Scientific productivity versus efficiency of R&D financing: bibliometric analysis of African countries

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Commonly, bibliometric analysis at the national level measures the scientific performance through the complete production of articles and citations and through productivity related to the number of inhabitants. In our study we also report on efficiency as the scientific output obtained related to the available financing. The results indicate that only two African countries (South Africa and Tunisia) have covered a learning process and become mature entities in the R&D process, the productivity being doubled by efficiency.

Keywords: Bibliometric analysis, multiple regression, R&D financing, scientific productivity.

IN the last decades, the growth of scientific and technological level of a country has become the main objective for majority of the nations. The implementation of knowledge into practice allows for the development of a competitive economy based on capital and on highly qualified labour force. Yet, the successes achieved in research and development (R&D) are extremely heterogeneous and the use of financial and human resources is a complicated mechanism[1], which can lead to important deviations from the expected results. Researchers have a rather common understanding of the manner in which scientific performance should be measured globally, namely the number of articles published in prestigious journals and the number of patent certificates. Chen *et al.*[2] demonstrate, by considering a significant sample of countries, that the two indicators are highly correlated ($R = 0.96$). In order to measure the scientific performance of a researcher or an institution, use of 'number of citations' or 'impact factor' can be misleading[3]. Nevertheless, in a country or in a domain where thousands of researchers are involved, such indicators are acceptable due to the law of large numbers.

Academic studies which assess the R&D activities at the national or international level aim at the benefits and the influence factors. The positive consequences of the scientific output are analysed from the perspective of productivity with an impact upon the economic activity[4], as well as from that of comparative differences among nations[5]. Regarding the influence factors, Leydesdorff and Gauthier[6] propose a global evaluation of the national scientific performances using scientometric methods, whereas Goldfarb[7] approaches the issue of correlation between the structure of the governmental organisms and the scientific output. The economic factors are, according to Ye[8], the most important. By applying a formula, he quantified the relationship between gross domestic product (GDP), R&D expenditures and patent applications. Using the Thomson-Web of Knowledge platform, some empirical studies focus on the bibliometric indicators regarding the number of articles or citations in highly relevant journals. In his survey of 147 countries, Gantman[9] demonstrated that economic dimension is the only indicator that affects all the research fields, whereas the political and linguistic factors only have a selective influence.

Several regional specificities are emphasized in the scientometric analysis of Africa. For the period 1991–1997, Narváez-Berthelemot *et al.*[10] analysed the most productive 15 countries of the continent. South Africa and Egypt occupy the top positions in the classification but have lower growth rate than those of other countries, especially Maghreb. The best performing countries, with over 10,000 papers published over the last 10 years in Thomson ISI indexed journals are South Africa, Egypt, Tunisia, Nigeria, Morocco and Algeria. A typically African issue is the dissemination of the results in national and regional journals, a practice called 'indigenous science'[11].

Scientometric analysis also allows for the studies of specific problems at the national level: the national rating system and the rewarding of the scientific output[12,13], as well as the gap between the results of the research and their implementation by the decision-making organisms[14]. Empirical studies[15,16] regarding coauthorship show that the number of publications is influenced more by the

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cooperation with countries outside Africa than by the continental cooperation.

Our study responds to two specific research questions:

1. What is the 'normal' production of each African country compared to the available resources?
2. Do countries with a large production also show productivity and efficiency? In other words, is there a learning process which allows for the transition from production to productivity (production related to human resources) and to the efficiency of financing?

Data and methodology

The sample includes the 30 most productive African countries. Data are collected from:

- Essential Science Indicators (Web of Knowledge, 2012) – the number of articles and citations in journals indexed by Thomson ISI for each country.
- World Development Indicators (World Bank, 2010) for variables which indicate the economic possibilities of the countries.

We use the following variables:

PPP, Publication per population – the number of articles in all fields published by a country in journals indexed by Thomson ISI, between 1 January 2002 and 30 June 2012, with reference to 1 million inhabitants.

CPP, Citation per population – the number of citations registered in ISI journals by the researchers in a country, between 1 January 2002 and 30 June 2012, with reference to 1 million inhabitants.

GDP/CAP, Gross Domestic Product per capita (US$).

PSE, Public spending on education as percentage of GDP; ExpEDU, Expenditure on education per capita (US$) – average values between 2002 and 2011. The methodology uses OLS multiple regression with PPP and CPP as endogenous variables.

Results and discussion

We compare the classification of the countries from Africa against two criteria:

(1) Productivity – scientific production related to the number of inhabitants. We use two dimensions to determine productivity: the number of published ISI articles (PPP), and the number of citations (CPP). These indicators allow for the elimination of the population effect when comparing countries. Some authors[17,18] consider that the two dimensions correspond to quantity and quality respectively. However, it is arguable that the number of citations alone can reflect the quality of scientific research. There are other established indicators that can be used to determine scientific performance: impact factor, *h*-index[19], article influence score, etc. Such indicators are mainly used to assess researchers, journals or institutions. At a national level, bibliometric studies use, almost exclusively, indicators that refer to the relative number of publications and citations.

(2) Efficiency of R&D financing – the actual values of PPP and CPP from each country, divided by the 'normal' number (resulted from the regression with PSE) of articles and citations.

In order to distinguish between the over-productive and under-productive countries, we compare PPP and CPP with the means of the sample. We normalize the two variables using average and standard deviation

$$\text{normPPP}_i = \frac{\text{PPP}_i - \text{M(PPP)}}{\sigma_{\text{PPP}}}, \quad (1)$$

$$\text{normCPP}_i = \frac{\text{CPP}_i - \text{M(CPP)}}{\sigma_{\text{CPP}}}. \quad (2)$$

Figures 1 and 2 reveal the distribution of the countries of the sample according to normPPP and normCPP. Scientific productivity splits the countries into three clusters (hierarchical cluster analysis, squared Euclidean distance and centroid clustering). We also tried using other grouping and splitting methods, but the results presented here are the most robust.

The countries in cluster A (South Africa, Tunisia, Gabon and Namibia) achieve good and very good levels of publications and citations, considering their population. The countries in cluster B (Botswana, Egypt, Morocco and Algeria) show slightly over-average values

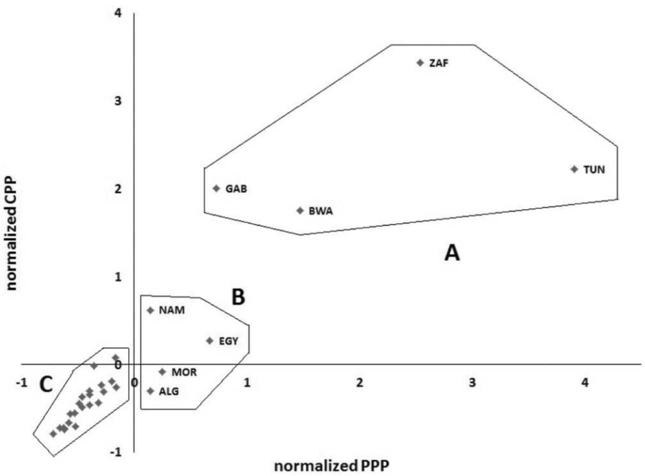

Figure 1. Distribution of African countries by normPPP and normCPP.

Table 1. Regression coefficients (t-values in parentheses)

	PPP eq. (1)	PPP eq. (2)	PPP eq. (3)	PPP eq. (4)	PPP eq. (5)	PPP eq. (6)
ExpEDU	2.32*** (4.41)	–	–	17.8*** (7.88)	–	–
Sqrt(ExpEDU)	–	55.9*** (5.96)	37.4*** (3.80)	–	411.9*** (7.99)	279.8*** (4.97)
Constant	90.3 (1.45)	–143.1 (–1.65)	–	638.2* (1.95)	–1022** (–2.14)	–
	$R^2 = 0.511$	$R^2 = 0.559$	$R^2 = 0.500$	$R^2 = 0.689$	$R^2 = 0.695$	$R^2 = 0.623$
	$N = 30$	$N = 30$	$N = 30$	$N = 30$	$N = 30$	$N = 30$

***,**,*Significant at 1%, 5% and 10% level. Source: Own calculations using STATA 9.1 software.

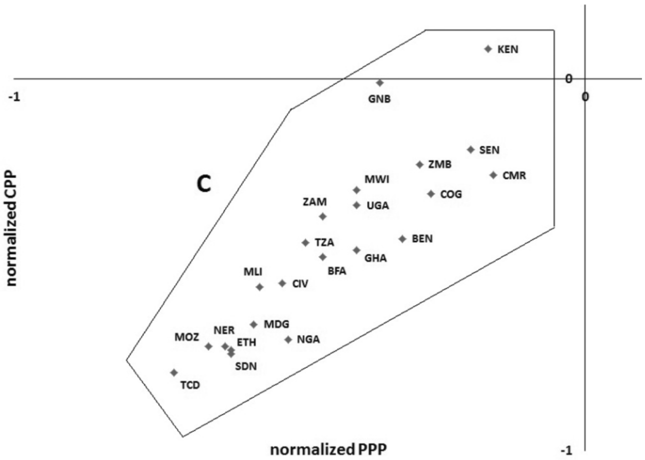

Figure 2. Distribution of African countries in cluster C by normPPP and normCPP.

of the number of articles, but they are not very competitive if we take into account the number of citations. However, they seem to be able to upgrade their scientific output, as indicated by the growth rates of the analysed indicators, which are above the mean of the African countries. Cluster C includes the worst performing countries, which have to seriously improve the quantity and quality of R&D activities in order to overtake the countries in the other groups.

The analysis of financing efficiency is different from the one regarding productivity. In order to 'normalize' the analysed indicators, we refer to the regression function (Table 1). We estimate three equations (eqs (1)–(3)), considering PPP to be the endogenous variable and another three equations (eqs (4)–(6)) considering CPP to be the endogenous variable.

We note that in both cases (eq. (2) related to eq. (1); eq. (5) related to eq. (4)), R^2 grows if we use the square root of the education expenditures. This is in accordance with the economic theory, which shows that the relationship is nonlinear. The expenditures with R&D activities, besides the material ones, include labour force remuneration, which is higher in the more developed countries. All coefficients show the expected positive sign, an increase in financing determining an increase in the number of both publications and citations. Nevertheless, we notice a stronger correlation between financing and the number of citations than the number of publications (R^2 is higher in eqs (4)–(6) than in eqs (1)–(3)). Consequently, we assume that generous financing stimulates researchers to address highly prestigious journals which, generally, can bring a higher number of citations.

The estimation of the 'normal' values of publications and citations for each country is inadequate if we use regressions with a constant term (eqs (1), (2), (4) and (5)). In the sample we also have countries with a very low financing level. From such an equation it may result that the number of articles published by a country with zero financing should be equal to the constant (negative in this case). Equations (3) and (6) are estimated without a constant and are only slightly less performing than the equations with a constant. These are utilized in order to express the 'normal' values (estimated from regressions) for PPP and CPP (estimPPP and estimCPP)

$$\text{estimPPP} = f(\text{sqrt(ExpEDU)}), \tag{3}$$

$$\text{estimCPP} = f(\text{sqrt(ExpEDU)}), \tag{4}$$

In order to classify the countries according to the success of the research activity (Figure 3), we calculate the relative difference (%) between the actual values and the ones estimated by regressions

$$R_{\text{PPP}} = \frac{(\text{PPP} - \text{estimPPP})}{\text{estimPPP}} \times 100\%, \tag{5}$$

$$R_{\text{CPP}} = \frac{(\text{CPP} - \text{estimCPP})}{\text{estimCPP}} \times 100\%. \tag{6}$$

As in the case of productivity, according to the efficiency of financing we distinguish three clusters. The countries in group A (South Africa and Tunisia) have significant over-average levels of financing efficiency. In cluster B (Zimbabwe, Egypt, Guinea-Bissau, Gabon, Malawi, Kenya, Zambia, Uganda), we have an interesting situation in which the publications are under-average, but the number of citations is at a reasonable level. All the other African nations, classified in cluster C, do not succeed in financing R&D activities efficiently.

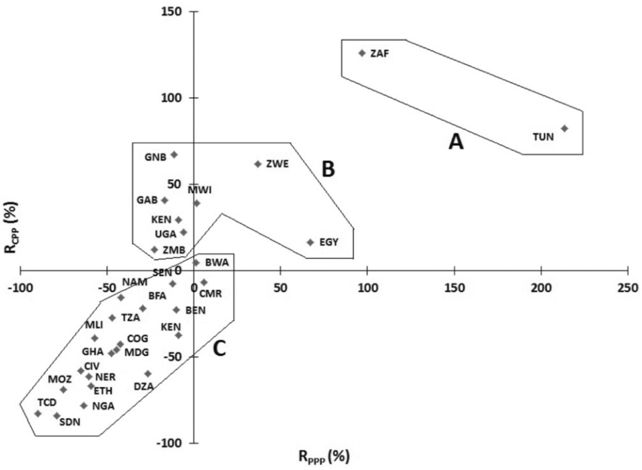

Figure 3. Distribution of African countries by R_{PPP} and R_{CPP}.

Conclusion

In keeping with the proposed research questions, we have indicated the 'normal' level of scientific production in each country. By comparing productivity with efficiency, we conclude that Gabon and Botswana do not achieve very good valorization of expenditures in education, although they have good results related to the number of inhabitants. South Africa and Tunisia are well positioned for both criteria, indicating that they have passed through a normal process of learning and behave as mature entities in the R&D process. All the other African countries are well behind this group, a gap which will not be reduced in the near future.

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Received 19 December 2013; revised accepted 7 January 2014