ao longo de toda a minha vida, e aos meus amigos e família por compreenderem a minha ausência durante o tempo em que estive dedicado a este trabalho.

RESUMO

Historicamente, a I&D em África tem sido diminuta. No entanto, a análise de dados bibliométricos indica que África tem comportamentos distintos em relação à produção científica (2,51% da produção mundial em 2011) e aos pedidos internacionais de patentes (0,25% do total em 2011).

Relativamente à produção científica, houve um ponto de viragem em 2004, quando a produção total do continente não ultrapassava as 15000 publicações anuais. Desde esse ano o crescimento anual tem sido mais rápido que a média mundial. Estes avanços são ofuscados pelo facto da produção do continente ser ainda altamente concentrada (África do Sul e Egito).

Quanto à especialização científica, a única área científica onde África apresenta maior diferenciação é em "Ciências Agrárias". Um resultado importante, ao nível dos países, é que maiores níveis de especialização e a existência da língua inglesa como língua colonial, parecem levar a publicações com maior "impacto científico".

Outra conclusão relevante é que parece haver uma dinâmica não-linear entre o número de publicações de um país e o número de pedidos PCT. Quanto maior o nível de publicação de um país na WoS, maior parece ser a capacidade dos agentes em transformar a informação científica em invenções tecnológicas.

Finalmente, a nossa análise de clusters demonstrou, que África é muito complexa para seguir um conjunto único de políticas de C&T. Cada país deve avaliar as suas características e, com uma visão realista (Lundvall, 2009), desenvolver as suas fronteiras de conhecimento para responder às circunstâncias e oportunidades locais.

Palavras chave: *África, Indicadores de Ciência e Tecnologia, Bibliometria, Análise de patentes, Investigação, Impacto Científico, Scientometria.*

ABSTRACT

It is known that Africa's R&D has been fragile. However, the analysis of bibliometric data indicates that Africa has relative distinguish behaviours on publication (2,51% of world output in 2011) and patent production (0,25% of total PCT Applications in 2011).
Regarding research output there was a turning point around 2004, when the continent's output was yet to reach 15,000 publications annually. Since that year African publications have grown faster than the world average, with its number more than duplicating until now. These advances are overshadowed by the fact the continent's production is still highly concentrated (South Africa and Egypt).
Concerning scientific specialization, the results indicate that the overall Africa's specialization is not too different of the world pattern with the exception of Agricultural Sciences, which are relatively more important in Africa. An important finding is that, at the nation level, higher level of specialization and English language colonial legacy seems to lead to better results on "scientific impact".
Other relevant result is that there seems to be a non-linear dynamics between publication output and patent output. The more a country publishes in WoS publications, the more it is able to transform scientific information into technological inventions.
Finally, as demonstrated, in a way, by our cluster analysis, Africa is too complex to follow one set of S&T policies. Each country must evaluate what already exists and, with a realistic vision (Lundvall, 2009), develop their knowledge frontiers to respond to local circumstances and opportunities.

Key words: *Africa, Science & Technology Indicators, Bibliometrics, Patent analysis, Research, Scientific impact, Scientometrics*

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ACRONYMS

A&HCI	Arts & Humanities Citation Index
ASTII	African Science, Technology and Innovation Indicators
CAGR	Compound annual growth rate
CWTS	Centre for Science and Technology Studies
CXC	Citation impact relative to subject area
Docs/GDP	Average number of publications per GDP
Docs/Pop	Average number of publications per million people
EPO	European Patent Office
ESI	Essential Science Indicators
EU27	European Union
GDP	Gross Domestic Product
GERD	Gross expenditure in research and development
IPC	International Patent Classifications
JPO	Japan Patent Office
NEPAD	The New Partnership for Africa's Development
OECD	Organisation for Economic Co-operation and Development
PCT Applications	Patent applications under the Patent Cooperation Treaty
R&D	Research and Development
RCA	Revealed comparative advantage index
RTA	Revealed technological advantage index
S&T	Science and Technology
SCI-EXPANDED	Science Citation Index Expanded
SSCI	Social Sciences Citation Index
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organization
US$	United States dollar
USA	United States of America
USPTO	United States Patent and Trademark Office
WIPO	World Intellectual Property Organization
WoS	Web of Science

1 - INTRODUCTION

The use of science and technology (S&T) indicators has been on the rise in recent years. The ability of bibliometric and patent analysis to enlighten political choices, by informing, compare internationally and allowing decisions to be more objective, has been the main force behind its growing popularity. The importance of this approach has also been recognized in Africa. The declaration stemming from the first NEPAD[1] Ministerial Conference on S&T commits to "develop and adopt common sets of indicators to benchmark our national and regional systems of innovation" (NEPAD, 2003).

A growing consensus seems to be developing over the continent, recognizing that scientific research rather than being a luxury is a requirement to create the necessary long term potential for sustainable economic development. A critical challenge for Africa is how to integrate the S&T knowledge in its development. Specifically, an important trade-off Africa is facing has to do with how much to invest in S&T knowledge. On the one hand if too little investment is undertaken (given the scarcity of resources and the relevance of the competing applications) there is the danger the continent will lag behind on the long term. On the other hand if too much investment occurs (which might not be much more than the "too little" investment mentioned above), the continent risks an intensification of the brain drain and, still, lagging behind. This question regarding the right investment (in quantity and orientation) in S&T is thus the relevant practical question behind our investigation. We will not be attempting to provide a direct answer to it, but by supplying organized data and systematic analysis we hope to contribute in the search for the appropriate answers. Of course, we are also aware those answers will vary in accordance to each specific country, as significant variation exists across the continent.

It is known that African knowledge production (in a bibliometric approach) is fragile. But we intend to understand whether African research output (and patent application to complement), as a whole, is converging or diverging in relation to the leading economies, assess how the scientific capacities and specialization varies between countries, analyse whether the impact of research in all subject fields is below or above the world average, correlate the scientific capacities of each African country with the technological capacities and access if there are relatively homogeneous groups of African countries that we can group into clusters. With this we hope to illustrate the current situation of S&T in Africa and to reach some relevant insights.

In this paper we will analyse the scientific publications in journals that are indexed by the Science Citation Index Expanded (SCI-EXPANDED), the Social Sciences Citation Index

[1] NEPAD stands for The New Partnership for Africa's Development.

(SSCI), the Arts & Humanities Citation Index (A&HCI), and also, the patent applications under the Patent Cooperation Treaty (PCT applications). Thereby, rather than focusing on input statistics, this empirical study focuses on outputs of scientific publications and international patent applications which can be easily compared internationally. Specifically, our analysis will focus on the publication and patent output of 53 African countries in the 10 years from 2002 to 2011.

In what follows we will first put forward the framework of our analysis, then explain the methodology applied, and afterwards we will present the results obtained. These results concern output trends, countries' and regional world shares, research productivity indicators, research and technological specialization indicators, scientific impact indicators, a cluster analysis and a regression analysis . Finally, some conclusions will be put forward.

2 - STATE OF THE ART

2.1 - Africa

34 Out of the 49 countries considered to be "least developed" by the *United Nations* (UN)[2] are in Africa. But Africa is a rich continent. Many of its 54 countries are rich in traditional knowledge, especially knowledge associated with indigenous and medical plants (Hassan, 2002), rich in bio-diversity and rich in mineral resources, including oil, metals and precious stones. It was estimated by *The Economist* (2013a) that this wealth in commodities has led to one-third of Africa's more recent GDP (Gross Domestic Product) growth, not counting indirect benefits[3].

However, in the recent *African Progress Report* (2013), Kofi Annan stresses that in many African countries "natural resources revenues are widening the gap between rich and poor. Although much has been achieved, a decade of highly impressive growth has not brought comparable improvements in health, education and nutrition". Poor governance, lack of transparency, tax evasion and illicit outflows may be eroding the revenue base for public finance in many countries.

The continent has made several bold efforts to turn around its development fortunes through treaties that include the *Monrovia Strategy* (1979), the *Lagos Plan of Action* (1980), the *Abuja Treaty* (1991) establishing the *African Economic Community* and, most recently, the adoption of

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[2] http://unstats.un.org/unsd/methods/m49/m49regin.htm

[3] The wave of global commodity higher prices, have benefited Africa's resource rich countries.

Africa's *Science and Technology Consolidated Plan of Action by the African Union* in January 2007 (UNESCO, 2010). Despite these attempts, Africa remains the poorest and most economically marginalized continent in the world.

But still, there is optimism in Africa. There are countries as Uganda, where farmers are using mobile phones to track diseases on bananas[4], or Nigeria, where the film-making industry is producing more new movies per year than the USA[5]. Despite several African regions still experiencing dire crises, on average, conflicts, starvation and dictatorships seem to be declining in the continent (The Economist, 2013c).

2.2 – Education, Science and Technology in Africa

Education and the competence to learn are critical to any society, including Africa. As Lundvall (1992) put it, "knowledge is the most important resource and learning the most important process". However in Africa buying books can still be seen as a luxury (Zegeye & Vambe, 2006). Modern S&T which led the industrialized countries to the development that they have today did not have the same transforming effect on Africa. Science has been described in the continent as in a dismal state (Hassan, 2002). The lack of critical mass and inadequate skills of its research and technical personnel, the poor and neglected quality of the infrastructure, limited access to the necessary information, the low level of instruction in primary and secondary schools, the low investments in universities and research institutes have been characteristics associated with science institutions in many African countries. Financial and logistical support for science is typically divided between many ministries with little coordination, and some states rely too much on intermittent external funding which often target short-term goals (Irikefe, 2011). Yet, the reality is that even the poorest nations must have scientists who are deeply involved in education at all levels, so as to produce the human capital on which much of the development depends (Arunachalam, 2004). More, indigenous research might help provide both effective and focused responses to each country problems. Carrying out their own studies or translating results of studies carried out elsewhere into their national settings could be a strong instrument for development (Nchinda, 2002). After enduring civil conflicts and crisis, many countries have entered a period of growth and leaders are starting to see S&T as keys to progress (Irikefe *et al.*, 2011).

[4] http://blogs.worldbank.org/ic4d/the-power-of-mobile-saving-ugandas-banana-crop
[5] http://en.wikipedia.org/wiki/Cinema_of_Nigeria#History

In terms of technology development, we know that the first tool used by humanoids was in the Lower Awash Valley in Ethiopia[6], about 3,4 million years ago. Nowadays, African countries depend a lot on developed ones to solve their technological issues. Many authors have already demonstrated the relevance of "technological capabilities" (Archibugi & Coco, 2004) for economic growth. For example Fagerberg *et al*. (2007) said that, "deteriorating technology and capacity competitiveness are, together with an unfavourable export structure, the main factors hampering many developing countries in exploiting the potential to catch-up in technology and income". Not every developing country can specialize in high-tech technologies, but successful catch-up has historically been associated not merely with the adoption of existing techniques in established industries, but also with innovation, particularly of the organizational kind, and with inroads into nascent industries (Fagerberg & Godinho, 2004).

Initiatives to track the African performance in S&T are scarce but needed to identify problems and enlighten political choices. In a 2007 research and development (R&D) survey conducted by the African Science, Technology and Innovation Indicators (ASTII) initiative covering 13 African countries[7], there were some relevant conclusions:

- Three countries (Malawi, Uganda and South Africa) scored on GERD/GDP[8] above 1%, but in the remaining 10 countries this ratio ranged between 0,20% and 0,48%.
- With the exception of South Africa and Malawi, the public sector (comprising the government and higher education sectors combined) accounted for the lion's share of R&D expenditure in all of the countries surveyed, accounting for over 50% of total GERD, while the private non-profit sector accounted for a relatively small share of total R&D activity.
- Government is the most important funding source of R&D activities in participating countries. Among the countries surveyed, Mozambique is currently the most dependent on foreign donors, in that more than 50% of its R&D is financed from abroad, followed by Mali (49.0%), Tanzania (38.4%), Senegal (38.3%) and Malawi (33.1%). By contrast, Nigeria and Zambia show very low dependence on foreign funding. In countries such as Ghana, South Africa and Malawi, the business enterprise sector accounts on average for 40% of R&D funding, while in most other countries its share of funding is less than 10%.

[6] http://www.nhm.ac.uk/about-us/news/2010/august/oldest-tool-use-and-meat-eating-revealed75831.html
[7] Cameroon (only partial data), Ghana, Gabon, Kenya, Malawi, Mali, Mozambique, Nigeria, Senegal, South Africa, Tanzania, Uganda and Zambia.
[8] Gross domestic expenditure on R&D (GERD) as a percentage of GDP.

- South Africa, of all the countries surveyed, has the highest number of human resources available for R&D activities, with a researcher density of 825 per million inhabitants, followed by Senegal with 635 researchers per million inhabitants. At the lower end of the scale, Mozambique, Uganda and Ghana have a researcher density of fewer than 25 per million inhabitants[9].

"Brain Drain" is a known problem in Africa. Big efforts are being made to improve education conditions across African countries, but as it is well known if in the end the best "minds" go abroad to work or develop their studies, the most important resource for development, "knowledge", will not be used for their gain. Docquier *et al.* (2007) in a study about brain drain in developing countries, with data for the period between 1990 and 2000, got to the conclusion that the highest average brain drain rates were observed in Sub-Saharan Africa (13%), Latin America and the Caribbean (11%) and the Middle East and North Africa (10%). Some factors that contribute to the increase of this phenomenon include: poor working conditions, low salaries, low level of development, high political instability, religious/ethnic fractionalization, strong colonial links, geographic proximity with Organisation for Economic Co-operation and Development (OECD) countries and country smallness. This is of course an issue that requires reflection when we discuss the "goodness" of African countries investing in science. Social/political stability, incentives to return and efforts helping to keep connections are essential to minimize the brain drain.

The legacy of colonial science is also a relevant issue. Many of the research institutes established during the colonial period still exist in African countries (AU-NEPAD, 2010) and the ties that link the countries can still be seen in the collaborations and co-authorships made between them. For example in Adams *et al.* (2010) we find that Algeria and Tunisia have unique links with France, with the share of international co-authorship with this European country being 42% and 33% respectively. The same happens with the UK's former colonies. Malawi and Kenya have collaboration shares with the former colonial power of 45% and 24%, respectively. Adams *et al.* (2010) also found that globally the most frequent collaboration partner is the USA. This could be a consequence of the researchers who have studied in the USA maintaining links with their former research groups after returning home.

[9] It must be noted that the definition of what a researcher is may condition these results

2.3 - Why to measure science and technology?

Science, technology and knowledge are driving forces of our modern society. Science is an activity mainly financed out of public funds and therefore, evaluation of scientific research is crucial to justify the choices taken and find whether society is getting the appropriate returns. Examining and evaluating the various aspects of the scientific enterprise is a necessary and integral part of science policy. Similarly, the number of patents awarded to a country can be used as an indicator of technological activity (OECD, 2009). Patents are a means of protecting inventions developed by firms, institutions or individuals, as such, patent indicators, within the S&T context, are used to measure inventive performance, diffusion of knowledge and internationalization of innovative activities.

However, knowledge is intangible, and to attempt to assess measurable outputs of S&T can be a risky and questionable task. Bibliometric studies start from the assumption that the most important findings of scientific research and inventions end up in the international literature or in patent applications. But publications are not a perfect measure of scientific production, and patents are not a perfect measure of technological innovation either. There are other forms of indigenous knowledge in Africa as genetic resources from plants, animals and microorganisms that are not explicitly existent in publications or patents. Also in those fields of science (Arts, Humanities and some Social Sciences) where scientific publication is not the main medium for communicating research findings, bibliometrics have a conditioned spectrum of analysis.

Nevertheless, “the mind comprehends a thing the more correctly the closer the thing approaches toward pure quantity as its origin” (Johannes Kepler, 1597). The more information we have about a phenomenon, even if it is a proxy, the better decisions we are able to do in the future as long as we understand the limitations of our instruments. In developing countries, these statistics can be used mainly as powerful indicators of successful catching-up processes (Albuquerque, 2004)

2.3.1 – Bibliometric Analysis

Bibliometrics is the field of science that deals with the development of quantitative measures and indicators for sciences and technology, based on bibliographic information (Leeuwen, 2004). One of the most crucial purposes in bibliometric analysis is to arrive at a consistent and *standardized set* of indicators (Van Raan, 2004). It is so, one of the few “objective” methods of assessing scientific performance[10]. An early definition describes it as "the application of statistical and mathematical methods to books and other media of communication" (Pritchard, 1969). Nowadays, bibliometric analysis is applied more commonly on research publications. When a scientist cites a given article, he or she indicates that the article was somehow relevant to the research performed. The citing author calls attention to some useful information included in the article, a method, a statistic, a result or other[11]. When an article is cited many times it is considered to have international scientific influence (Van Raan, 2003) or impact. Studies such as Moed (2005) provide further reasons to support this view. However, a clear understanding of limitations and caveats is required to interpret the results. For example: language bias, incorrect author affiliations, "Matthew Effect"[12], "Sleeping Beauties"[13], statistical issues, etc., are problems to take in account when making conclusions about the different metrics.

In this study it will be used what van Leeuwen (2004) calls a "descriptive bibliometrics" approach. It is a top-down process, in which all output is collected using the address information of the publications in the chosen citation indexes. Contrary to the "evaluative bibliometrics" approach, where specific target groups are assessed in a bottom-up perspective, this method only offers insight on rather high level of aggregation.

Bibliometric analysis offers insights mainly along four dimensions (Ismail *et al.*, 2009):

1. Activity measurement – number of articles as a measure of output in a given research field, during a given period of time;
2. Knowledge transfer measurement – on the basis that the citation process reflects the communication of knowledge within the scientific community and provides an indirect measure of research quality;
3. Linkage measurement – involving the assessment of links between individuals and research fields as an indication in which the social and cognitive networks of scientific research are developed and sustained;
4. Citation analysis – as a proxy for quality/impact of scientific output.

Despite the referred limitations, bibliometric analysis is one of the most reliable ways to measure the relative importance of a given country or group of countries in the world of science (Gaillard, 2010).

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[10] Others methods are peer reviewing, reputational surveys or analysing industry income from research (See for example: http://www.timeshighereducation.co.uk/world-university-rankings/2012-13/world-ranking/methodology).
[11] Negative or self-citations may be also counted.
[12] "Mathew Effect" can be defined as the enhancement of the position of already eminent scientists who are given disproportional credit in cases of collaboration or of independent multiple discoveries. (Merton, 1968). The more acknowledged is the scientist, the more likely he is cited.
[13] A "Sleeping Beauty" in Science is a publication that goes unnoticed for a long time and then, almost suddenly, attracts a lot of attention (citations) (Van Raan, 2003)

2.3.2 – Patent Analysis

Patent statistics have also been used to assess S&T activities for a long time. According to the *OECD Patent Statistics Manual* in the 1950s Jakob Schmookler was already using patent counts as indicators of technological change in particular industries.

About the use of patents as an innovation indicator, Griliches (1990) published a classic paper assessing ways of using such data, highlighting also some problems. One of these problems is that not all inventions are transformed into patents, because companies have other appropriability mechanisms (see for example Levin *et al*. (1987)). Other methodological problems include evidences of differing patenting behaviour across industries and countries overtime, and skewed value distribution of patents. Some authors argue that it is more reliable to acknowledge patents as an output of R&D or an input to innovation (OECD, 2009).

Our objective when assessing African patent activity is not to create other different object of study, but instead to complement the previous scientific publication analysis with patent data that can offer us information along several topics, for example:

1. Technological Performance – Output, specialization and geography;
2. Emerging technologies – Identify technical fields that are gaining technological relevance;
3. Knowledge diffusion – Patent citations points to the use of previous inventions in new inventions, which allows to track the influence of particular inventions and map the knowledge diffusion
4. The economic value of inventions – Correlations between the value of a patent and the number and quality of its forward citations have been demonstrated (Hall et al. 2005)

Our analysis will be made at the country level. Due to a reduce number of patents applications in Africa, the technological specialization analysis may be skewed.

2.4 - Studies already made

There are limited bibliometric studies analysing S&T in the African countries. Examples include Garfield (1983), Narvaéz-Berthelemot *et al*. (2002), Tijssen (2007), Uthman (2007), Pouris *et al*. (2009), Waast & Rossi (2010), Pouris (2010), Adams (2010) and AU-NEPAD (2010). Most of these studies focus in countries or regions with higher levels of scientific publication and rarely examine science in smaller countries in the region. Some main findings are:

- Already in 1973 South Africa and Egypt were the African countries with higher scientific output (Gaillard, 1983)

- Little scientific co-authorship is found between African countries, preference being given to collaboration with the most developed nations (Narvaez-Berthelemot *et al.,* 2002).
- During the years 1980-2004, Africa's share in worldwide science has steady declined, the share of international co-publications has increased very significantly and low levels of international citation impact have persisted (Tjissen, 2007).
- Some fields of science, like medical sciences, are internationally oriented and tend to attract more international funds, partnerships, and opportunities to publish in international scientific literature (Tjissen, 2007).
- Research production in Africa is highly skewed across nations and disciplinary areas (Uthman *et al.*, 2007).
- Output is sensitive to political instabilities, being the impact higher when the scientific communities are small (Waast *et al.*, 2010).
- Few African countries have the minimum critical mass that may be required for the proper functioning of a scientific discipline (Pouris, 2009).
- Malawi, with one-tenth of the annual research output of Nigeria, produces research of quality that exceeds the world average benchmark while Nigeria research displays about half of the world's impact value (Adams, 2010).
- In Southern Africa there is an emphasis on traditional research areas (agriculture, plant and animal sciences, etc.) and an under-emphasis in scientific areas with higher potential to support innovation such as engineering, material sciences and molecular biology (Pouris, 2010).

With regard to this previous research, our study will update the available information by adopting some previously used methodologies, innovate by using in the African context the indicator "Impact relative to subject area", try to identify some signals on whether African scientific and patenting output shows signs of "catching-up" and compute a cluster analysis to identify groups of countries with similar performances.

3 – METHODOLOGY AND DATA

This study is based on data from two different platforms. For publications we used the relatively new *InCites*[14] tool proposed by *Thomson Reuters,* which is a web-based research evaluation tool that facilitates national and institutional comparisons across long time periods using publication output, productivity and normalized citation impact values (Bornmann *et al*, 2013). To enrich and extend the analysis, PCT applications were also analysed based on the relatively new *WIPO Statistics database*.

3.1 - Publications

InCites has three main modules, of which, in this study, we have only used the "global comparisons". This module provides output and citation metrics from the WoS (*Web of Science, Thomson Reuters*), which in turn will access data and metrics from a dataset (SCI-EXPANDED, SSCI and A&HCI)[16] of 22 million WoS papers from 1981 to 2011 (InCites, 2012). The metrics for comparisons are created based on address criteria[17], using the whole-counting method, i.e. counts are not weighted by number of authors or addresses.

Regarding the subject area scheme, several possibilities existed[18]. Each paper is assigned to a "WoS: 249 Subject Area", according to the journal where it is published (e.g. if a paper is published in *Econometrica* it will go for the "WoS subject area" of Economics). After being affiliated to a certain "WoS subject area", a match is made between "WoS categories" and other categories. In this study we mainly used the *22 Essential Science Indicators* (22 *ESI*). These choices were based on a trade-off between robustness of results and specificity of the subject area. These 22 fields represent themselves conglomerates of many subfields. It must therefore be pointed out that in some fields there could be the case that the overall scores, whether higher or lower, may hide both excellent and less excellent performance at the subfield level. On appendix, we also use the six main subject areas of *OECD: Frascati Fields of Science*[20]. Those were also analysed to compare results and obtain insights from a different perspective.

[14] http://researchanalytics.thomsonreuters.com/incites/

[16] Science Citation Index Expanded (SCI-EXPANDED); Social Sciences Citation Index (SSCI); Arts & Humanities Citation Index (A&HCI). These data sources only cover a small proportion of the world's scientific production. To observe this restricted universe has been seen as an advantage as it refers to the journals that publish the articles that exert more influence in the international literature (Pouris, 2010).

[17] Addresses are taken from the WoS file of each publication belonging to the indexes analysed. The address consolidation process is a complex scheme that is made jointly with some universities cyclically.

[18] Australia ERA 2012 FOR Level 1 (23 Broad categories 2 digit codes); Australia ERA 2012 FOR Level 1 (150 Narrow categories 4 digit codes); China SDADC Subject Categories (12 Broad level by 2 digit codes); China SDADC Subject Categories (77 Narrow level by 4 digit codes); Essential Science Indicators: 22 Subject Areas; FAPESP (BRAZIL); OECD: Frascati Fields of Science; UK RAE 2008 Units of Assessment (65 categories) and Web of Science: 249 Subject Areas.

[20] Which are: (1) Natural Sciences, (2) Engineering and Technology, (3) Medical and Health Sciences, (4) Agricultural Sciences, (5) Social Sciences and (6) Humanities.

3.2 - **Patents**

To compile patent statistics, certain methodological choices have to be made: the treatment of internationally comparable aggregates, reference date, reference country and technology disaggregation scheme.

Concerning the patent office choice we have to take into account that, for a patent to be economically relevant, an institution must apply it in the most important markets (USA, Europe, Japan, China) to maximize the potential economic benefit of it. A statistical solution is to analyse "*triadic patents*[21]" or PCT applications. *Triadic patents* improve the international comparability of patent-based indicators, as only patents applied in the same set of countries are included in the family[22]. But *triadic patents* can be "too selective" for the African context and the only available database[23] didn't provide data from all African countries. The choice fell on African PCT applications and publications[24]. Complementary, we also used the "*Trilateral Co-operation database*[25]" to provide some comments on United States Patent and Trademark Office (USPTO) and European Patent Office (EPO) granted patents. The PCT is an international treaty that provides a unified procedure for filing patent applications in each of the 147 contracting states (as of May 2013)[26]. It allows to seek patent protection by filing an "international application" at the World Intellectual Property Organization (WIPO). This application must then be validated in each national patent office where patent protection is sought (OECD, 2009). PCT information has two drawbacks: first, it is not completely free of bias as applicants make uneven use of it across countries (but has less bias than national offices counting). Second, PCT applications don't lead directly to any patent grant. They are options for future applications to patent offices around the world. Because of the relatively low cost of the initial PCT phase, the PCT procedure is not very selective[27].

The *WIPO Statistics database* also allowed analysing the PCT publications by technological field. This was a plus in the decision of the patent office choice because the alternative solution, *International Patent Classifications*[28] (IPC), is established in an examiner technical point of view in order to retrieve patent documents that reflect the state of the art in a particular field

[21] Set of patent applications filed at the EPO and the JPO, and granted by the USPTO, sharing one or more priority applications (OECD, 2009).
[22] Also patents included in the family are typically of higher value, as patentees only take on the additional costs and delays of extending protection to other countries if they deem it worthwhile (OECD, 2009)
[23] http://stats.oecd.org/Index.aspx?DatasetCode=PATS_IPC
[24] We use again the whole-counting method. Fractional counting is recommended because there could be multiple inventors, from different countries, in the same international application. Our database didn't provide us this information.
[25] http://www.trilateral.net/statistics/grants.html
[26] In Africa, only Democratic Republic of Congo, Ethiopia, Eritrea, Djibouti, Somalia, Cape Verde and Mauritius are not PCT contracting states.
[27] Applicants that are unsure of the value of their invention can file "just in case" and postpone the decision on proceeding to a national phase later
[28] http://www.wipo.int/classifications/ipc/

(OCDE, 2009). The *WIPO Technologies classification* proposed by U. Schmoch (2008)[29] was constructed in a more adequate perspective for economic analysis.

Regarding reference date the choices are made based on the different timings of the patenting process: Priority date, application date, publication date, grant date[30]. In order to reflect the inventive performance, it is recommended to use the priority date to compile patent statistics (Hinze & Schmoch, 2004). But because our database only allows the application date (maximum of 12 months of difference) for trend analysis, and publication dates for technological fields analysis, those were the choices made.

Concerning the reference country, OCDE (2009) recommends choosing the inventor's country of residence or the applicant's country of residence in order to identify the country where the innovative performance really is. It is also possible with this methodology to identify applicants that are not in the countries where the international application is made.

3.3 - **Metrics**

For world trend research output and PCT application output analysis, we used logarithmic world percentages and not absolute values[31]. With this method it is easier to perceive growth rates. We have also analysed the research/PCT performance of African countries relatively to GDP and population. We hope to get a better understanding of research/patenting productivity of each country with these measures.

Besides publication and patent applications output, we will present specialization indexes, both for scientific publications and PCT publications, to assess which countries are more or less specialized in which subject areas/technological fields and also which countries are generally more specialized than others. The *Revealed Comparative Advantage* (RCA) index[35], proposed by Balassa (1965), will be adapted to this paper to compare the specialization intensity of a subject area/technological field *s* in country *i* with the equivalent relative specialization intensity of that subject area/technological field for all countries worldwide.

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29 http://www.wipo.int/export/sites/www/ipstats/en/statistics/patents/pdf/wipo_ipc_technology.pdf

30 For more details see for example: http://www.epo.org/learning-events/materials/inventors-handbook/protection/patents.html

31 To simplify the analysis, in some figures and tables, Africa was divided in three regions (**Northern Africa** (Egypt, Tunisia, Morocco, Algeria, Sudan, Libya); **Central Region** (Nigeria, Kenya, Cameroon, Ethiopia, Uganda, Ghana, Senegal, Cote Ivoire, Burkina Faso, Madagascar, Benin, Gambia, Gabon, Mali, Niger, Republic of the Congo, Togo, Eritrea, Guinea Bissau, Rwanda, Mauritania, Central African Republic, Guinea, Chad, Burundi, Sierra Leone, Liberia, Comoros, Equatorial Guinea, Cape Verde, Djibouti, Sao Tome & Principe, Somalia); **Southern Region** (South Africa, Tanzania, Zimbabwe, Botswana, Malawi, Zambia, Namibia, Mozambique, Mauritius, Democratic Republic of the Congo, Swaziland, Seychelles, Angola, Lesotho). These regional groups broadly correspond to the regional scheme[31] employed by the UN, although the five UN groups have been compressed into three, with the nations designated by the UN as "eastern", "middle" and "western" placed into a "central" region (South Sudan was the only African country recognized by the UN left out because they became an independent state very recently, on the 9th of July 2011). A similar methodology was used by Adams *et al*. (2010).

35 For patent analysis it can also be called revealed technological advantage index (RTA).

$$1)\ \ RCA = \frac{P_{is}/P_i}{P_s/P}$$

P_{is} Accounts for the number of publications/patents in subject area/technological field s in country i, P_i accounts for the total number of publications/patents in that same country i, P_s accounts for the total number of publications/patents in subject area/technological field s in the world, and finally P accounts for the total number of publications/patents in the world.

In order to assess whether a country is "specialized" or "not specialized"[36] the Chi-square of sectoral specialization used by Godinho & Ferreira (2012) is adapted to our context. This measure provides a ratio which in the numerator displays the square of the difference between specialization intensity of class s in country i and specialization intensity of that class in the world, while the same denominator displays the sum of the weighting of all subject areas in country i, with this ratio summed up across all s subject areas/technological fields. The Chi-square of sectoral specialization grows with the specialization intensity of a country and is calculated as follows:

$$2)\ \ X_i^2 = \sum_s \left(\frac{[(X_{si}/\sum_s X_{si}) - (\sum_i X_{si}/\sum_s \sum_i X_{si})]^2}{(\sum_i X_{si}/\sum_s \sum_i X_{si})} \right)$$

In the bibliometric analysis we will also show normalized citation impact values for the most prolific African nations and also world comparisons for the period of 2007-2011. Additionally, in the appendix, we present the evolution of impact relative to subject area in all *22 ESI*, from the aggregate period of 2002-2006 to the aggregate period of 2007-2011.

Citation impact relative to subject area (CXC) is a calculation made by *Thomson Reuters,* based on previous research made by Centre for Science and Technology Studies (CWTS) of Leiden University (See for example Moed, 1995), that estimates the mean citation rate of a country's set of publications (c) in a specific subject area, in a specific period of time, for the specific document type, and then divides it by the mean citation rate of all publications (μ_f) within the relevant subject area/period/doc type.

$$3)\ \ CXC = \frac{\sum_{i=1}^{P} c_i}{\sum_{i=1}^{P} [\mu_f]_i}$$

A value of 1 for a specific country (in a specific subject area-period-document) indicates that the citation impact of papers published by scientists in this country is no more or less than the worldwide average impact of papers in the same subject area. If this value stands at 1.2, for

[36] The word "specialization" generally means "concentration" rather than "advantage".

example, the corresponding papers were cited 20 percentage points, on average, above the worldwide average in the subject area (Bornmann *et al*, 2013)[37].

Then, a cluster analysis will group bibliometric and other relevant indicators to understand if there is the case for similar performances and patterns between countries. For this end, we will iterate some clustering algorithms and see if the results are similar using different hierarchical clustering methods. The 19 indicators chosen are distributed in 7 dimensions. Their description can be seen on table 9 on appendix. The clusters obtained where computed, after standardization of indicators, using the "Between groups linkage" with "Squared Euclidean distance".

Finally, to perform a regression analysis that describes the relationship between WoS Publications (2002-2011) and PCT Applications (2002-2011), a simple model is made. The observations are all African countries that have at least one PCT application in a two-dimensional plot in a log-log scale. WoS Publications and PCT Applications are both divided yearly per million of inhabitants in each country in the period analysed and then summed up to establish each indicator.

4 – RESULTS

In what follows, we begin from a broader perspective and as we progress along the section we will move to more specific aspects of Africa's research and patent activity. In the next point (4.1) we will provide information about the bibliometric analysis. First we will show 'the big picture' (4.1.1), then the productivity analysis (4.1.2), specialization patterns (4.1.3), the impact of scientific output (4.1.4) and a cluster analysis (4.2). Subsequently we will move to the patent analysis. Output trends first (4.3.1) and specialization patterns (4.3.2) after. Finally we will compute a regression analysis analysing publications versus patents (4.4)

4.1 – Bibliometric Analysis

4.1.1 – General developments and trends

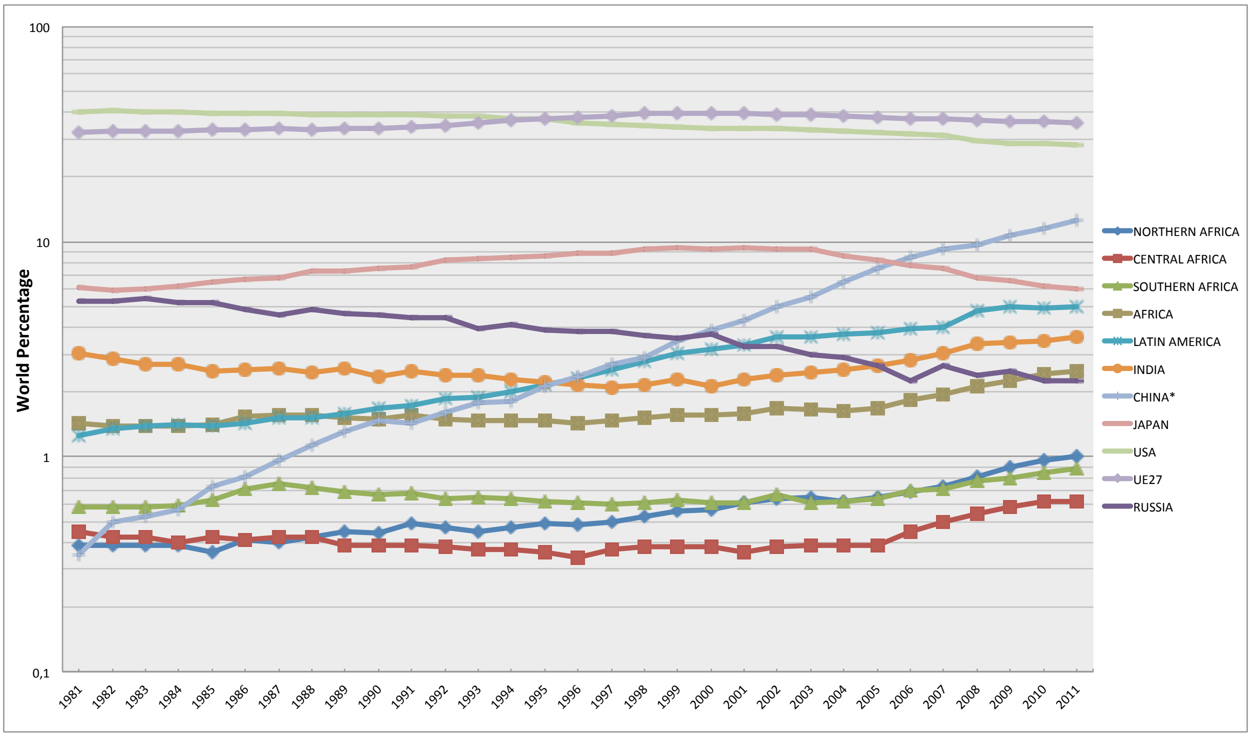
Africa's long-term publication output trends indicate that its relative contribution lowered slightly during the 1990s[38], but since then it has been growing at a constant rate, with a sort of

[37] *InCites* is one of the only sources of normalized data currently available for bibliometrics. Because it uses data from the reliable WoS Indexes, it is assumed that the obtained results are also reliable (see Greco *et al*., 2013 and Bornmann *et al*. 2013).

[38] Tijssen (2007) points out that one possible explanation for this could be the removal of African journals from the citation indexes in this period.

"take-off" in 2004. This "take-off" occurs at the same time in the three African regions analysed. Figure 2 shows that "Northern Africa" is the region that has grown faster in Africa.

Figure 1: Trends in research article output by countries/regions (shares as world percentage) in the international journal literature (1981-2011)

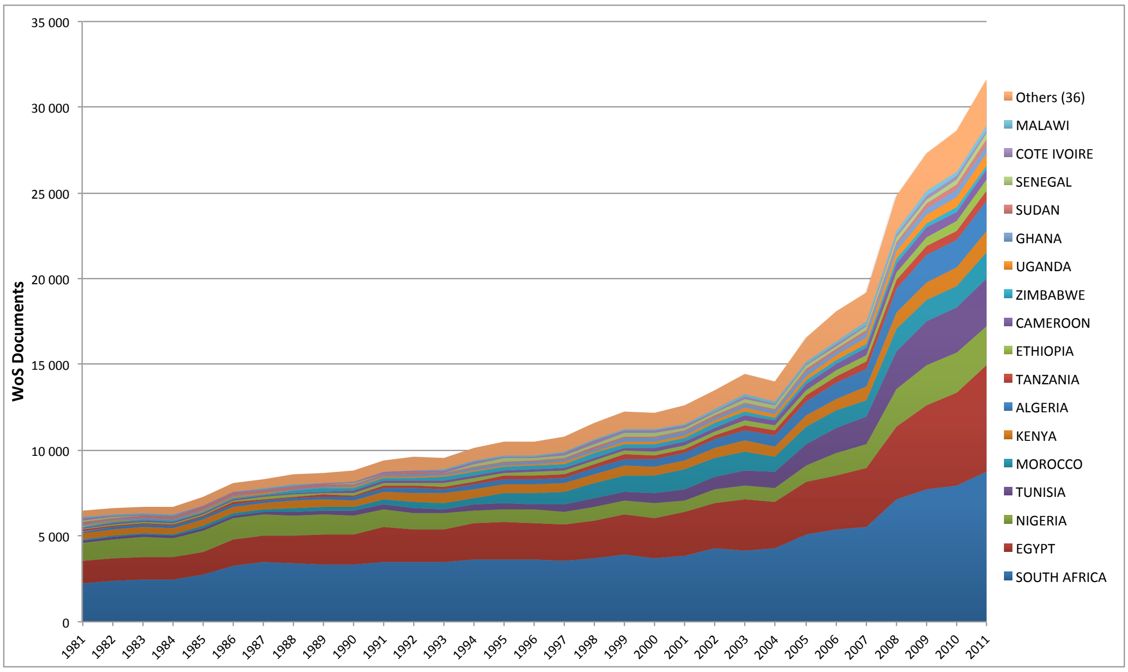


Source: InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI)
*China includes Hong Kong and Macau
** This analysis has a limitation. There is a bias in Africa, Northern Africa, Central Africa and Northern Africa results. The whole-counting method implies that when the publications of each country are added in one of these aggregates, there could be multiple counting if a publication has two or more African countries in the addresses. Contrary to Latin America, InCites doesn´t provide aggregate results for Africa. Nevertheless, our estimations suggest that this bias don't undermine the discovery of a turning point in 2004.

It is important to keep in mind that the evolution of these world shares does not reflect decreases or increases in absolute terms, but rather variations in relation to the worldwide growth rate. For example, the European Union (EU27) had 309,508 publications in 2002 and 450,327 in 2011, amounting to an approximate 50% absolute increase in the period. But if we compare the 10-year compound annual growth rate (CAGR 10) for the EU27 (3,8%) and the World (4,7%), we understand why the EU27's world share is shrinking. In contrast, the growth of China is outstanding. China has come from the same level as the African "Northern Region" in 1981 up to reaching more than ten percent of the world publication output in 2011.

Only since 2004 Africa's share of the world output has started to grow at a constant higher pace. If we look to the CAGR over a 30-year period, we see that the difference between the world's growth (3,3%) and Africa's growth (5,4%) is just 2,1%. But if we take the most recent 10-year period and look at Africa's CAGR (8,9%) and compare it with the world's average (4,7%) we realize the differential has grown bigger (4,2%). In Africa, "Northern Africa" is the region that has moved faster and increased most its relative share in world output. Nevertheless, "Central" and "Southern Africa" have also started to move faster gaining bigger share recently. Africa, as a whole, has even got above Russia's output by 2010. Africa has now (2011) a 2,51% share of the World scientific production.

Figure 2: Research output trends of individual African countries (Top17*)



Source: InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI)
*Countries with more than one percent of Africa's output.

Figure 2 illustrates that until 2004 African countries had a constant publications aggregate growth rate of approximately five percent a year. In 2004 the total number of publications originated in Africa didn't reach 15,000. From that year on, however, there is an acceleration of Africa's output. This trend has been driven mainly by South Africa, Egypt, Nigeria and Tunisia[39]. If we compare the 5-year CAGR of Africa (10,5%) and the World (5,1%) over the most recent period (2007-2011), it becomes quite clear that a convergence in scientific production with other world regions is happening now. In this most recent period only China (with a CAGR of 11,7%) is performing better.

We have also estimated the 5/10/30-year CAGR for all African countries individually between 1982 and 2011 (Table 6 on the appendix). Almost all the main countries have grown above

[39] 5-year CAGR: South Africa (9,6%), Egypt (12,8%), Nigeria (9,6%) and Tunisia (12%).

world average. Exceptions to this rule, in the last ten years, are: Morocco (research seems to have lost priority in S&T Policy – Waast, 2010), Zimbabwe (Mugabe's governance, economic difficulties and hyperinflation), Gambia (relatively small and "poor" country fustigated by coups), Eritrea (still in conflict with Egypt), Guine-Bissau (also harassed by coups), etc. In contrast, the recent growth in GDP and consequently more resources for R&D, fewer conflicts, increasing collaborations among researchers in Africa and the developed world, and awareness for the creation of concrete S&T policies, may have originated the growth in publications in South Africa, Egypt, Nigeria and Tunisia.

We have seen that the world output of publications is quite concentrated in the last years in three regions/countries (EU27, USA, China). They represent more than 75% of the world output in 2011. If we make a similar exercise within the publications of Africa, we will notice that a small number of nations also dominate African production. South Africa and Egypt alone stand for more than 50% of total publications in the period of 1981-2011. There are historical influences as well-established universities in both countries (some exist for more than a century) which lead to clear advantages over those science systems where universities were established only four or five decades ago (AU-NEPAD, 2010). The remaining 51 African countries analysed are approximately responsible for the remaining 50%. Contributions from Nigeria (9%), Tunisia (6%), Morocco (5%), Kenya (4%) and Algeria (4%) are also significant. The breakdown also reveals that there are only 17 countries out of the 53 , which represent more than 1% of total African production. These discrepancies have been changing (in 1981 South Africa, Egypt and Nigeria represented 71% of the total African output and in 2011 they "only" represent 55%) but it is still a clear sign of the differences in "African science". This catch-all term "African science" is therefore dangerous because it covers a broad collection of African nations with a very heterogeneous set of research systems in terms of size, human and financial resources, scientific specialization, general objectives, and local governance structures (Tijssen, 2007).

4.1.2 – Research productivity in Africa

The absolute volume of published papers is one indicator of research activity and indirectly of research capacity. But countries have different dimensions. It is likely that countries with higher populations will have more publications. The same logic is also true in relation to Gross Domestic Product (GDP). A wealthier economy will have, in principle, more resources to invest in education and R&D; therefore a bigger propensity to publish papers is expectable. Data in Table 1 allows for a comparison of the scientific productivity (per thousand million US$ and per million inhabitants) of African countries.

Table 1: Research performance of African countries relative to GDP and population: Summary statistics (2002-2011)

	Country	GDP p. Cap	Total Docs Output			Docs/GDP*		Docs/Pop**	
		2011 (current$)	2002-2006	2007-2011	CAGR 10 (02-11)	2002-2006	2007-2011	2002-2006	2007-2011
1	SOUTH AFRICA	8 070 $	23 191	37 035	7,4%	30	40	99	150
2	EGYPT	2 781 $	14 596	24 341	9,0%	25	32	40	61
3	TUNISIA	4 297 $	5 292	11 709	13,9%	41	73	106	224
4	NIGERIA	1 502 $	4 578	10 526	11,4%	16	26	7	14
5	MOROCCO	3 054 $	5 138	6 329	3,2%	23	22	34	40
6	ALGERIA	5 244 $	3 519	7 335	12,9%	11	19	22	42
7	KENYA	808 $	3 147	5 080	7,9%	43	55	18	26
8	TANZANIA	532 $	1 540	2 637	10,3%	23	28	8	12
9	CAMEROON	1 260 $	1 523	2 596	9,2%	28	41	18	27
10	ETHIOPIA	357 $	1 447	2 509	11,3%	29	30	4	6
11	UGANDA	487 $	1 217	2 699	15,7%	29	45	9	17
12	GHANA	1 570 $	1 040	1 946	10,8%	34	46	10	16
13	SENEGAL	1 119 $	970	1 378	8,6%	35	41	18	23
14	ZIMBABWE	757 $	1 052	1 194	0,5%	42	60	17	19
15	MALAWI	365 $	608	1 196	10,4%	66	95	10	17
16	BURKINA FASO	600 $	625	1 064	11,5%	37	48	9	13
17	BOTSWANA	8 533 $	714	937	4,6%	20	23	77	95
18	SUDAN	1 435 $	526	1 122	12,9%	7	10	4	7
19	COTE IVOIRE	1 195 $	648	957	5,3%	13	17	7	10
20	ZAMBIA	1 425 $	469	853	10,4%	24	32	8	13
21	BENIN	802 $	423	890	11,5%	32	55	11	21
22	MADAGASCAR	465 $	475	807	9,3%	23	32	5	8
23	LIBYA	9 957 $	340	621	8,6%	2	2	12	20
24	MALI	601 $	357	588	10,9%	23	29	6	8
25	GAMBIA	536 $	373	439	0,3%	85	83	51	52
26	GABON	7 409 $	332	464	6,9%	12	15	49	63
27	MOZAMBIQUE	423 $	234	550	15,9%	8	13	2	5
28	NAMIBIA	3 983 $	330	382	3,6%	14	13	32	34
29	CONGO REP.	2 434 $	259	416	8,6%	14	18	15	21
30	NIGER	351 $	192	387	11,3%	18	29	3	5
31	MAURITIUS	6 929 $	246	313	3,0%	10	10	40	49
32	CONGO DEM. REP.	231 $	85	332	25,2%	3	10	0	1
33	RWANDA	583 $	165	242	25,5%	6	17	2	6
34	TOGO	588 $	73	308	9,7%	24	31	6	8
35	SWAZILAND	3 725 $	73	171	10,6%	9	18	14	33
36	ERITREA	482 $	126	96	-6,3%	32	25	6	4
37	GUINEA BISSAU	629 $	98	111	0,4%	96	94	15	15
38	GUINEA	498 $	79	119	7,2%	5	6	2	2
39	CENT AFR REPUBL	489 $	82	107	5,4%	19	22	4	5
40	MAURITANIA	1 151 $	90	91	4,9%	11	9	6	5
41	ANGOLA	5 318 $	57	117	10,6%	2	2	1	1
42	SEYCHELLES	11 711 $	58	114	20,6%	19	31	139	264
43	LESOTHO	1 106 $	78	73	9,6%	9	20	4	10
44	CHAD	823 $	39	102	2,9%	6	5	2	1
45	SIERRA LEONE	374 $	27	90	16,5%	5	12	1	3
46	BURUNDI	271 $	36	74	20,9%	8	13	1	2
47	LIBERIA	374 $	18	26	5,8%	6	5	1	1
48	CAPE VERDE	3 798 $	10	32	-	4	7	4	13
49	DJIBOUTI	1 203 $	9	26	25,9%	4	4	2	6
50	EQUATORIAL GUINEA	27 478 $	14	18	5,2%	1	1	5	5
51	COMOROS	810 $	11	19	17,5%	10	16	4	5
52	SAO TOME & PRINCIPE	1 473 $	10	9	0,0%	0	0	13	11
53	SOMALIA	-	5	10	11,6%	0	0	0	0
	NORTHERN AFRICA	-	29 411	51 457	9,4%	19	28	32	52
	CENTRAL AFRICA	-	18 023	33 419	10,1%	22	30	8	13
	SOUTHERN AFRICA	-	29 210	46 711	7,5%	27	34	26	37
	AFRICA	-	76 644	131 587	8,9%	22	30	17	27
	WORLD	-	4 502 449	5 803 473	4,7%	25	28	140	170

Source: Own calculations. World Bank. InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI)
* Average number of publications per GDP (constant 2000 thousand million US$)
** Average number of publications per million people
*** CAGR 10 (Compound aggregate growth rate) green if above African average, red if below World average
**** The GDP per capita of Libya and Djibouti is from 2009 due to lack of data in 2011. In the event of failures in time series (GDP or Pop) the indicators are averages of data in the existing years

The 53 African countries are ranked by aggregate production between 2002 and 2011. It becomes evident that different countries have different levels of productivity. The four leading countries by output are South Africa, Egypt, Tunisia and Nigeria. From these, only Nigeria is below the African average[40] in both productivity indicators analysed in the table above.

In the indicator "average number of publications per GDP" (**Docs/GDP**), the average African performance was below the world average in 2002-2006, but has since then risen above it 2007-2011. This means that, generally, despite the recent "impressive growth" of African GDP[41], the scientific publication in Africa has grown even more[42]. Countries such as Tunisia, Malawi (very low GDP), Gambia (very low GDP) and Guine-Bissau (very low GDP) are pulling-up Docs/GDP average in Africa. Other countries like South Africa, Nigeria, Cameroon, Zimbabwe, Uganda, Ghana and Benin had also a great improvement in this indicator from one period to the other. In Uganda, for example, a possible cause for this rise may be the increases in education quality (UNDP, 2013). Adams *et al.* (2010) doing the same analysis, for 2008 only, reached similar results. Zimbabwe, Tunisia and Malawi had strong relative productivity growth, and South Africa, Kenya, Egypt, Ethiopia, Uganda, Tanzania, Cameroon and Ghana were next with significant relative productivity increases.

However, when we turn to the indicator "average number of publications per million people" (**Docs/Pop**) the results are much worse for Africa. Only Tunisia and Seychelles[43] are above the world average (170 Docs/Pop) while other countries such as Nigeria, Tanzania, Ethiopia, Burkina Faso, Sudan, Cote d'Ivoire, Zambia, Madagascar, Mali, etc., have less than 15 Docs/Pop in the period of 2007-2011. From the three regions, "Northern Africa" is the region that has better results, and "Central Africa" is clearly the region where countries have the lowest African productivity in this indicator. However, the African average in this indicator has increased more than 50% between the two periods, much more than world average. AU-NEPAD (2010) have done a similar study, but for different periods (1990-1994 and 2005-2009). The results obtained by that study in the second period were, generally, below our last period (2007-2011). Nevertheless, the "big picture" obtained is the same.

It's relevant to notice that this indicator (Docs/Pop) is not biased, as the indicator Docs/GDP, by the low levels of GDP that African countries in general have. Therefore, it could be a more

[40] This average is simply the mean of the 53 countries indicator.
[41] http://www.economist.com/blogs/dailychart/2011/01/daily_chart
[42] The African average is a simple average of all the countries indicators
[43] Seychelles had approximately 86000 people in 2011 (World Bank, 2013)

reliable source of measure, when comparing countries "real" productivity on scientific production.

In short, the general productivity of African countries is relatively much higher if we measure it by Docs/GDP than by Docs/Pop. "Central Africa" is the extreme in this phenomenon. It has on average relative high Docs/GDP because it has countries with very low GDPs, but has a residual/insignificant Docs/Pop because in reality the productivity of those countries is relatively low[44].

4.1.3 - Research specialization in Africa

Countries often try to invest strategically in research areas important to their economic development. But differences in the shape and distribution of scientific output across scientific fields in different countries and regions are context-dependent. This may happen because of changing research demands (agrarian vs. industrialized economies), strengths of scientific establishments ("Path dependence", historical and cultural influences) as well as incentives and government funding of scientific research. Also important is the science system size, as larger science systems have the capacity for more diversity and more coverage of the full scope of sciences while smaller systems may be limited in their ability to invest in specific domains.

In this first specialization analysis we will use the 22 *Essential Science Indicators* (*ESI)*. Table 2 gives us the Top5 African countries with higher output in each of the *22 ESI*, the relative percentage of that output in the world and, in addition, the RCA in the period of 2007-2011.

[44] International comparisons of scientific productivity could also be measured by dividing the number of scientific papers by R&D workforce (either headcounts or full-time equivalents). This is generally regarded as a more refined measure because it directly quantifies the productivity of the workforce that produced the papers. However, the lack of available data and the possible unreliability of the statistics on the research workforce in some countries (AU-NEPAD, 2010) would mean careful analysis when interpreting the results of such calculation.

Table 2: Top5 African nations with more publications in the 22 main fields used in Thomson Reuters *ESI* database, 2007-2011

Most prolific African nations in 22 ESI fields, 2007-2011

Top five nations ranked by number of papers, percent of papers worldwide in subject area and revealed comparative advantage

FIELD / RANK	1	Docs	%Docs W	RCA	2	Docs	%Docs W	RCA	3	Docs	%Docs W	RCA	4	Docs	%Docs W	RCA	5	Docs	%Docs W	RCA
Agricultural Sciences	NIGERIA	1 171	0,89%	**4,90**	SOUTH AFRICA	961	0,73%	1,18	EGYPT	885	0,67%	**1,58**	TUNISIA	660	0,50%	**2,45**	KENYA	488	0,37%	**4,23**
Biology & Biochemistry	SOUTH AFRICA	1 640	0,55%	0,77	NIGERIA	1 318	0,44%	**2,44**	EGYPT	855	0,29%	0,68	TUNISIA	801	0,27%	1,32	KENYA	221	0,07%	0,85
Chemistry	EGYPT	4 631	0,70%	**1,65**	SOUTH AFRICA	2 896	0,44%	0,71	ALGERIA	1 418	0,21%	**1,67**	TUNISIA	1 192	0,18%	0,88	MOROCCO	1 073	0,16%	0,49
Clinical Medicine	SOUTH AFRICA	5 662	0,47%	0,76	EGYPT	4 593	0,38%	0,89	NIGERIA	2 618	0,22%	1,19	TUNISIA	2 279	0,19%	0,92	KENYA	1 329	0,11%	1,25
Computer Science	EGYPT	362	0,31%	0,72	SOUTH AFRICA	343	0,29%	0,47	TUNISIA	270	0,23%	1,12	ALGERIA	227	0,19%	1,50	MOROCCO	98	0,08%	0,75
Economics & Business	SOUTH AFRICA	960	0,93%	**1,52**	NIGERIA	116	0,11%	0,62	KENYA	99	0,10%	1,10	TUNISIA	96	0,09%	0,46	ETHIOPIA	62	0,06%	1,39
Engineering	EGYPT	2 919	0,60%	1,41	SOUTH AFRICA	1 895	0,39%	0,63	ALGERIA	1 509	0,31%	**2,40**	TUNISIA	1 247	0,26%	1,25	MOROCCO	581	0,12%	1,07
Environment & Ecology	SOUTH AFRICA	2 328	1,41%	**2,29**	KENYA	564	0,34%	**3,90**	EGYPT	501	0,30%	0,72	NIGERIA	477	0,29%	**1,59**	TUNISIA	440	0,27%	1,31
Geosciences	SOUTH AFRICA	1 819	1,11%	**1,80**	EGYPT	680	0,41%	0,98	MOROCCO	346	0,21%	**1,91**	TUNISIA	252	0,15%	0,75	ALGERIA	205	0,13%	0,97
Immunology	SOUTH AFRICA	794	1,21%	**1,95**	KENYA	299	0,45%	**5,18**	UGANDA	253	0,38%	**8,24**	EGYPT	183	0,28%	0,66	TUNISIA	131	0,20%	0,97
Materials Science	EGYPT	1 876	0,70%	**1,66**	ALGERIA	848	0,32%	**2,47**	SOUTH AFRICA	765	0,29%	0,46	TUNISIA	712	0,27%	1,30	MOROCCO	277	0,10%	0,94
Mathematics	SOUTH AFRICA	1 009	0,62%	1,01	TUNISIA	690	0,43%	**2,09**	EGYPT	585	0,36%	0,85	MOROCCO	571	0,35%	**3,19**	ALGERIA	514	0,32%	**2,47**
Microbiology	SOUTH AFRICA	789	0,82%	1,32	EGYPT	498	0,52%	1,22	TUNISIA	378	0,39%	**1,92**	NIGERIA	317	0,33%	**1,81**	KENYA	208	0,22%	0,57
Molecular Biology & Genetics	SOUTH AFRICA	413	0,26%	0,43	EGYPT	274	0,17%	0,41	TUNISIA	252	0,16%	0,79	KENYA	76	0,05%	0,55	NIGERIA	68	0,04%	0,24
Multidisciplinary	SOUTH AFRICA	160	1,20%	**1,94**	NIGERIA	107	0,80%	**4,41**	KENYA	31	0,23%	**2,64**	EGYPT	15	0,11%	0,26	ETHIOPIA	15	0,11%	**2,58**
Neuroscience & Behavior	SOUTH AFRICA	322	0,20%	0,32	EGYPT	169	0,10%	0,24	TUNISIA	121	0,07%	0,36	NIGERIA	65	0,04%	0,22	MOROCCO	44	0,03%	0,24
Pharmacology & Toxicology	EGYPT	995	0,89%	**2,09**	NIGERIA	513	0,46%	**2,52**	SOUTH AFRICA	494	0,44%	0,71	TUNISIA	190	0,17%	0,83	CAMEROON	122	0,11%	**2,42**
Physics	EGYPT	2 247	0,44%	1,04	SOUTH AFRICA	1 581	0,31%	0,50	ALGERIA	1 207	0,24%	**1,85**	TUNISIA	745	0,15%	0,72	MOROCCO	641	0,13%	1,14
Plant & Animal Science	SOUTH AFRICA	4 936	1,59%	**2,57**	EGYPT	1 367	0,44%	1,04	NIGERIA	1 040	0,34%	**1,85**	TUNISIA	1 029	0,33%	**1,62**	KENYA	832	0,27%	3,05
Psychiatry/ Psychology	SOUTH AFRICA	1 026	0,71%	1,15	NIGERIA	150	0,10%	0,57	UGANDA	79	0,05%	1,17	EGYPT	60	0,04%	0,10	KENYA	52	0,04%	0,41
Social Sciences, general	SOUTH AFRICA	3 564	1,26%	**2,05**	NIGERIA	707	0,25%	1,38	KENYA	437	0,16%	**1,77**	TANZANIA	314	0,11%	**2,45**	ETHIOPIA	307	0,11%	**2,50**
Space Science	SOUTH AFRICA	759	1,19%	**1,92**	EGYPT	107	0,17%	0,39	NAMIBIA	54	0,08%	**12,75**	NIGERIA	52	0,08%	0,45	ALGERIA	52	0,08%	0,63

Source: Own calculations; InCites/Thomson Reuters (SCI-EXPANDED; SSCI)
* RCA = Share of a country's papers in a given field relative to the share of world papers in that field
** %Docs W = World percentage of publications in a subject area.
*** Bold above 1,50. Considered here to be relative high specialization at the country level. If the country has low overall output the results can be skewed by relative high publication in one subject area (See Namibia on Space Science).

South Africa is the only country that appears in all 22 *ESI* Top5. Apart from demonstrating their dominance in Africa, it shows that the distribution between subject areas is quite evenly spread. Only in areas such as engineering, materials science, molecular biology & genetics, computer science, neuroscience & behaviour and physics the country is underrepresented (less the 0,4% of the world output). Pouris (2010) also detected this relatively weaker performance in the first three subject areas mentioned here. On the other hand, there are seven areas where South Africa has more than 1% of the world output percentage. Space Science performance must be related with the inauguration of the Southern African Large Telescope[45] in November 2005. Located in Surtherland, it is the largest optical telescope in the southern hemisphere, and is able to record distant stars, galaxies and quasars.

Egypt is also very well represented in this table. In six areas it is the main contributor for Africa (Chemistry, Computer Science, Engineering, Materials Science, Pharmacology & Toxicology and Physics). Nigeria is the main contributor for Agricultural Sciences with 0,89% of the world output and Tunisia and Kenya are also present in the first positions of almost all subject areas.

The areas with bigger aggregate output from Africa relatively to the world are: Agricultural Sciences (5,12%), Immunology (4,58%), Plant & Animal Science (4,34%), Environment & Ecology (4,21%), Microbiology (3,58%), Geosciences (2,96%), Social Sciences (2,70%) and Pharmacology & Toxicology (2,62%)[46].

In appendix, on table 7, it is also showed the research specialization of the 53 African countries in the 6 main Frascati Fields[47] between 2002 and 2011. From there we can also conclude that "Agricultural Sciences" is the area where Africa specializes more relatively to the world output. This seems reasonable because Africa is still heavily dependent on income from natural resources as agricultural commodities. For example in Ethiopia, late Prime Minister Meles Zenawi developed a vision for the country that focuses mainly on improving precisely agriculture. Nowadays, this sector (with coffee and sesame as the biggest exports) accounts for 46% of GDP and employs 79% of the workforce (The Economist, 2013b). In table 7 we can also see that, between the two periods, Africa almost doubled its scientific production in all fields. "Medical and Health Sciences" is outstanding in this respect, with countries like Egypt, Tunisia, Nigeria and Uganda more than doubling its output. Tjissen (2007) argues that this specialization, in some countries, may be a consequence of the research work on tropical

[45] http://www.salt.ac.za/

[46] Areas above African average world percentage.

[47] There is no linear relation between Frascati Fields and 22 *ESI*, despite the two schemes being derived from the WoS categories. Frascati Fields includes Humanities.

diseases and specific health problems in Sub-Saharan Africa, the location of international medical research centres on African soil and the abundance of international cooperation between African researchers and those overseas.

Also surprising are the levels of specialization of Northern African countries such as Algeria, Egypt, Tunisia and Morocco in the "Engineering and Technology" field. This may be related to relative differences in industrialization bases between both Northern African countries and South Africa, on one side, and the rest of Africa, on the other side. Colonial heritage from French and English-speaking zones may be a contributing factor when we look at the potential for historical co-operation with researchers from industrialized powers.

Another way to look at these results is to invert the previous table 2 and see which subject areas are more relevant in each country.

Table 3: Top5 subject areas in African nations with more than 1% of Africa total output, 2007-2011

Subject areas of higher relative specialization in each African country, 2007-2011

Top five nations ranked by revealed comparative advantage, number of papers and percent of papers worldwide in subject area

COUNTRY (Xi^2)/RANK	Docs	%Docs W	RCA	Docs	%Docs W	RCA	Docs	%Docs W	RCA	Docs	%Docs W	RCA	Docs	%Docs W	RCA
	1			2			3			4			5		
SOUTH AFRICA (0,39)	Plant & Animal Science			Environment & Ecology			Social Sciences, general			Immunology			Space Science		
	4 936	1,59%	**2,57**	2 328	1,41%	**2,27**	3 564	1,26%	**2,05**	794	1,21%	**1,95**	759	1,19%	**1,92**
EGYPT (0,22)	Pharmacology & Toxicology			Materials Science			Chemistry			Agricultural Sciences			Engineering		
	995	0,89%	**2,09**	1 876	0,70%	**1,66**	4 631	0,70%	**1,65**	885	0,67%	**1,58**	2 919	0,60%	1,41
TUNISIA (0,23)	Agricultural Sciences			Mathematics			Microbiology			Plant & Animal Science			Biology & Biochemistry		
	660	0,50%	**2,45**	640	0,43%	**2,09**	378	0,39%	**1,92**	1 029	0,33%	**1,62**	801	0,27%	1,32
NIGERIA (0,84)	Agricultural Sciences			Pharmacology & Toxicology			Biology & Biochemistry			Plant & Animal Science			Microbiology		
	1 171	0,89%	**4,90**	513	0,46%	**2,52**	1 318	0,44%	**2,44**	1 040	0,34%	**1,85**	317	0,33%	**1,81**
ALGERIA (0,77)	Materials Science			Mathematics			Engineering			Physics			Chemistry		
	848	0,32%	**2,47**	514	0,32%	**2,47**	1 509	0,31%	**2,40**	1 207	0,24%	**1,85**	1 418	0,21%	**1,67**
MOROCCO (0,30)	Mathematics			Geosciences			Chemistry			Agricultural Sciences			Environment & Ecology		
	571	0,35%	**3,19**	346	0,21%	**1,91**	1 073	0,16%	1,47	193	0,15%	1,33	220	0,13%	1,21
KENYA (1,38)	Immunology			Agricultural Sciences			Environment & Ecology			Plant & Animal Science			Microbiology		
	299	0,45%	**5,18**	488	0,37%	**4,23**	564	0,34%	**3,90**	832	0,27%	**3,06**	208	0,22%	**2,46**
UGANDA (1,46)	Immunology			Environment & Ecology			Agricultural Sciences			Microbiology			Social Sciences, general		
	253	0,38%	**8,24**	239	0,15%	**3,11**	144	0,11%	**2,34**	105	0,11%	**2,33**	286	0,10%	**2,17**
TANZANIA (1,01)	Immunology			Environment & Ecology			Agricultural Sciences			Social Sciences, general			Plant & Animal Science		
	118	0,18%	**3,95**	261	0,16%	**3,49**	160	0,12%	**2,68**	314	0,11%	**2,45**	285	0,09%	**2,02**
CAMEROON (0,49)	Agricultural Sciences			Immunology			Pharmacology & Toxicology			Microbiology			Plant & Animal Science		
	202	0,15%	**3,41**	79	0,12%	**2,67**	122	0,11%	**2,42**	100	0,10%	**2,30**	304	0,10%	**2,18**
ETHIOPIA (1,26)	Agricultural Sciences			Plant & Animal Science			Environment & Ecology			Social Sciences, general			Geosciences		
	244	0,19%	**4,27**	485	0,16%	**3,60**	250	0,15%	**3,49**	307	0,11%	**2,51**	153	0,09%	**2,15**
GHANA (1,13)	Agricultural Sciences			Environment & Ecology			Immunology			Social Sciences, general			Microbiology		
	230	0,17%	**5,22**	201	0,12%	**3,64**	69	0,10%	**3,13**	235	0,08%	**2,49**	75	0,08%	**2,32**
SENEGAL (0,61)	Microbiology			Immunology			Agricultural Sciences			Geosciences			Plant & Animal Science		
	78	0,08%	**3,40**	52	0,08%	**3,33**	99	0,08%	**3,17**	74	0,05%	**1,90**	139	0,04%	**1,88**

Source: Own calculations; InCites/Thomson Reuters (SCI-EXPANDED; SSCI)
* RCA = Share of a country's papers in a given field relative to the share of world papers in that field
** Bold above 1,50. Considered here to be relative high specialization at the country level.
*** %Docs W = World percentage of publications in a subject area.

**** Xi^2 = Chi-square of sectoral specialization. This measure provides a ratio to assess whether a country is "specialized" or "not specialized". It grows with the specialization intensity of a country.

Table 3 does that for the countries with more than 1% of Africa total output (almost 88% of total African production in this period).Countries are ranked by total output between 2007 and 2011, and the five scientific areas are ordered by revealed comparative advantage (descending order). It is clear that research specialization is different across African countries. Countries like Uganda (1,46), Kenya (1,38), Ethiopia (1,26), Ghana (1,13) and Tanzania (1,01) are highly specialized in some specific areas: Environment & Ecology, Agricultural Sciences and Immunology; and others such as Egypt (0,22), Tunisia (0,23), Morocco (0,30) and South Africa (0,39) are not so relatively specialized[48].

To summarize, in the last 5 years African Countries have become specialized mainly in Agricultural Sciences (Related areas such as Environmental & Ecology and Plant & Animal Sciences also) and some specific health sciences (Immunology, Microbiology). South Africa and Egypt are output leaders in almost all subject areas but are not so much specialized, in some specific subject areas, as countries like Kenya and Uganda. Neuroscience & Behaviour, Computer Science and Molecular Biology & Genetics are, in general, neglected disciplines.

4.1.4 – Scientific output vs. Impact relative to subject area and evolution of impact

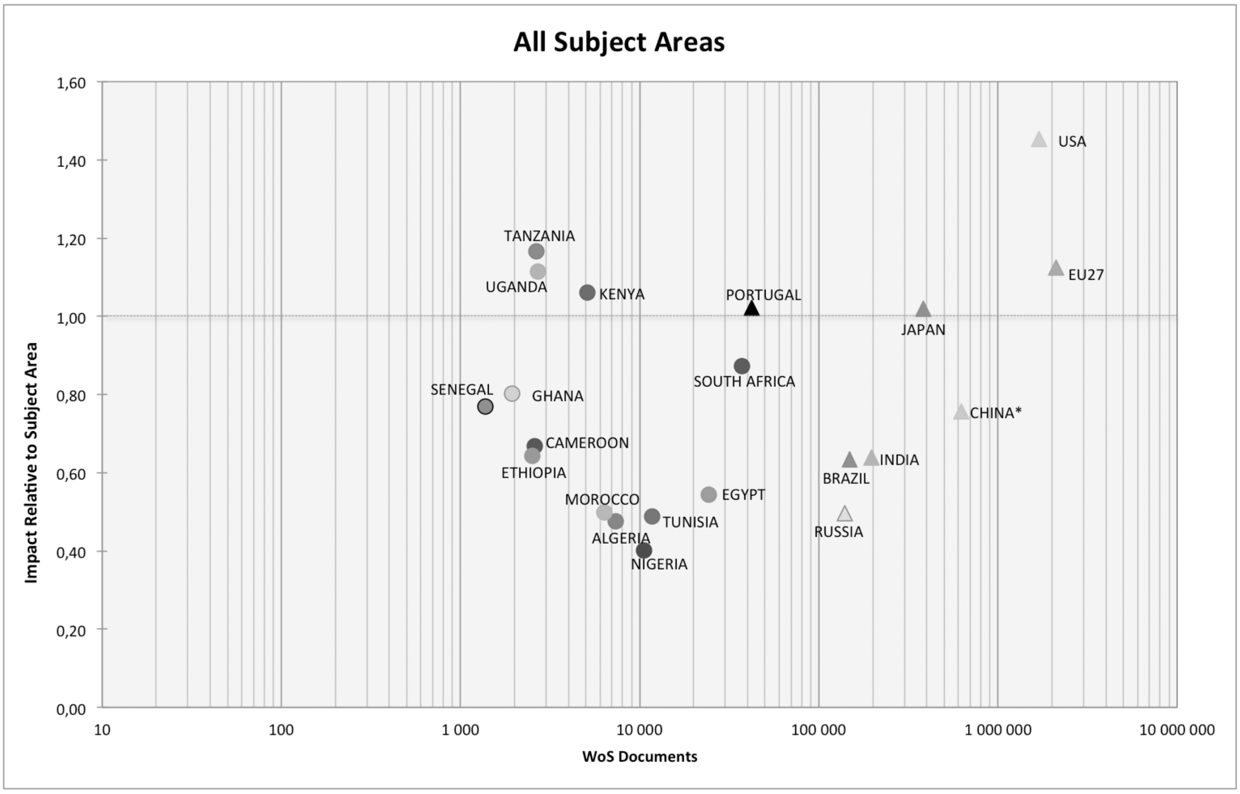
To compare the scientific production and the impact of African Countries, with the rest of the World, we have used again the 22 *ESI*. We will show Figures 3, 4, 5, 6, 7 and 8 that present the aggregation of all subject areas in one average, and the Top5 *ESI* subject areas where Africa, as a whole, has more world output (all above 3,58%)[49].

The graphs will show the scientific production *versus* impact, in the most recent aggregate period (2007-2011), for African countries with more than 1% of Africa's total scientific output, and also some benchmark countries (USA, EU27, Russia, China, Brazil, India, Japan and Portugal). "Impact" is accounted for CXC, which means, "Impact relative to subject area". We have also data about the evolution of CXC in each African Country and their standard deviation (on Table 8 – Appendix).

[48] It is important to remember that not all the subject areas have the same propensity for publication. For example, Clinical Medicine is generally the subject area with more output of these 13 countries (only in Egypt (Chemistry), Algeria (Engineering) and Ethiopia (Plant & Animal Science) this doesn't happen), nevertheless this subject area doesn't appear at all on this table of relative specialization (Clinical Medicine world publication output is also very high).

[49] Other subject areas can be provided upon request.

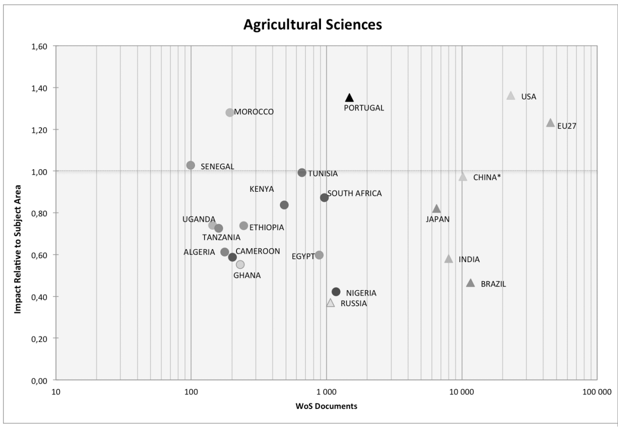
Figure 3: All subject areas: Scientific production vs. CXC (2007-2011)

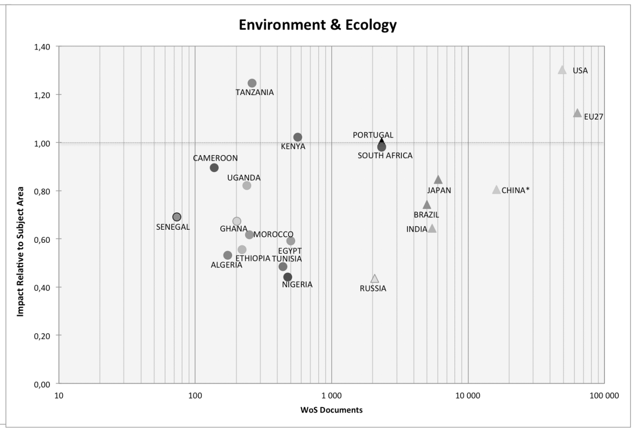


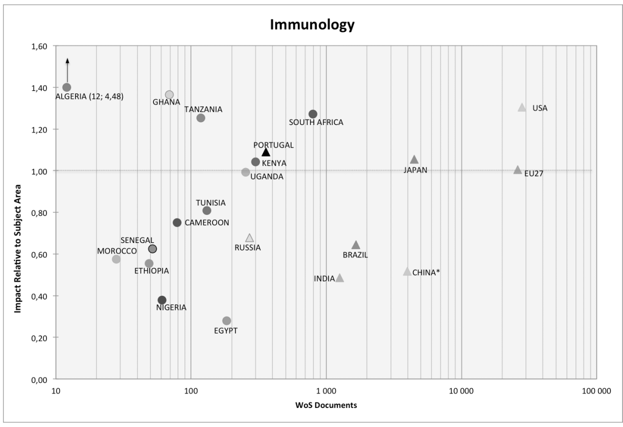
Source: Own calculations; InCites/Thomson Reuters (SCI-EXPANDED; SSCI)

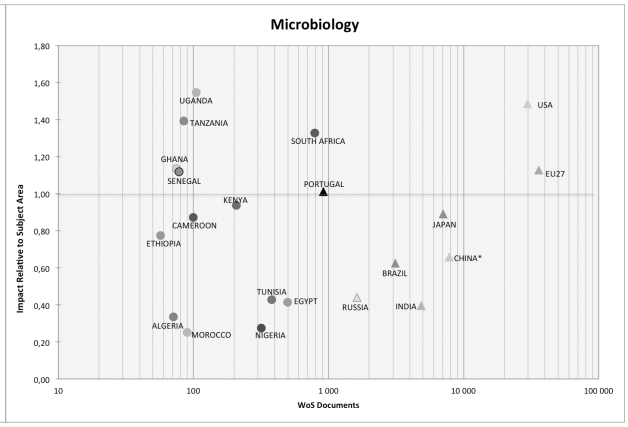
In terms of output, South Africa and Egypt are the leading countries. Regarding CXC, the "average" trend is clearly positive, from 0,50 in 1998-2002 to 0,69 in 2007-2011. Tanzania, Uganda and Kenya are the "stars", Kenya with higher output of the three and Tanzania with highest growth rate in CXC. Kenya is a special case; it has high impact on two (Clinical Medicine – 1,26 and Social Sciences – 1,29) of its five most prolific subject areas, and it is close to world average in the other subject areas.

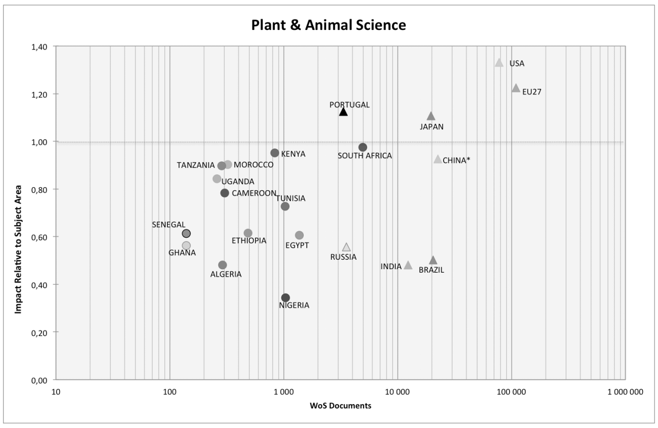
Figures 4, 5, 6, 7 and 8 - Agriculture Sciences; Environment & Ecology; Immunology; Microbiology and Plant & Animal Science: Scientific production vs. CXC (2007-2011)











Based on figures 4, 6 and 8, specific comments can be made on three of the most prolific African subject areas:

Agricultural Sciences: Nigeria is the African country with highest output but lowest impact. It is a country with long tradition in Agricultural Research (the Agricultural Society of Nigeria exists since 1962[53]) and, according to the Agricultural Research Council of Nigeria[54] there are nowadays 15 research institutes fully dedicated to this topic.

Immunology: This is the aggregate African subject area with higher CXC. South Africa, Tanzania and Ghana have high impact (>1,20) in 2007-2011. Kenya is also above the world average and Uganda is also very close to the world average[55]. Successful research in major infections such as HIV and Malaria may explain this results. For example in Uganda, there was a 5-year program in 2006, implemented by the Uganda National Council for Science and Technology and financed by the World's Bank Millennium Science initiative ($30 million), which paid for the training of 102 scientists (PhDs and MSc). Among these projects, one at Med Biotech Laboratories in Kampala existed to develop a malaria vaccine that has undergone successful testing in baboons (Irikefe, 2011).

Plant & Animal Science: This is the subject area that South Africa is relatively more specialized, accounting for almost 37% of African output. South Africa is one of the richest countries in biodiversity and wildlife worldwide, and tries to preserve it in protected areas as the Kruger National Park. New sources of knowledge may arise in this subject area from as a result.

A relevant conclusion is that the language legacy of colonial countries is relevant when measuring the CXC "average". African countries influenced by the "British Empire" as Tanzania, Uganda, Kenya, South Africa and Ghana have relatively high impact on their publications than the other African countries on this sample (Nigeria is the exception). Because nearly all scientific journals in SCI-EXPANDED, SSCI, A&HCI are written in English, researchers with English as native language and with linkages that can materialize in co-publications with British/North American researchers, seem to have an advantage in scientific impact relatively to African non-native English speakers.

It seems reasonable to argue that in certain subject areas the amount of output we are dealing with is too small to perform calculations about the CXC. However, from the analysis above it is evident that, on average, this impact measure is increasing in fields as Plant & Animal Science, Mathematics, Immunology, Environment & Ecology, Engineering, Clinical Medicine, Agricultural Sciences and Material Sciences.

[53] http://www.agriculturalsocietynigeria.org/
[54] http://www.arcnigeria.org/
[55] Algeria displays a high impact, but it has only 12 publications in this period. It is important not to forget that great care must be taken when interpreting the CXC in countries with low output. A very small number of articles co-published with a large number of foreign authors in high-impact journals can boost and bias this indicator.

4.2 – Cluster Analysis

We have seen that scientific knowledge production behaviour of each African country is quite unique. But there are some countries that display similar publication trends, common native languages, similar dimensions, etc. In the next analysis we will group some of the indicators[58] already computed (table 9) in order to understand if there is the case for similar performances and patterns between countries. The clusters obtained, after standardization of indicators, using the "between groups linkage" with a "Squared Euclidean distance measure" are resumed in the following table 5.

Table 4: African countries cluster classification according to the computed 19 indicators

COUNTRIES	CLUSTERS
Benin, Burkina Faso, Cameroon, Ghana, Mali, Niger, Nigeria, Ethiopia, Senegal, Sierra Leone, Sudan, Togo, Eritrea, Burundi, Madagascar, Swaziland, Comoros, Democratic Republic of Congo, Djibouti, Mozambique, Rwanda, Uganda, Zambia, Zimbabwe, Tanzania, Angola, Central African Republic, Chad, Gabon, Guinea, Equatorial Guinea, Liberia, Republic of the Congo, Sao Tome e Principe, Cote Ivoire, Kenya	**C1**
Cape Verde, Mauritania, Morocco, Libya, Algeria	**C2**
Botswana, Lesotho, Mauritius, Namibia	**C3**
Gambia, Guinea-Bissau, Malawi	**C4**
Egypt, Tunisia	**C5**
Seychelles	**C6**
Somalia	**C7**
South Africa	**C8**

Source: Own calculations using SPSS. World Development Indicators. CIA Factbook. UNESCO. InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI).
Note: Figure 18 presents the dendogram in which this table is based.

The results suggest that South Africa, Somalia and Seychelles have an independent performance from the rest of Africa. For the rest the results are not straightforward. Egypt and Tunisia show similar indicators, Gambia and Guine-Bissau also appear together in almost every clustering method, but the remaining cluster formation varies according to different clustering methods (Nearest neighbour, furthest neighbour, Ward, etc.) and measures (Euclidian distances, Minkowski, etc.)[59]. This is an indication of lack of robustness of the clusters obtained. Although there seems to be some rationality in their formation, in our understanding, it is questionable to say that the countries within each cluster have similar performances. We can observe that by the high standard deviations of the clusters in table 10, on appendix. African countries have, in general, very miscellaneous sets of indicators that should be interpreted individually, country by country.

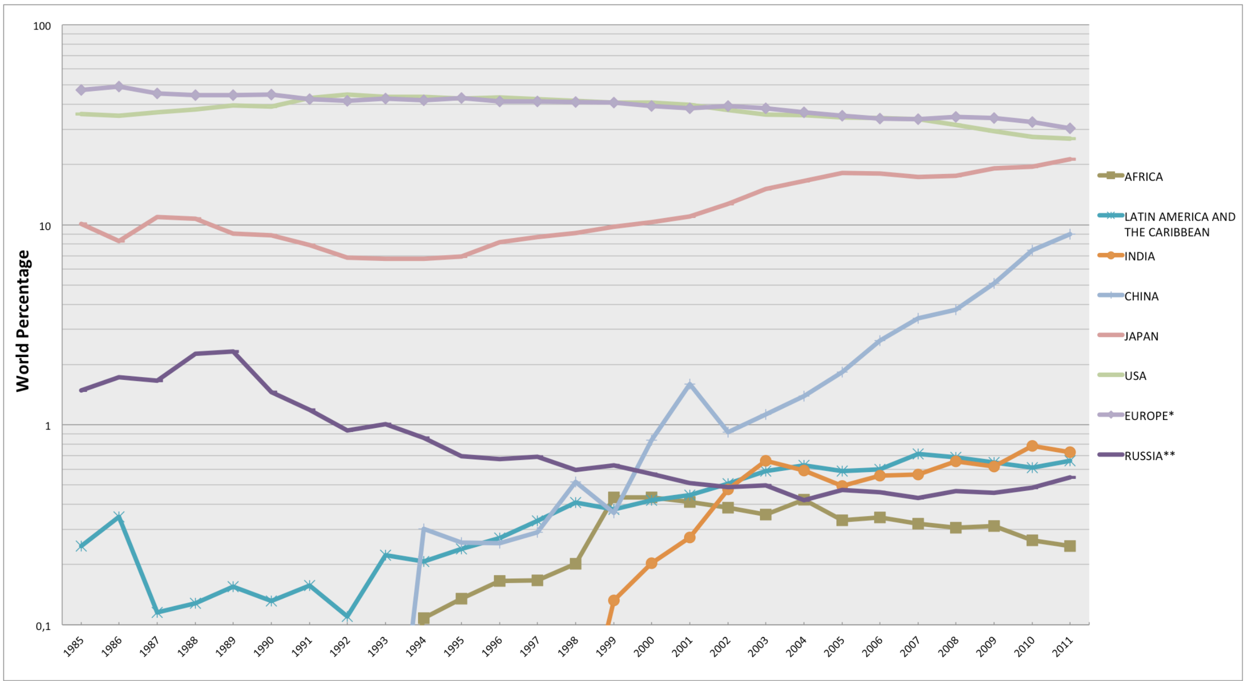
[58] PCT applications were not included because only South Africa showed a relevant output.
[59] The 46 Countries on C1 appear disaggregated in several different dispositions, according to the clustering method.

4.3 – Patent analysis

4.3.1 – General developments and trends

The discrepancies between the world regions are much higher in patenting activity than in research activity. Africa, for example, has in 2011 about 0,25% of the PCT applications world output, against 2,51% of world research output in the same period. Due to the small weight of Africa's patent output, we've decided not to disaggregate the data in three regions as done previously in publications analysis. Figure 10 shows that Africa started to have some significance since 1999, but thereafter their World share has been decreasing

Figure 9: Trends in PCT international applications by countries/regions (shares as world percentage) from 1985 to 2011



Source: WIPO Statistics Database
*Europe includes the 53 countries referred by WIPO[60], less Russia.
**The Russian Federation was only established in December 1991. Before that the data refers to the Soviet Union.

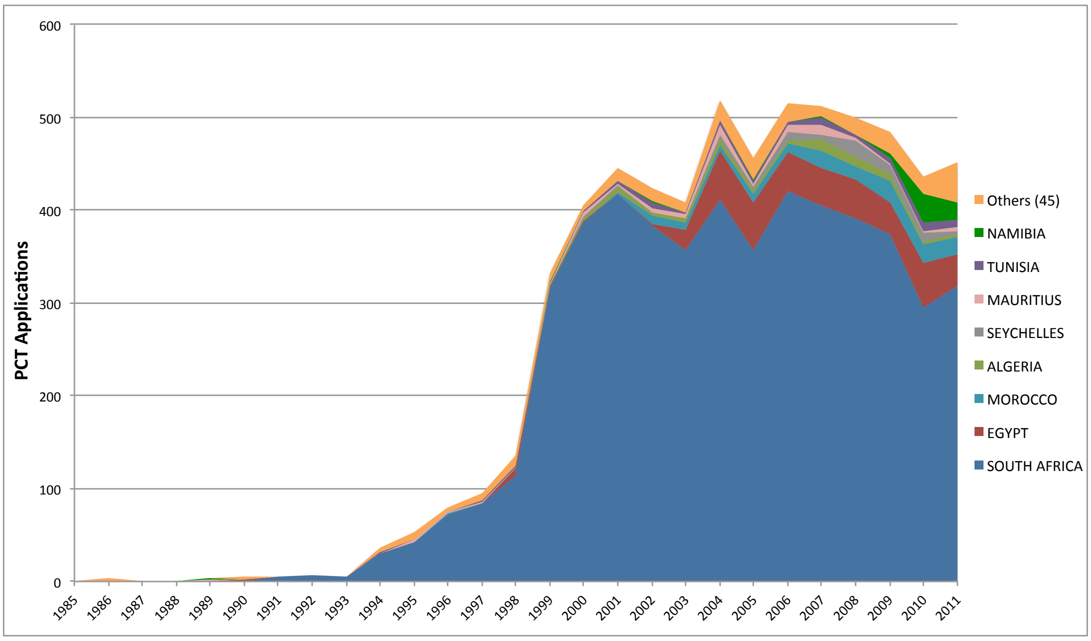
We have to keep in mind that the PCT system only illustrates a part of the patent applications made by the African countries. For example, if we look at the African share on the granted patents in USPTO and EPO patent systems results are even lower. On USPTO between 2006 and 2010 all African countries together only represent 0,07% of the total granted patents. On EPO, in the same period, African represented slightly more (0,11% of the total granted patents). South Africa alone accounts for 84% and 87%, respectively, of total grants from Africa[62] in

[60] http://ipstatsdb.wipo.org/ipstatv2/ipstats/ipstats/patentsHelp
[62] Data provided by the Trilateral Co-operation (See: http://www.trilateral.net/statistics/grants.html)

those two systems. This may be related with the low "quality" of African patent applications (they are not granted), or with the high cost of going to national phases (discourages African applicants).

This uneven distribution in Africa may be observed in figure 11 where South Africa, in the period analysed, represents 82,3% of the total PCT international applications.

Figure 10: PCT international applications of individual African countries (Top8*)



Source: WIPO Statistics Database
*Countries with more than one percent of Africa's output.

The number of countries (8) with more than one percent of African PCT share is also smaller than in the bibliometric analysis (17). This may also be a proof of the unequal distribution of patenting activity in Africa.

Surprisingly, Seychelles, Mauritius and Namibia are in this Top8. These are all countries with relatively low population (Namibia is the bigger with 2,3 million in 2011[63]) and in this period they had respectively 66, 65 and 61 PCT applications. Namibia is a special case because the last two years have been the only ones with substantial patenting activity. Seychelles and Mauritius PCT applications might be related with offshore schemes to minimize taxes[64].

[63] (World Bank, 2013)
[64] An example of the type of services offered by this offshore companies can be seen here: http://www.conpak.com/Offshore-Company-Incorporation.html

4.3.2 - Technological specialization in Africa

Table 4, next, will allow us to analyse the technology specialization of African countries with more than one percent of African share between 2002 and 2011. South Africa is the only country where the results have some statistical significance. The other countries have too few PCT Publications to draw serious conclusions about this analysis.

Table 5: Top5 technologies in African nations with more than 1% of Africa's total PCT Publications output, 2002-2011

Technologies with higher relative specialization in each African country by amount of PCT Publications, 2002-2011
Top five technologies by revealed comparative advantage, number of PCT Publications and percent of PCT publications worldwide in each technology

COUNTRY (Xi^2)/RANK	PCT Pub	%PCT Pub W	RCA	PCT Pub	%PCT Pub W	RCA	PCT Pub	%PCT Pub W	RCA	PCT Pub	%PCT Pub W	RCA	PCT Pub	%PCT Pub W	RCA
	1			2			3			4			5		
SOUTH AFRICA (0,63)	Civil Engineering			Furniture, Games			IT methods for management			Materials, Metallurgy			Handling		
	355	0,96%	**3,47**	236	0,79%	**2,86**	161	0,79%	**2,85**	173	0,70%	**2,53**	212	0,61%	**2,22**
EGYPT (0,68)	Thermal processes and apparatus			Control			Engines, pumps, turbines			Transport			Environmental technology		
	14	0,08%	**3,21**	16	0,07%	**2,93**	24	0,07%	**2,81**	30	0,06%	**2,50**	11	0,06%	**2,47**
MOROCCO (0,64)	Environmental technology			Food chemistry			Control			Thermal processes and apparatus			Civil Engineering		
	6	0,03%	**4,18**	7	0,03%	**2,94**	6	0,03%	**2,89**	4	0,02%	**2,42**	8	0,02%	**2,32**
SEYCHELLES (1,37)	Medical technology			Chemical engineering			Control			Environmental technology			Civil Engineering		
	23	0,02%	**4,18**	7	0,02%	**3,50**	4	0,02%	**3,01**	7	0,02%	**2,76**	5	0,01%	**2,26**
ALGERIA (1,15)	Engines, pumps, turbines			Civil Engineering			Pharmaceuticals			Thermal processes and apparatus			Environmental technology		
	7	0,02%	**4,39**	7	0,02%	**4,12**	10	0,01%	**2,94**	2	0,01%	**2,46**	2	0,01%	**2,40**
TUNISIA (1,09)	Food chemistry			Thermal processes and apparatus			Environmental technology			Other consumer goods			Textile and paper machines		
	4	0,03%	**6,48**	3	0,02%	**4,00**	3	0,02%	**3,91**	4	0,02%	**3,63**	2	0,01%	**2,20**
MAURITIUS (3,24)	Semiconductors			Other special machines			Surface technology, coating			IT methods for management			Handling		
	17	0,04%	**9,24**	7	0,02%	**4,66**	4	0,02%	**4,03**	3	0,01%	**3,48**	3	0,01%	**2,06**

Source: Own calculations; WIPO Statistics Database
* RCA = Share of a country's PCT Publications in a given technology relative to the share of world PCT Publications in that field. Analysing a small number of patents in a country leads to a distorted picture of country's advantages.
** Bold above 1,50. Considered here to be relative high specialization at the country level.
*** %PCT Pub W = World percentage of PCT Publications in a specific technology.
**** Xi^2 = Chi-square of sectoral specialization. This measure provides a ratio to assess whether a country is "specialized" or "not specialized". It grows with the specialization intensity of a country.

The remaining unanalysed 46 African countries account for only 4,37% of the total African output[65]. Of the 35 areas, the only area where all African countries together have more than one percent of world patent share is "Civil Engineering" (South Africa alone accounts for 0,96%). In contrast, African representation in areas such as "Micro-structural and nano-technology", "Optics" and "Digital Communication" are less than 0,1% of the world share[66].

Concerning the specialization of each country we may say that South Africa specialization is low. They have PCT Publications in all technological areas in the period analysed, with a fair

[65] Namibia doesn't appear on this analysis probably because the applications examined in the figure 11 have not yet been transformed into PCT publications (there is a time-lag between the two phases).
[66] It is important to note that, like in publications, not all technological areas have the same patenting propensity.

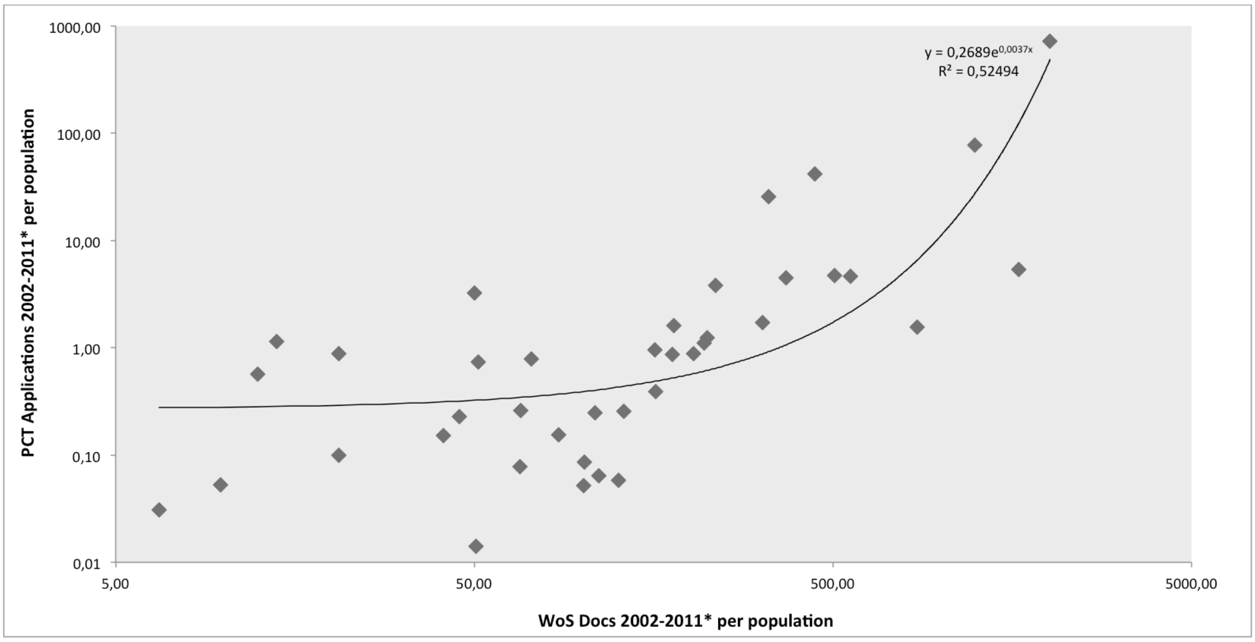
distribution. On the contrary, Seychelles and Mauritius have a high level of specialization in "Medical Technology" and "Semiconductors" respectively.

4.4 – Scientific publications versus international patent applications per population

The interactions between science-industry systems are a crucial aspect of the knowledge-based economy. We now understand that the first linear models of innovation "science-push" (there is a causal relation from basic science to technology and than market) and "demand-pull" (that the needs of the market define the new innovations) are just a partial view, because they forget that innovation and new ideas can emerge from many different sources of knowledge.

In the next graph we don't intend to establish any causality between scientific publications and patent applications. We merely wish to analyse the statistical patterns that this indicators exhibit. In figure 12 we relate bibliometric (WoS Publications 2002-2011) and patent data (PCT Applications 2002-2011).

Figure 11: Log-log plot of WoS publications per million people versus PCT applications per million people



Source: Own Calculations; InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI); WIPO Statistics Database
*Only African countries with one or more PCT applications are in this plot
**The exponential regression was computed using the trendline function of Microsoft Excel.

In a two-dimensional plot in log-log scale it is possible to define an exponential regression which correlates the two series. This means that for each new publication per million people, PCT applications per million people increase by 0,37%. Though relatively small, the coefficient of determination (R^2) is higher in this type of regression than in any other type of possible first order regressions (linear, logarithmic, power). The coefficient is 0,04 (rounded) and the t statistics is 6,4, with an associated p value of 0,000. Seychelles[67] and Tunisia are the countries in better position on this analysis.

Albuquerque (2004) computed a similar analysis for 120 less developed countries. His results were quite comparable, but instead of an exponential regression, he defined two different stages of development. In the first stage, the power function grows with a positive trend but in a much smaller scale than the second stage. His data also suggests a non-linear dynamics. As the scientific production grows, the more a country is able to transform scientific information into technological inventions (seen here as PCT applications).

5 - CONCLUSIONS

Africa has relative distinct behaviours on publication and patent production. Africa's share of world science has started to rise since 2004**.** Northern Africa, Central Africa and Southern Africa have each been getting closer to one percent of world output percentage since then. Individually countries like South Africa, Egypt, Nigeria and Tunisia are driving that output increase. South Africa and Egypt alone have contributed to more than 50 % of Africa's output since 1981 and the Top10 countries to about 85% of this output.

When we analyse the relative scientific output in terms of GDP (Docs/GDP) and population (Docs/Pop) the results show quite distinct situations. The African productivity relative to GDP is close to world average and is rising. South Africa, Tunisia and some countries with smaller GDPs such as Kenya, Zimbabwe or Malawi are the most important contributors to this increase. However, the African productivity relatively to his population is well below world average. In particular the Central African countries have extremely low productivity, while only Tunisia and Seychelles are above the world average.

As regards the analysis of research specialization, we have seen that the two most prolific African nations in all subject areas are South Africa and Egypt (with the exception of "Agricultural Sciences" where Nigeria performs best). Additionally, countries as Kenya and Uganda are specialized in a few specific areas (Immunology, Environment & Ecology and Agricultural Sciences), and others (such as Egypt and Morocco) have a more disperse

[67] Seychelles can be interpret here as an outlier due to its relatively small dimension. If removed, one power function or two as Albuquerque (2004) could be more appropriate to define the relation between variables.

distribution between subject areas. In the Frascati disaggregation we have seen that Africa, as a whole, is more specialized than the world average in just one area, Agricultural Sciences.

In the scientific impact analysis we have examined, in depth, the CXC evolution of the 22 *ESI* of the African countries with more scientific output, and compared the scientific production of these countries with others outside Africa. The general trend of the CXC is positive between 2002 and 2011, mainly in areas such as: "Agricultural Sciences", "Clinical Medicine", "Environment & Ecology", "Engineering", "Plant & Animal Science", "Mathematics", "Immunology" and "Material Sciences". There are areas where output is very low in many countries; therefore it is not reasonable to do specific conclusions. When we compare African countries with other relevant nations we see that only South Africa performs well, although in many subject areas ("Immunology", "Microbiology", "Environment & Ecology", etc.) there are other African countries (Tanzania, Uganda, Kenya, etc.) whose scientific impact was higher than the World average.

In addiction our results have shown that relatively high levels of RCA in few scientific disciplines, and English language cultural heritage, may lead to research output with higher impact.

Regarding the patent analysis, the results have shown that African relative world output is much worse for PCT applications (0,25%) than for scientific publications (2,51%) in 2011. The main contributor is again, by far, South Africa with 82,3% of total output over the period analysed and the world patent share of Africa has slightly declined since 1999.

Finally, as Albuquerque (2004) also showed, there seems to be a non-linear (exponential) dynamics between publication output and patent output. As the scientific production grows, the capacity of the technological sector also increases, becoming more able to create technological inventions (patents).

As stated elsewhere, and in a way demonstrated by our cluster analysis, Africa is too big to follow one set of policies. Each country must evaluate what already exists and, with a realistic vision (Lundvall, 2009), develop their knowledge frontiers to respond to local circumstances and opportunities. The strategic focus for Africa should therefore be to generate research that has immediate local use. Achieving this goal will require a focus on building a new generation of universities, which are focused on problem-solving and hold direct links with enterprises and local communities. It is through such strategies that Africa will be able to make its own unique contributions to the global scientific enterprise. The most natural strategic bet, seems to be, to efficiently convert their wealth in natural resources into education capabilities and a better knowledge base (both scientific knowledge and good practice know-how) for agriculture, water quality, soil erosion, health, energy supply and use of natural resources. African countries have begun to understand that, without investment in S&T, the continent will stay on the periphery of the global Knowledge-based economy on the long term (UNESCO, 2010).

As specified in the last Human Development Report, one of the most powerful instruments for Human Development is education. Education boosts people's self-confidence and enables them to find better jobs, engage in public debate and make demands on government for health care, social security and other entitlements (UNDP, 2013). More investment in R&D will not only respond to problems of the society but also give the researchers/professors better capabilities and knowledge to teach and educate the new generations. A long-term vision is needed to promote such virtuous cycle.

Since this work was made in a macro perspective, based on S&T international output indicators, there was some lack of understanding about the specificities of the African S&T system. To complement this quantitative analysis with a more qualitative approach (investigating the S&T institutions of Africa and their interactions) would certainly enhance this study. Further research on causes for higher scientific impact in some specific scientific areas, examination of collaboration networks intra and extra Africa and analysis over the research publications cited in African patents, are suggestions for future studies.

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7 - APPENDIX

Table 6: Compound annual growth rate (five, ten and thirty-year periods) of output by country/region

Country	CAGR 5	CAGR 10	CAGR 30	Country	CAGR 5	CAGR 10	CAGR 30
SOUTH AFRICA	9,6%	7,4%	4,5%	TOGO	11,2%	9,7%	6,0%
EGYPT	12,8%	9,0%	5,3%	RWANDA	26,5%	25,5%	12,3%
NIGERIA	9,6%	11,4%	2,3%	SIERRA LEONE	26,9%	16,5%	0,5%
TUNISIA	12,0%	13,9%	11,5%	CENT AFR REPUBL	0,0%	5,4%	2,7%
MOROCCO	8,9%	3,2%	9,0%	SWAZILAND	22,4%	10,6%	7,5%
KENYA	9,7%	7,9%	4,4%	BURUNDI	14,9%	20,9%	3,1%
ALGERIA	10,7%	12,9%	9,4%	GUINEA BISSAU	-3,0%	0,4%	-
TANZANIA	6,8%	10,3%	5,8%	GUINEA	5,4%	7,2%	-
ETHIOPIA	12,4%	11,3%	7,4%	LESOTHO	4,6%	9,6%	4,1%
CAMEROON	7,5%	9,2%	10,2%	MAURITANIA	1,0%	4,9%	10,7%
ZIMBABWE	3,2%	0,5%	3,0%	ERITREA	-14,8%	-6,3%	-
UGANDA	12,8%	15,7%	11,1%	ANGOLA	20,5%	10,6%	9,8%
GHANA	11,5%	10,8%	6,5%	SEYCHELLES	1,6%	20,6%	5,6%
SUDAN	18,6%	12,9%	3,2%	LIBERIA	28,5%	5,8%	2,9%
SENEGAL	10,9%	8,6%	7,9%	CHAD	4,2%	2,9%	9,7%
COTE IVOIRE	9,4%	5,3%	2,3%	SOMALIA	-	11,6%	-2,3%
MALAWI	11,4%	10,4%	6,9%	DJIBOUTI	58,5%	25,9%	-
ZAMBIA	9,9%	10,4%	5,1%	EQUATORIAL GUINEA	38,0%	5,2%	-
BOTSWANA	6,1%	4,6%	7,7%	CAPE VERDE	10,8%	-	-
BURKINA FASO	12,5%	11,5%	9,2%	COMOROS	-6,5%	17,5%	-
LIBYA	2,3%	8,6%	1,9%	SAO TOME & PRINCIPE	-12,9%	0,0%	-
MADAGASCAR	5,1%	9,3%	8,3%	NORTHERN AFRICA*	11,8%	9,4%	6,6%
BENIN	9,9%	11,5%	15,2%	CENTRAL AFRICA*	10,0%	10,1%	4,7%
GABON	9,7%	6,9%	7,2%	SOUTHERN AFRICA*	9,4%	7,5%	4,7%
MALI	13,7%	10,9%	10,0%	AFRICA*	10,5%	8,9%	5,4%
CONGO DEMOCRATIC REPUBLIC	41,6%	25,2%	4,7%	LATIN AMERICA	*10,0%*	*8,1%*	*7,9%*
GAMBIA	-0,5%	0,3%	7,6%	INDIA	*10,3%*	*9,0%*	*4,1%*
NIGER	10,7%	11,3%	7,7%	CHINA*	*13,6%*	*14,8%*	*15,0%*
CONGO PEOPLES REP	1,9%	8,6%	5,5%	JAPAN	*-0,2%*	*0,3%*	*3,4%*
NAMIBIA	6,1%	3,6%	8,9%	USA	*2,5%*	*2,9%*	*2,1%*
MOZAMBIQUE	15,4%	15,9%	13,1%	UE27	*4,2%*	*3,8%*	*3,7%*
MAURITIUS	9,3%	3,0%	7,7%	OCDE	*3,3%*	*3,4%*	*2,9%*
				WORLD	5,1%	4,7%	3,3%

Source: Own calculations; Web of Science/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI)

Table 7: Research specialization of African countries in relation to 6 main Frascati Fields of Science. (2002-2011)

	1 - NATURAL SCIENCES			2 - ENGINEERING AND TECHNOLOGY			3 - MEDICAL AND HEALTH SCIENCES			4 - AGRICULTURAL SCIENCES			5 - SOCIAL SCIENCES			6 - HUMANITIES		
COUNTRY	02-06	07-11	%Total 02-11	02-06	07-11	%Total 02-11	02-06	07-11	%Total 02-11	02-06	07-11	%Total 02-11	02-06	07-11	%Total 02-11	02-06	07-11	%Total 02-11
1 SOUTH AFRICA	13 054	18 999	45%	3 492	5 558	13%	5 658	9 450	21%	1 824	2 682	6%	2 369	5 160	11%	1 076	2 044	4%
2 EGYPT	9 388	13 493	47%	4 440	7 446	24%	3 261	7 488	22%	698	1 637	5%	177	357	1%	53	113	0%
3 TUNISIA	3 104	6 704	45%	1 627	3 859	25%	1 422	3 264	21%	286	1 122	6%	81	317	2%	23	59	0%
4 NIGERIA	1 704	2 939	25%	1 293	2 711	21%	1 635	4 298	31%	1 151	1 834	16%	289	794	6%	58	173	1%
5 MOROCCO	3 502	3 921	53%	1 288	1 533	20%	1 118	1 721	20%	326	377	5%	86	136	2%	20	42	0%
6 ALGERIA	2 655	5 049	55%	1 471	3 439	35%	228	521	5%	131	330	3%	38	106	1%	1	17	0%
7 KENYA	1 487	2 145	35%	251	431	7%	1 234	2 239	34%	764	955	17%	229	467	7%	40	62	1%
8 TANZANIA	604	967	31%	125	185	6%	789	1 405	44%	252	303	11%	90	240	7%	8	36	1%
9 CAMEROON	903	1 457	45%	221	433	13%	492	947	28%	240	343	11%	56	86	3%	12	23	1%
10 ETHIOPIA	550	992	32%	117	214	7%	524	888	29%	473	712	25%	98	218	7%	8	31	1%
11 UGANDA	476	959	30%	63	162	5%	685	1 633	48%	190	282	10%	87	241	7%	8	18	1%
12 GHANA	396	737	29%	148	339	13%	502	797	34%	213	335	14%	83	249	9%	9	43	1%
13 SENEGAL	463	642	39%	84	158	9%	426	568	35%	174	178	13%	34	67	4%	5	13	1%
14 ZIMBABWE	441	488	34%	112	98	8%	366	481	31%	269	230	18%	85	114	7%	17	48	2%
15 MALAWI	178	334	23%	20	78	4%	442	767	55%	61	127	9%	28	131	7%	2	15	1%
16 BURKINA FASO	256	410	32%	69	105	8%	292	520	39%	163	204	18%	17	39	3%	1	10	1%
17 BOTSWANA	437	437	44%	83	146	11%	126	227	18%	70	107	9%	119	201	16%	9	44	3%
18 SUDAN	187	425	29%	82	207	14%	275	512	37%	138	254	18%	7	38	2%	1	11	1%
19 COTE IVOIRE	324	470	39%	80	146	11%	313	395	35%	100	144	12%	25	32	3%	5	12	1%
20 ZAMBIA	174	242	26%	24	37	4%	261	545	50%	90	103	12%	34	95	8%	7	2	1%
21 BENIN	244	439	41%	57	112	10%	121	289	25%	116	244	22%	6	24	2%	3	4	0%
22 MADAGASCAR	310	532	56%	32	46	5%	159	247	27%	47	96	9%	18	24	3%	3	2	0%
23 LIBYA	165	331	43%	128	172	26%	92	207	26%	17	24	4%	7	12	2%	3	6	1%
24 MALI	144	214	30%	26	43	6%	177	314	42%	96	127	19%	10	20	3%	3	7	1%
25 GAMBIA	103	156	27%	7	13	2%	321	319	66%	17	13	3%	10	7	2%	0	0	0%
26 GABON	196	248	44%	20	13	3%	205	256	45%	23	21	4%	16	6	2%	3	9	1%
27 MOZAMBIQUE	92	197	31%	26	34	6%	104	316	45%	45	59	11%	13	51	7%	3	2	1%
28 NAMIBIA	275	275	68%	12	32	5%	21	37	7%	48	53	12%	17	28	6%	5	10	2%
29 CONGO REP.	112	203	38%	34	32	8%	137	200	41%	40	44	10%	3	12	2%	0	5	1%
30 NIGER	83	184	39%	20	44	9%	59	120	26%	61	91	22%	5	17	3%	0	6	1%
31 MAURITIUS	165	176	50%	51	58	16%	44	59	15%	26	29	8%	18	50	10%	0	1	0%
32 CONGO DEM. REP.	45	121	33%	8	22	6%	48	208	50%	2	28	6%	3	16	4%	1	6	1%
33 RWANDA	30	118	30%	7	28	7%	41	172	44%	9	30	8%	6	42	10%	2	3	1%
34 TOGO	70	90	33%	12	25	8%	63	112	36%	39	53	19%	6	6	3%	1	3	1%
35 SWAZILAND	42	77	41%	5	29	12%	18	55	25%	8	31	14%	3	16	7%	3	1	1%
36 ERITREA	80	38	46%	6	21	11%	22	29	20%	22	10	13%	12	13	10%	3	0	1%
37 GUINEA BISSAU	26	37	26%	0	0	0%	86	89	73%	1	0	0%	1	1	1%	0	0	0%
38 GUINEA	38	53	38%	4	6	4%	44	60	44%	8	16	10%	1	6	3%	0	2	1%
39 CENT AFR REPUBL	44	62	47%	6	10	7%	40	47	38%	6	7	6%	0	3	1%	0	1	0%
40 MAURITANIA	60	57	55%	9	11	9%	15	19	16%	18	17	17%	1	3	2%	0	1	0%
41 ANGOLA	29	55	42%	6	6	6%	24	60	42%	5	7	6%	2	4	3%	0	1	1%
42 SEYCHELLES	41	65	54%	2	2	2%	15	39	27%	6	20	13%	2	6	4%	0	0	0%
43 LESOTHO	22	40	37%	2	17	11%	7	35	25%	0	11	7%	8	17	15%	4	4	5%
44 CHAD	45	41	52%	5	4	5%	18	27	27%	15	4	12%	3	1	2%	0	2	1%
45 SIERRA LEONE	6	34	28%	5	16	15%	8	41	35%	6	11	12%	4	8	8%	2	1	2%
46 BURUNDI	25	40	51%	2	8	8%	9	23	25%	0	13	10%	0	7	5%	1	0	1%
47 LIBERIA	8	10	31%	1	2	5%	13	16	50%	1	1	3%	1	3	7%	1	1	3%
48 CAPE VERDE	9	23	71%	0	3	7%	1	4	11%	1	2	7%	0	2	4%	0	0	0%
49 DJIBOUTI	4	14	44%	0	2	5%	6	14	49%	0	1	2%	0	0	0%	0	0	0%
50 EQUATORIAL GUINEA	7	8	42%	0	0	0%	7	11	50%	3	0	8%	0	0	0%	0	0	0%
51 COMOROS	5	10	43%	1	0	3%	5	11	46%	2	1	9%	0	0	0%	0	0	0%
52 SAO TOME & PRINCIPE	4	4	40%	0	0	0%	6	5	55%	0	0	0%	0	1	5%	0	0	0%
53 SOMALIA	0	3	17%	0	0	0%	3	5	44%	1	2	17%	2	1	17%	0	1	6%
NORTHERN AFRICA	19001	29923	49%	9036	16656	26%	6396	13713	20%	1596	3744	5%	396	966	1%	101	248	0%
CENTRAL AFRICA	7902	12837	32%	2548	5092	12%	7510	14468	34%	3953	5695	15%	1005	2376	5%	165	431	1%
SOUTHERN AFRICA	15909	23005	44%	4000	6348	12%	8082	13931	25%	2753	3886	7%	2809	6153	10%	1138	2216	4%
AFRICA	42812	65765	42%	15584	28096	17%	21988	42112	25%	8302	13325	8%	4210	9495	5%	1404	2895	2%
WORLD	2398516	2938044	43%	906912	1283479	18%	1452556	1900892	27%	213524	295835	4%	321111	493430	7%	103104	143997	2%

Source: InCites/Thomson Reuters (SCI-EXPANDED; SSCI; A&HCI)

Table 8: Variation of CXC between 2002-2006 and 2007-2011 in the 13 African Countries analysed and standard deviation

	Agricultural Sciences			Biology & Biochemistry			Chemistry			Clinical Medicine			Computer Science			Economics & Business		
	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*
ALGERIA	0,44	0,61	*0,13*	0,22	0,31	*0,04*	0,34	0,47	*0,05*	0,49	0,72	*0,13*	0,17	0,43	*0,06*	0,00	0,17	*0,77*
CAMEROON	0,56	0,59	*0,04*	0,21	0,33	*0,11*	0,23	0,41	*0,07*	0,79	0,78	*0,07*	0,21	0,50	*0,15*	0,52	0,52	*0,11*
EGYPT	0,65	0,60	*0,04*	0,31	0,37	*0,04*	0,38	0,49	*0,06*	0,53	0,55	*0,01*	0,61	0,83	*0,07*	0,41	0,53	*0,11*
ETHIOPIA	0,38	0,74	*0,16*	0,15	0,36	*0,15*	0,44	0,42	*0,15*	0,38	0,77	*0,16*	0,52	0,09	*0,19*	1,07	0,65	*0,26*
GHANA	0,45	0,55	*0,04*	0,37	0,30	*0,11*	0,15	0,20	*0,09*	0,72	1,02	*0,14*	0,00	1,36	*0,05*	0,36	0,38	*0,24*
KENYA	0,66	0,83	*0,08*	0,72	0,40	*0,13*	0,53	0,47	*0,19*	1,31	1,26	*0,17*	0,78	1,31	*0,29*	1,21	0,91	*0,33*
MOROCCO	0,85	1,28	*0,18*	0,27	0,41	*0,07*	0,55	0,49	*0,04*	0,25	0,28	*0,05*	0,53	0,60	*0,04*	0,52	0,64	*0,23*
NIGERIA	0,38	0,42	*0,02*	0,10	0,20	*0,04*	0,24	0,48	*0,12*	0,30	0,34	*0,02*	0,47	0,18	*0,19*	0,26	0,51	*0,13*
SENEGAL	0,95	1,03	*0,14*	0,24	0,31	*0,07*	0,46	0,26	*0,11*	0,61	0,78	*0,07*	0,39	1,73	*0,07*	0,52	2,27	*0,74*
SOUTH AFRICA	0,80	0,87	*0,06*	0,62	0,77	*0,09*	0,72	0,66	*0,05*	0,91	1,21	*0,13*	1,19	0,83	*0,11*	0,39	0,44	*0,04*
TANZANIA	0,62	0,72	*0,04*	0,27	1,00	*0,20*	0,46	0,27	*0,12*	1,04	1,19	*0,16*	0,00	0,76	*0,27*	0,23	0,99	*0,29*
TUNISIA	0,55	0,99	*0,16*	0,25	0,43	*0,06*	0,37	0,42	*0,03*	0,27	0,42	*0,09*	0,34	0,42	*0,03*	0,29	0,52	*0,11*
UGANDA	0,49	0,74	*0,10*	0,60	0,28	*0,98*	0,44	0,60	*0,16*	1,12	1,17	*0,10*	0,00	0,41	*0,71*	0,81	0,79	*0,36*
Average	0,58	0,72	*0,04*	0,39	0,46	*0,03*	0,46	0,52	*0,04*	0,68	0,79	*0,06*	0,70	0,65	*0,05*	0,51	0,53	*0,06*

	Engineering			Environment & Ecology			Geosciences			Immunology			Materials Science			Mathematics		
	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*
ALGERIA	0,53	0,68	*0,07*	0,56	0,53	*0,17*	0,59	0,60	*0,05*	0,05	4,48	*1,43*	0,48	0,58	*0,06*	0,52	0,90	*0,18*
CAMEROON	0,45	0,71	*0,07*	0,46	0,90	*0,17*	0,48	0,50	*0,07*	0,76	0,75	*0,10*	0,29	0,54	*0,16*	0,72	1,10	*0,25*
EGYPT	0,71	0,88	*0,15*	0,39	0,59	*0,07*	0,38	0,46	*0,05*	0,44	0,28	*0,09*	0,54	0,68	*0,09*	0,62	1,10	*0,23*
ETHIOPIA	1,18	0,79	*0,24*	0,62	0,62	*0,05*	1,01	1,10	*0,15*	0,51	0,55	*0,10*	2,53	6,19	*2,90*	0,00	1,47	*0,52*
GHANA	0,69	0,63	*0,14*	0,34	0,67	*0,13*	0,47	0,63	*0,09*	0,82	1,36	*0,22*	0,20	0,56	*0,14*	0,00	0,43	*0,24*
KENYA	0,47	0,71	*0,31*	0,77	1,02	*0,09*	0,66	0,89	*0,24*	0,72	1,04	*0,10*	1,22	1,14	*0,28*	2,73	1,99	*0,77*
MOROCCO	0,96	0,81	*0,08*	0,44	0,56	*0,06*	0,63	0,75	*0,13*	0,45	0,58	*0,14*	0,81	0,93	*0,14*	0,59	0,64	*0,11*
NIGERIA	0,38	0,75	*0,16*	0,40	0,44	*0,06*	0,35	0,32	*0,03*	0,75	0,38	*0,18*	0,53	1,17	*0,33*	0,53	0,93	*0,23*
SENEGAL	0,77	1,18	*0,27*	0,71	0,69	*0,22*	0,57	1,07	*0,29*	0,93	0,62	*0,14*	1,87	1,06	*0,47*	0,70	0,32	*0,17*
SOUTH AFRICA	0,72	0,87	*0,04*	0,95	0,98	*0,11*	0,79	0,83	*0,04*	0,83	1,27	*0,18*	0,68	0,76	*0,06*	0,79	0,94	*0,13*
TANZANIA	0,23	0,93	*0,25*	0,56	1,25	*0,21*	0,48	0,92	*0,18*	0,65	1,25	*0,19*	0,17	1,67	*0,41*	0,00	1,52	*0,44*
TUNISIA	0,58	0,81	*0,13*	0,30	0,48	*0,09*	0,46	0,47	*0,05*	0,32	0,81	*0,17*	0,54	0,58	*0,09*	0,55	0,47	*0,03*
UGANDA	0,41	1,05	*0,31*	0,31	0,82	*0,26*	0,14	0,57	*0,17*	0,81	0,99	*0,10*	0,13	0,51	*0,24*	0,52	0,91	*0,51*
Average	0,68	0,82	*0,08*	0,69	0,82	*0,07*	0,66	0,71	*0,04*	0,74	1,03	*0,10*	0,58	0,71	*0,07*	0,64	0,83	*0,11*

	Microbiology			Molecular Biology & Genetics			Multidisciplinary			Neuroscience & Behavior			Pharmacology & Toxicology			Physics		
	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*
ALGERIA	0,31	0,33	*0,07*	1,38	0,83	*0,18*	0,00	0,05	*0,12*	0,87	0,62	*0,75*	0,54	0,64	*0,14*	0,33	0,49	*0,06*
CAMEROON	1,15	0,87	*0,13*	0,91	1,07	*0,28*	2,36	1,24	*0,91*	0,27	0,54	*0,13*	0,29	0,62	*0,14*	0,46	0,38	*0,15*
EGYPT	0,42	0,41	*0,03*	0,33	0,49	*0,06*	0,10	0,04	*0,05*	0,52	0,46	*0,13*	0,52	0,50	*0,07*	0,56	0,59	*0,07*
ETHIOPIA	0,50	0,77	*0,11*	0,22	1,21	*0,34*	4,03	0,92	*1,34*	0,08	0,66	*0,20*	0,38	0,72	*0,10*	0,27	0,61	*0,19*
GHANA	0,91	1,13	*0,11*	0,89	1,00	*0,23*	0,00	3,45	*1,08*	0,38	0,49	*0,29*	0,44	0,48	*0,40*	0,11	0,25	*0,05*
KENYA	1,02	0,93	*0,11*	0,40	1,48	*0,33*	1,42	2,27	*0,56*	1,98	0,60	*0,45*	0,49	0,63	*0,24*	0,26	0,13	*0,29*
MOROCCO	0,35	0,25	*0,06*	0,65	0,72	*0,07*	0,00	0,03	*1,73*	0,40	0,32	*0,04*	0,53	0,64	*0,07*	0,44	0,48	*0,04*
NIGERIA	0,60	0,27	*0,20*	5,19	2,71	*1,77*	0,00	0,07	*0,06*	0,22	0,49	*0,11*	0,24	0,33	*0,03*	0,18	0,70	*0,19*
SENEGAL	0,75	1,12	*0,15*	0,45	2,29	*0,87*	0,00	1,54	*0,49*	0,00	0,06	*0,42*	0,14	0,23	*0,15*	0,20	0,27	*0,07*
SOUTH AFRICA	0,93	1,33	*0,16*	0,64	0,72	*0,07*	0,30	0,63	*0,10*	0,60	0,83	*0,09*	0,64	0,73	*0,06*	0,66	0,97	*0,11*
TANZANIA	1,07	1,39	*0,23*	0,91	1,92	*0,54*	0,00	1,75	*0,68*	0,27	0,86	*0,26*	0,39	0,64	*0,21*	0,41	0,99	*0,27*
TUNISIA	0,31	0,43	*0,05*	0,59	0,31	*0,26*	1,64	0,03	*1,23*	0,29	0,45	*0,11*	0,38	0,63	*0,11*	0,35	0,42	*0,03*
UGANDA	1,00	1,55	*0,25*	0,34	0,62	*0,17*	0,20	0,04	*0,07*	0,13	0,95	*0,35*	0,64	0,52	*0,20*	0,51	2,54	*0,71*
Average	0,76	0,82	*0,03*	0,85	0,81	*0,08*	0,46	0,65	*0,10*	0,54	0,63	*0,06*	0,49	0,54	*0,04*	0,50	0,62	*0,05*

	Plant & Animal Science			Psychiatry & Psychology			Social Sciences			Space Science			All Subject Areas		
	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*	02-06	07-11	*Std Dev*
ALGERIA	0,31	0,48	*0,06*	0,00	0,21	*4,59*	1,06	1,05	*0,30*	0,05	0,25	*0,34*	0,32	0,48	*0,05*
CAMEROON	0,68	0,78	*0,08*	0,17	0,97	*0,26*	0,71	1,00	*0,16*	0,00	0,10	*0,05*	0,60	0,67	*0,03*
EGYPT	0,55	0,61	*0,10*	0,69	0,69	*0,09*	0,64	0,71	*0,07*	0,51	0,23	*0,11*	0,43	0,54	*0,07*
ETHIOPIA	0,40	0,62	*0,09*	0,80	0,61	*0,32*	1,58	0,71	*0,59*	0,00	1,00	*0,35*	0,48	0,64	*0,07*
GHANA	0,37	0,56	*0,09*	0,13	0,30	*0,14*	0,97	0,77	*0,12*	0,15	0,25	*0,10*	0,65	0,80	*0,08*
KENYA	0,78	0,95	*0,14*	0,51	0,57	*0,16*	1,27	1,29	*0,10*	0,00	0,00	*0,00*	0,92	1,06	*0,09*
MOROCCO	0,53	0,90	*0,13*	0,44	0,77	*0,24*	0,83	1,68	*0,34*	0,66	0,21	*0,23*	0,43	0,50	*0,05*
NIGERIA	0,39	0,34	*0,04*	0,66	1,36	*0,22*	0,59	0,40	*0,06*	0,09	0,20	*0,11*	0,39	0,40	*0,04*
SENEGAL	0,64	0,61	*0,13*	0,00	0,21	*0,08*	0,40	0,50	*0,19*	0,00	0,00	*0,00*	0,72	0,77	*0,04*
SOUTH AFRICA	0,76	0,97	*0,10*	0,65	0,65	*0,07*	0,94	0,91	*0,04*	0,85	1,37	*0,22*	0,71	0,87	*0,08*
TANZANIA	0,67	0,90	*0,16*	0,90	0,54	*0,29*	1,23	1,64	*0,25*	0,29	0,00	*0,15*	0,83	1,17	*0,16*
TUNISIA	0,47	0,73	*0,13*	0,15	0,86	*0,38*	0,20	0,66	*0,17*	0,06	0,13	*0,02*	0,34	0,49	*0,06*
UGANDA	0,73	0,84	*0,13*	0,49	1,11	*0,26*	0,92	1,33	*0,17*	0,29	0,06	*0,29*	0,94	1,11	*0,06*
Average	0,66	0,80	*0,08*	0,64	0,74	*0,06*	0,93	0,91	*0,04*	0,74	1,06	*0,15*	0,57	0,69	*0,06*

Source: Own calculations; Web of Science/Thomson Reuters (SCI-EXPANDED; SSCI)

Table 9: Variables chosen for cluster analysis, distributed in 8 dimensions

DIMENSION	DESCRIPTION	SOURCE
Scientific Production	World percentage of publications from 2002 to 2006	InCites (SCI-EXPANDED; SSCI; A&HCI)
	World percentage of publications from 2007 to 2011	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Output Compound Growth Rate from 2002 to 2011	InCites (SCI-EXPANDED; SSCI; A&HCI)
Scientific Productivity	Publications from 2002 to 2006 divided by GDP (2000 constant$) from 2002 to 2006	InCites (SCI-EXPANDED; SSCI; A&HCI) & World Bank
	Publications from 2007 to 2011 divided by GDP (2000 constant$) from 2007 to 2011	InCites (SCI-EXPANDED; SSCI; A&HCI) & World Bank
	Publications from 2002 to 2006 divided by Population from 2002 to 2006	InCites (SCI-EXPANDED; SSCI; A&HCI) & World Bank
	Publications from 2007 to 2011 divided by Population from 2007 to 2011	InCites (SCI-EXPANDED; SSCI; A&HCI) & World Bank
Scientific Impact	Impact Relative to Subject Area from 2002 to 2006 (All subject areas)	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Impact Relative to Subject Area from 2007 to 2011 (All subject areas)	InCites (SCI-EXPANDED; SSCI; A&HCI)
Scientific Specialization	Subject Area RCA (6 Frascati) between 2002-2011 - Natural Sciences	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Subject Area RCA (6 Frascati) between 2002-2011 - Engineering & Technology	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Subject Area RCA (6 Frascati) between 2002-2011 - Medical & Health Sciences	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Subject Area RCA (6 Frascati) between 2002-2011 - Agricultural Sciences	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Subject Area RCA (6 Frascati) between 2002-2011 - Social Sciences	InCites (SCI-EXPANDED; SSCI; A&HCI)
	Subject Area RCA (6 Frascati) between 2002-2011 - Humanities & Arts	InCites (SCI-EXPANDED; SSCI; A&HCI)
Education*	Gross enrolment ratio. Tertiary (ISCED 5 and 6). 2011	World Bank & UNESCO
Wealth	GDP per capita (current US$ 2011)	World Bank
Location	Geographic Coordinates - Latitude	CIA Factbook
	Geographic Coordinates - Longitude	CIA Factbook

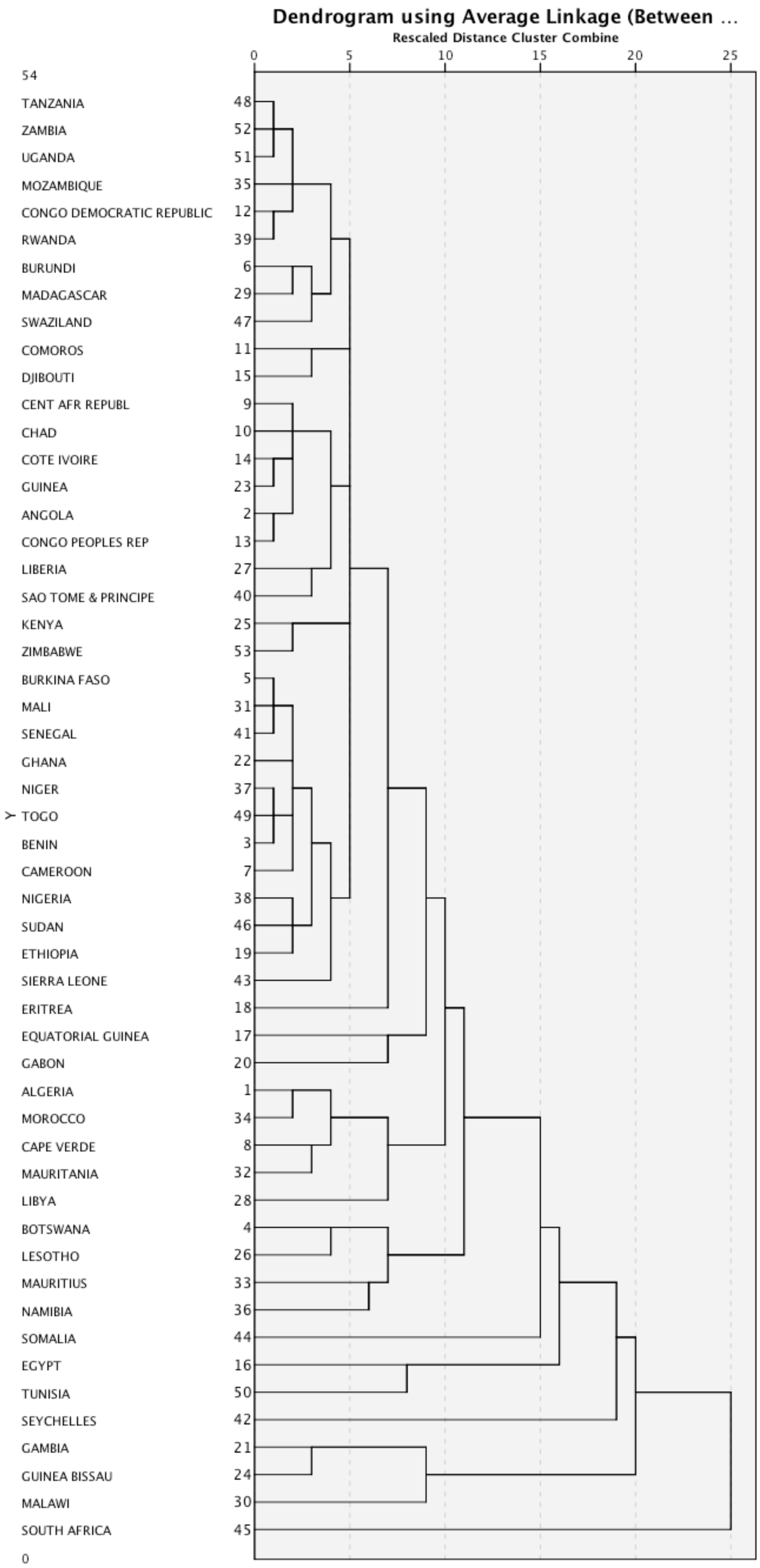
* ISCED stands for International Standard Classification of Education; if there was no 2011 data, we have used the earliest available year for analysis.

Table 10: Means and standard deviations of five variables in the cluster analysis

Cluster	W% WoS output 07-11		CAGR 10		Docs/POP 07-11		MNCS 07-11		GDP per capita 2011	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
Cluster 1	0,02%	0,03%	10,44%	7,02%	12	12	0,87	0,29	1989	4213
Cluster 2	0,05%	0,06%	5,92%	4,98%	24	16	0,65	0,37	4757	3515
Cluster 3	0,01%	0,01%	5,20%	3,01%	47	36	0,75	0,28	5921	3394
Cluster 4	0,01%	0,01%	5,97%	5,16%	24	26	1,88	1,12	446	78
Egypt, Tunisia	0,31%	0,16%	11,45%	3,46%	143	115	0,52	0,03	3661	974
Seychelles	0,00%	x	20,60%	x	264	x	1,31	x	12118	x
Somalia	0,00%	x	11,60%	x	0	x	0,45	x	145	x
South Africa	0,64%	x	7,40%	x	150	x	0,87	x	7943	x

Source: Own calculations. SPSS

Figure 12: Cluster Analysis Dendogram



Source: Own calculations. SPSS
Note: It was chosen the step 9 for cluster division