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Institutions and scientific research in Africa

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Abstract

This paper examines the macroeconomic determinants of scientific production in Africa by focusing on direct and indirect roles that political and economic institutions may play. A theoretical model of scientific production that integrates the quality of institutions, as well as econometric estimations conducted on a panel of 47 African countries over the period 1994 to 2009, suggest significant direct and indirect effects of institutions on scientific research performance.

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1. Introduction

Many studies have highlighted the necessary role of scientific research in productivity and long term economic growth (Romer, 1990; Bravo-Ortega and Marín, 2011), as well as in industrial development and poverty alleviation (Thirtle et al., 2003). According to United Nations Economic Commission for Africa, UNECA (2012), as Africa prepares to become the next global growth pole, national governments must emphasize university education, with a particular focus on science and technology, and a strong research culture in African universities. Indeed, in Africa, the scientific production is not only relatively low compared to other regions of the world, but also variously distributed among countries of the continent (Gaillard, 2002; Table 8 and 9). In addition, most of African countries develop abysmal political and economic institutions, reflected in the weakness of governance and institutional indicators (Table 2.), that may lead most talented people into rent-seeking activities in detriment of science and innovative activities. In this context, understanding the role of institutions in the scientific wealth of nations is important for improving scientific research, innovation and the chances of success of recent reforms in higher education inspired by the Bologna process (Khelfaoui, 2009).

Studies that assess the determinants of scientific production take either microeconomic or macroeconomic approach. According to microeconomic approaches, the differences among researchers, university departments or companies in terms of scientific production can be explained by differences in inputs such as time, physical resources, human (intellectual) resources (Zucker et al., 2007), individual characteristics (age, gender, initial publication performance) and research funding opportunities (Kossi et al., 2012). As such, these studies partially indicate the determinants of knowledge production and do not evaluate fully the effect of institutions and macroeconomic policies regarding higher education and scientific research. Most of the studies using macroeconomic approach (Crespi and Geuna, 2008; Wang, 2010) do not include the quality of institutions in the factors that determine the scientific wealth of nations. In addition, studies (related to the New Institutional Economics) that assess economic effects of Institutions (Cavallo and Daude, 2011; Rajkumar and Swaroop, 2008) do not deal explicitly with the issue of scientific production. However, this paper attempts to fill these gaps.

The aim of this paper is to examine the macroeconomic determinants of scientific production (as measured by the publication of scientific papers) in Africa by focusing for the first time on direct and indirect roles that economic and political institutions may play. We derive testable hypotheses from a theoretical model of scientific production function that incorporates the quality of institutions. We test empirically our hypothesis using econometric estimations on a panel of 47 African countries over the period 1994-2009.

This paper contributes to the literature on institutions, knowledge production and allocation of talents. It is shown that in countries with weak institutions, trainings correlated with rent seeking activities (business and law) are preferred to trainings in productive activities like engineering and sciences (Acemoglu and Verdier, 1998; Ebeke and Omgba, 2011; Murphy et al., 1991; Timur and Polishchuk, 2012). Institutions can also affect the composition and the effectiveness of public spending, particularly spending in education and scientific research. It is shown that the composition of public expenditures is tilted towards physical capital and away from education and health in countries with lower levels of governance (Cavallo and Daude, 2011; De la Croix and Delavallade, 2009). This paper shows that Better institutions improve scientific production directly and indirectly through allocation of talents and the effectiveness of scientific production inputs.

The reminder of the paper is organized as follows: Section 2 below presents an analytical framework. Section 3 presents the method of analysis and the data. The results and interpretations are presented in section 4, followed by the conclusion in section 5.

2. Analytical Framework: A simple model of scientific research production

Following the methodological framework of Crespi and Geuna (2005, 2008) and Cavallo and Daude (2011), we formulate the scientific knowledge production function as a Cobb-Douglas augmented by the quality of institutions. We assume that the scientific knowledge production function of Africa is given by:

$$Y_{it} = A_i K_{it}^{\alpha} X_{it}^{1-\alpha} e^{u_{it}} \text{ with } 0 < \alpha < 1 \tag{1}$$

Where Y measures scientific output at the macroeconomic level of a given scientific units (country), A is a constant. The index i stands for research unit (or country); and t is time index, e is the natural logarithm base. X stands for an index of conventional inputs such as human (intellectual) resources. K is a measure of physical resources and u represents all other unmeasured determinants of scientific production. α is a parameter.

When the quality of institutions is taken into account, the scientific production function takes the following form for a given country:

$$Y(K, X, \theta, u) = A(\theta) K^{\alpha} X(L, \theta)^{1-\alpha} e^{u} \tag{2}$$

We assume that $A(.)$ is an increasing function of the quality of public institutions(θ) and the function $X(.)$ which maps enrollment in higher education and institutions into a measure of the effective amount of educational infrastructure and other public goods and services provided by the public sector to encourage enrollment in higher education, is given by the following CES aggregator:

$$X(L, \theta) = (\lambda L^{\gamma} + (1-\lambda)\theta^{\gamma})^{\frac{1}{\gamma}} \tag{3}$$

with $0 < \lambda < 1$ and $\gamma < 0$

An important assumption is that in the provision of public goods (educational infrastructures), the degree of substitutability between enrollment in higher education and institutions is limited, which is reflected by the assumption that the parameter γ is negative (Cavallo and Daude, 2011).

The impact of enrollment in higher education on scientific output[1] is given by:

$$\frac{\partial Y}{\partial L} = \lambda(1-\alpha) A(\theta) K^{\alpha} L^{\gamma-1} X(L, \theta)^{1-\alpha-\gamma} e^{u} \tag{4}$$

This impact is positive, $\frac{\partial Y}{\partial L} > 0$.

The effect of institutional quality on the relationship between enrollment in higher education and the scientific production is given by:

$$\frac{\partial Y_L}{\partial \theta} = \lambda(1-\alpha) K^{\alpha} L^{\gamma-1} X(L, \theta)^{1-\alpha-\gamma} [A'(\theta) + (1-\alpha-\gamma)(1-\lambda) A(\theta) \theta^{\gamma-1} X(L, \theta)^{-\gamma}] e^{u} \tag{5}$$

This effect is positive, $\frac{\partial Y_L}{\partial \theta} > 0$, under the sufficient (not necessary) condition of a low degree of substitutability between public investment (in higher education) and institutions (γ < 0).

In sum, two major testable hypothesis are derived from our analytical framework. First better institutions raise directly scientific production by increasing A(.). Second, enrolment in higher education (intellectual resources) is one of the channel through which institutions affect the scientific production. Better institutions improve scientific production indirectly through allocation of talents and the effectiveness of scientific production inputs. Indirectly

[1] $\frac{\partial Y}{\partial L} = Y_L = \frac{\partial Y}{\partial X} * \frac{\partial X}{\partial L}$

through $X(.)$, good institutions plausibly increase the marginal productivity of public investment in the infrastructure of higher education and scientific research. Good institutions may lead skillful graduates into productive activities like engineering and sciences (Acemoglu and Verdier, 1998; Ebeke and Omgba, 2011; Murphy et al., 1991; Timur and Polishchuk, 2012). On the contrary, weak institutions may reduce the positive effects of public investment projects (Cavallo and Daude, 2011; Rajkumar and Swaroop, 2008).

According to Séka (2008), corruption negatively affects the accumulation of human capital. This author argues that very talented students, who otherwise could have pushed further their studies (and become researchers), suddenly dropout when they compare the level of well being of those who are well educated with that of those who are not but enriched through corruption. This idea is in line with Acemoglu and Verdier (1998) who show that corruption could lead to misallocation of talent because rents in the public (or non scientific research) sector attract agents with no comparative advantage for this sector.

Armed with the intuition given by the analytical framework developed above, we test empirically our hypotheses using econometric estimations with data on African countries over the period 1994-2009. As measure of scientific production, we focus only on the number of scientific and engineering articles published in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences.

3. Empirical Analysis

3.1. Econometric estimation method

In order to evaluate the determinants of scientific production at the macro level, we use system GMM estimators developed by Arellano and Bover (1995) and Blundell and Bond (1998). This estimation method is suitable for our study, because it allows for dealing with econometric (endogeneity) problems and taking into account the dynamic specification. First, the dynamic specification of scientific production model leads to highlight the “Saint Matthew Effect” or the “knowledge begets knowledge” of the cumulative advantage model of the knowledge production process (Crespi and Geuna, 2005; Kossi et al., 2012; Zucker et al., 2007). Second, some of the variables especially the quality of institutions and public spending may be endogenous. The System GMM estimator allows us to address this endogeneity problem. We use lagged variables as instruments. All our regressions include the small sample correction proposed by Windmeijer (2005) in order to obtain robust two-step standard errors.

For the analysis of the direct effect of institutions, our empirical equation is given by

$$y_{it} = \alpha_0 + \alpha_1 y_{it-1} + \alpha_2 l_{it} + \alpha_3 g_{it} + \beta' \boldsymbol{X}_{it} + u_{it} \tag{6}$$

y_{it}, l_{it}, g_{it} and $\boldsymbol{X}_{it}$ respectively denote the scientific production specifically the number of publications (in logarithm) of country i at the period (year) t, the logarithm of enrollment in higher education (proxy of the number of researchers), the quality of institutions, and the vector of control variables (including the Information and Communication Technologies (ICT), the level of income per capita, foreign direct investment, the proxy of public spending in Research and Development). u is the error term.

For the analysis of indirect effects of institutions (through intellectual resources), we consider the following equation:

$$y_{it} = \alpha_0 + \alpha_1 y_{it-1} + \alpha_2 l_{it} + \alpha_3 g_{it} + \alpha_4 (g * l)_{it} + \beta' \boldsymbol{X}_{it} + u_{it} \tag{7}$$

$(g * l)_{it}$ is the interaction term between institutions and one of the inputs of scientific production, enrollment in higher education. Its coefficient α_4 reflects the effect that the quality of institutions exerts on the relationship between enrollment in higher education and scientific production. It is expected to be positive (given that good institution index is used)

The dependent variable is the **scientific production** (*Publication*). It is captured by Scientific and technical journal articles published which refer to the number of scientific and engineering articles published during a given period (year) in the following fields: physics, biology, chemistry, mathematics, clinical medicine, biomedical research, engineering and technology, and earth and space sciences. As we do not opt for count data models[2], and inspired by Crespi and Geuna (2005, 2008), our dependant variable *Publication* is log (1 + *Scientific and technical journal articles published*); log is natural logarithm.

Explanatory variables include the (one period) lagged dependent variable, governance and institutional variables, colonial origin dummy, Enrolment in higher education, income per capita, *ICT*, public spending, Foreign knowledge.

The **lagged dependent variable** (scientific production at period $t-1$) measures the dynamic bias known as "Saint Matthew effect" by which the most productive or famous research unit (researchers, countries), maintains the highest possibility of publication with more favorable scientific environment (Kossi et al., 2012). In a macroeconomic approach, this means that "The more knowledge has been produced, the more it can be recombined to produce new knowledge" (Crespi and Geuna, 2005). In other term it captures "knowledge begets knowledge" of the cumulative advantage model of the knowledge production process (Zucker et al., 2007). It is expected to have a positive sign.

Concerning **governance and institutional variables**, we use three categories of indicators that characterize democratic governance, political freedom and civil liberties, freedom of expression and information. First, we consider the six (6) governance indicators produced by Kaufman, Kraay and Mastruzzi. These indicators range from -2.5 (weak) to 2.5 (strong) governance performance. The indices reflect respectively, Voice and Accountability (*VA*), Political Stability and Absence of Violence (*PS*), Government Effectiveness (*GE*), Regulatory Quality (*RQ*), Rule of Law (*RL*), and Control of Corruption (*CC*). Second, we use indicators from Freedom House. Originally, Political Rights and Civil Liberties are measured on a one-to-seven scale, with one (1) representing the highest degree of Freedom and seven (7) the lowest. However, in order to harmonize the interpretation of the sign of governance indicators, we operate a small modification in the scale (we define a new variable *POL* and *CIL* with *POL*= (8 - Political Rights score), and *CIL*= (8- Civil Liberties score)) to have one (1) representing the lowest degree of Freedom and seven (7) the highest. Finally, we use democracy index *Polity2* from PolityIV database. It is a combined index of democracy and autocracy, ranged from -10 (strongly autocratic) to +10 (strongly democratic). The expected sign of their coefficient is positive.

Colonial origin: we use dummy variable (*BritishD*) which takes the value of 1 if the country is former British colony and 0 if not. The expected sign of this variable is positive assuming that former British colonies achieve higher scientific production compared to former other colonies in Africa (La Porta et al., 2008).

[2] The data, on the dependent variable, we use (Scientific and technical journal articles) seem not be count data. Even though in the WDI database online (http://data.worldbank.org/indicator/IP.JRN.ARTC.SC, accessed 22 May 2013), data refer to the number of scientific and engineering articles published per year, they are not count or discrete data (we have decimal or continuous data since 1995). As mentioned in the related Databank, one reason is that: "Counts are based on fractional assignments; articles with authors from different countries are allocated proportionately to each country…. Articles are counted on a fractional-count basis that is, for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions".

Moreover, the number of zeros is likely to be small (Table 9). In our database, we have zeros for few years in only four (4) countries (Liberia 4 years, Djibouti 2 years, Comoros 4 years and Cape Verde 4 years). Consequently, count model may not be suitable for our estimations.

Enrolment in higher education, we use gross tertiary school enrollment ratio (%) in logarithm (*Enrolment*). It is a proxy of the number of researchers and research institutions, or intellectual resources. Higher education can impact economic growth through the Research and Development Channel. Higher education is necessary to increase a country's capacity to conduct research and generate new knowledge to develop new product and production technologies (Kimenyi, 2011). According to Wang (2010), tertiary education and the proportion of scientific researchers are robust determinants that had positive effects on Research and Development intensity in OECD countries.

The **level of income per capita**: We use gross national income per capita in logarithm (*Income*). Van Pottelsberghe (2004) shows that the level of income per capita may explain difference across countries in terms of Research and Development intensity.

Information and Communications Technology (*ICT*): We use total telephone (mobile and fixed-line) subscribers per 100 people (in logarithm) as measure of the level of ICT in a given country at a given period. ICTs provide greater, faster and more convenient access to (national and foreign) scientific and technological literature (Khelfaoui, 2009). It is therefore expected to affect positively scientific output.

Public spending: Gross public investment (% of GDP) in logarithm is used as proxy of public expenditure on education and scientific research[3]. According to van Pottelsberghe (2004), research intensity depends on the public expenditure.

Foreign knowledge: Foreign Direct Investment inflow in logarithm (*FDI*) is used as proxy for foreign research and development. Foreign knowledge (knowledge generated in other countries) is a third source of new technology for any national economy, (Guellec and van Pottelsberghe, 2001). Foreign direct investment is one of the channels through which foreign technology or research could reach national economy (firms and researchers). National researchers can interact with foreign scientists, engineers or competitors who invested in their country. FDI is expected to affect positively domestic scientific production, even though Wang (2010) found for 26 OECD countries from 1994 to 2006 that foreign technology inflows had a robust and negative impact on domestic Research and Development.

3.2. Data

We use data from various sources (National Science Foundation, Science and Engineering Indicators, Worldwide Governance Indicators, Polity-IV, freedom house, Africa Development Indicators, World Development Indicators) on a panel of 47 African countries over the period 1994-2009. Data sources are presented in Table 1. Descriptive statistics of data variables are also reported in Table 2.

In 2009, about 5080 articles were published in Africa. South Africa, Egypt and Tunisia have published the largest number of scientific articles, respectively 2863, 2247, and 1022 articles. In contrast, Liberia, Sao Tome and Principe, Comoros, and Somalia have made lesser effort in terms of scientific production with hardly one paper published. In our sample, indicator of the number of scientific and engineering articles varies between zero article (Liberia, Djibouti, Comoros, Cape Verde) to 2916 articles (South Africa, 2008) with an average publication of 141 scientific articles. The enrollment in tertiary education rate ranges from less than 1% (Angola, Chad, Djibouti, and Malawi) to 37% (Egypt, 1998) with a mean of 5.18%. The mean values of all the six governance indicators (of Worldwide Governance Indicators) exhibit negative sign.

[3] The ideal is to use Research and development spending, but unfortunately data on Research and development expenditure are not available for most of African countries for the period covered by this study. We approximate it by Gross public investment, but having in mind the eventual bias related to this approximation.

4. Regression results

Table 3 presents results on direct effects of institutional quality on scientific production. The results show that the coefficients of all the six governance indexes produced by Kaufman, Kraay and Mastruzzi, are positive and statistically significant (columns 3.1 to 3.6). *VA* and *CC* have the highest coefficients (0.678 and 0.671). These results suggest that better institutions increase the number of scientific journal articles published by a given country. In other words, countries with better institutions publish more. We obtain similar results using alternative measures of governance indicators from various databases.

Column 3.7 reports the results using the democracy index, polity2. The coefficient of this index is positive and statistically significant showing that democracy enhances scientific production. The last two columns 3.8 and 3.9 contain the results with the use of respectively the political freedom and civil liberties indexes from freedom house database, as governance indicators. The coefficients of these indices are positive and statistically significant. This suggests that countries with high degree of civil and political freedom achieve higher scientific production.

In sum, results shows that better institutions affect directly and positively scientific output. These findings validate our first hypothesis.

Institutions can affect scientific production indirectly through allocation and the effectiveness of inputs. In this paper, we analyze the indirect effect through the allocation of intellectual resources.

Estimations results of the indirect effects of institutions through enrollment in higher education are presented in Table 4. As expected, the coefficients of interaction terms between governance indicators and enrollment rate are positive and statistically significant. These results suggest that better institutions reinforce the positive effect that intellectual resources exert on scientific production. This suggests that countries with weak institutions achieve lower tertiary education enrollment rate and less scientific production, and similarly, countries with better institutions achieve higher tertiary education enrollment rate (intellectual resources), a factor that may be crucial for scientific production. These results are in line with the finding of Weinberg (2011) that democracy is associated with the production of more important scientists and Séka (2005) that corruption affects negatively enrollment in higher education. These results allow us not to reject our second main hypothesis that better institutions improve scientific production through allocation of talents and the effectiveness of inputs.

As South Africa dominates the production of research on the continent, one may wonder whether the results are driven largely by this country. We test this by excluding South Africa in the sample. Specifically, we report the estimation results using:

(a) the sub-sample of African countries excluding South Africa (Table 5),

(b) the sub-sample of Sub-Saharan African countries (Table 6) and

(c) the sub-sample of Sub-Saharan African countries excluding South Africa (Table 7).

The results for the independent variables of interest (institution variables and interaction terms) in all these sub-samples are largely consistent with those of the full sample in Table 4. However, the coefficient values in the regressions are different from a sub-sample to another. This reflect various degree of sensitivity of each sub-sample scientific production vis-à-vis a given governance indicator.

In our econometric estimates, results indicate that the lagged dependent variable is positive and statistically significant reflecting the “Saint Matthew effect”. This result not only highlights the suitability of the dynamic GMM approach used, but also confirms the opinion of Zucker et al. (2007) that the rate of creation of new knowledge increases proportionally to the level of existing stock of knowledge (“Knowledge begets knowledge”).

5. Conclusion

In this paper, we examine the macroeconomic determinants of scientific production in Africa by focusing for the first time on direct and indirect roles that institutions and colonial origins may play. We test empirically hypotheses derived from a theoretical model of scientific production function that incorporates the quality of institutions, using econometric estimations. Our main results indicate that better economic and political institutions improve scientific production directly and indirectly through provision and effectiveness intellectual resources. Furthermore, the positive and significant coefficient associated with lagged dependent variable indicates that countries that publish more today are likely to produce more knowledge in the future.

The findings of this paper suggest the following policy implications: First, higher education should be improved (quantitatively and qualitatively) in order to increase the number and the productivity of highly qualified researchers (intellectual resources) through increased government spending in higher education (infrastructure and research funding).

Second, promotion of good governance, institutional quality and learning languages (especially English) must be at the heart of reforms for improvement of scientific research and innovation in Africans countries.

Finally, future researches should analyze the political economy of scientific research in various research fields and make comparison in order to look for the role of specialization. The comparison of the scientific research effects of different colonial legacies would also be a focus of further research.

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Appendix

Table 1. Data and data sources

Variable	Definition	Source
Publication1	Scientific and technical journal articles refer to the number of scientific and engineering articles published	National Science Foundation, Science and Engineering Indicators World Development Indicators
Publication	log (1 + Scientific and technical journal articles published)	World Development Indicators
Enrollment	log (1 + gross tertiary school enrollment ratio)	World Development Indicators
ICT	mobile and fixed-line subscribers (total telephone subscribers) per 100 people (in logarithm)	Africa Development Indicators
Infrastructure	Gross public investment (as a percentage of GDP) in logarithm	Africa Development Indicators
FDI	Foreign Direct Investment net inflows (as a percentage of GDP) in logarithm	Africa Development Indicators
Income	The GNI (gross national income) per capita, using the World Bank Atlas method, divided by the midyear population. (Current U.S. dollar) in logarithm.	Africa Development Indicators
BritishD[*]	Dummy variable which takes the value of 1 if the country is former British colony and 0 if not	
VA	*Voice and Accountability* ranges from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
PS	*Political Stability and Absence of Violence*: ranges from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
GE	*Government Effectiveness*: range from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
RQ	*Regulatory Quality*: ranges from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
RL	*Rule of Law*: ranges from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
CC	*Control of Corruption*: ranges from -2.5 (weak) to 2.5 (strong) governance performance	The Worldwide Governance Indicators, www.govindicators.org
polity2	polity2 is a combined index of democracy and autocracy of POLITY IV project, ranged from -10 (strongly autocratic) to +10 (strongly democratic)	Polity IV
POL	Index Political right measured on a one-to-seven scale, with seven (7) representing the highest degree of Freedom and one (1) the lowest	Freedom House , http://www.freedomhouse.org/report-types/freedom-world
CIL	Index Civil liberties measured on a one-to-seven scale, with seven (7) representing the highest degree of Freedom and one (1) the lowest	Freedom House, http://www.freedomhouse.org/report-types/freedom-world

*** Former British colonies** (17): Botswana, Egypt, Gambia, Ghana, Lesotho, Kenya, Malawi, Namibia, Nigeria, Sierra Leone, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe.

Other former colonies (French) (21): Algeria, Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, Gabon, Guinea, Madagascar, Mali, Mauritania, Mauritius, Morocco, Niger , Senegal, Togo, Tunisia. (Portuguese + Belgian + Italian + Spanish) (9): Angola, Burundi, Cape Verde, Congo (Democratic Republic), Guinea-Bissau, Mozambique, Rwanda, Equatorial Guinea, Ethiopia.

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Table 2. Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Publication1	784	141.2	413.6	0	2916
Publication	784	3.1	1.8	0	8.0
Enrollment	752	1.5	0.7	0	3.6
Income	784	6.4	1.1	4.4	9.6
ICT	784	0.9	0.8	0	3.4
Infrastructure	768	1.8	0.7	-2.3	3.5
FDI	768	1.2	0.9	-2.3	5.0
BritishD	784	0.3	0.5	0	1.0
VA	686	-0.6	0.7	-1.9	1.0
PS	686	-0.5	0.9	-3.0	1.2
GE	686	-0.7	0.6	-2.0	0.9
RQ	686	-0.6	0.6	-2.4	0.9
RL	686	-0.7	0.7	-2.2	1.1
CC	686	-0.6	0.6	-2.1	1.2
polity2	768	0.8	5.3	-9	10
POL	784	4.5	1.8	1.0	7.0
CIL	784	4.3	1.3	1.0	7.0

Table 3. Directs effects of institutions in Africa. Dependent Variable, log(1+ Scientific and technical journal articles)

	3.1	3.2	3.3	3.4	3.4	3.6	3.7	3.8	3.9
L.*Publication*	0.706***	0.478*	0.728***	0.546***	0.610***	0.502***	0.526***	0.327**	0.387***
	(5.40)	(1.87)	(6.97)	(3.66)	(5.91)	(3.54)	(4.48)	(2.12)	(2.65)
Income	-0.772***	-0.651**	-0.191*	-0.530**	-0.465**	-0.558**	-0.163	-0.752***	-0.794***
	(2.62)	(1.99)	(1.65)	(2.21)	(2.44)	(2.50)	(1.20)	(3.36)	(3.59)
ICT	-1.282**	-0.886**	-0.243***	-0.869**	-0.795***	-1.086***	-0.154	-1.104**	-0.971**
	(2.40)	(2.21)	(2.61)	(2.35)	(2.74)	(3.19)	(0.67)	(2.23)	(2.45)
FDI	-0.303*	-0.153	-0.300***	-0.422**	-0.410**	-0.538*	-0.072	-0.463**	-0.422*
	(1.96)	(0.88)	(2.92)	(2.24)	(2.52)	(1.83)	(1.29)	(2.51)	(1.92)
Enrolement	2.034***	1.800***	0.675***	2.009***	1.812***	2.364***	0.931***	3.131***	2.938***
	(3.08)	(3.21)	(2.89)	(3.11)	(3.63)	(4.10)	(2.97)	(4.14)	(4.29)
Infrastructure	0.251*	0.159	0.114	0.241**	0.248**	0.254*	-0.114	0.252*	0.261**
	(1.85)	(0.93)	(1.55)	(2.06)	(2.44)	(1.70)	(0.69)	(1.95)	(2.16)
BritishD	0.552*	2.416*	0.279*	0.732**	0.592**	0.768*	0.600*	1.021**	0.995***
	(1.67)	(1.88)	(1.94)	(1.97)	(1.97)	(1.73)	(1.95)	(2.18)	(2.61)
VA	0.678**								
	(2.53)								
PS		0.414**							
		(2.14)							
RQ			0.260**						
			(2.24)						
GE				0.517**					
				(2.03)					
RL					0.383**				
					(2.13)				
CC						0.671**			
						(2.19)			
polity2							0.043*		
							(1.76)		
POL								0.205*	
								(1.70)	
CIL									0.190*
									(1.72)
Intercept	4.128***	3.223*	1.528**	2.764**	2.325**	2.880**	1.396*	2.153	2.412**
	(2.93)	(1.96)	(2.02)	(2.12)	(2.27)	(2.31)	(1.78)	(1.55)	(2.30)
Observations	599	599	599	599	599	599	599	599	599
countries	47	47	47	47	47	47	47	47	47
Instruments	38	38	24	38	39	38	39	39	39
AR(1) (p-value)	0.003	0.022	0.001	0.001	0.000	0.002	0.002	0.009	0.010
AR(2) (p-value)	0.099	0.127	0.207	0.160	0.195	0.261	0.214	0.286	0.226
Hansen (p-value)	0.207	0.297	0.842	0.258	0.277	0.114	0.352	0.435	0.266

Note: The estimation method is two-step system GMM with Windmeijer (2005) small sample robust correction.
L.*Publication* is the lagged dependent variable.
The values in parentheses are absolute value of z-statistics.
The null hypothesis of the AR tests is that the errors exhibit no second order serial correlation.
***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 4. Indirect Effects of institutions in Africa. Dependent Variable, log(1+ Scientific and technical journal articles)

	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9
L.*Publication*	0.831***	0.711***	0.740***	0.772***	0.778***	0.774***	0.779***	0.941***	0.879***
	(8.54)	(6.18)	(8.12)	(9.80)	(7.83)	(9.47)	(9.66)	(15.22)	(8.20)
Income	-0.351*	-0.470***	-0.269**	-0.253**	-0.257*	-0.311**	-0.355***	-0.334	-0.263
	(1.85)	(2.62)	(2.32)	(2.01)	(1.87)	(2.44)	(2.90)	(1.44)	(1.05)
ICT	-0.544	-0.621**	-0.741**	-0.683***	-0.572*	-0.691**	-0.467**	0.016	-0.262
	(1.64)	(2.05)	(2.25)	(2.96)	(1.66)	(2.26)	(2.42)	(0.10)	(0.99)
FDI	-0.178***	-0.157**	-0.116*	-0.123**	-0.134**	-0.132**	-0.275*	-0.177	-0.180*
	(2.67)	(2.50)	(1.93)	(2.44)	(2.50)	(2.54)	(1.73)	(1.13)	(1.78)
Enrolement	1.635**	1.670***	1.622***	1.485***	1.228**	1.670***	1.103***	-0.118	-0.868
	(2.31)	(2.63)	(2.98)	(3.41)	(2.48)	(3.17)	(3.01)	(0.33)	(1.36)
Infrastructure	1.234***	0.911**	0.727**	0.856***	0.814**	0.862**	0.840***	0.820***	1.728***
	(2.82)	(2.10)	(2.23)	(2.81)	(2.07)	(2.56)	(3.09)	(2.96)	(3.05)
BritishD	0.498*	0.691**	0.610***	0.588***	0.580**	0.492**	0.489**	0.157	0.515*
	(1.69)	(2.53)	(2.67)	(2.85)	(2.45)	(2.40)	(2.28)	(0.80)	(1.72)
VA	-1.497***								
	(2.76)								
EnrolmentxVA	0.789**								
	(2.45)								
PS		-0.633**							
		(2.49)							
EnrolmentxPS		0.397***							
		(2.74)							
GE			-1.307**						
			(2.56)						
EnrolmentxGE			0.805**						
			(2.51)						
RQ				-1.372***					
				(3.18)					
EnrolmentxRQ				0.843***					
				(3.23)					
RL					-0.945**				
					(2.36)				
EnrolmentxRL					0.543***				
					(2.59)				
CC						-1.643***			
						(3.05)			
EnrolmentxCC						0.951***			
						(2.97)			
polity2							-0.078*		
							(1.79)		
Enrolmentxpolity2							0.039*		
							(1.68)		
POL								-0.311*	
								(1.89)	
EnrolmentxPOL								0.142*	
								(1.71)	
CIL									-0.808***
									(2.61)
EnrolmentxCIL									0.366**
									(2.49)
Intercept	-1.608	0.279	-0.787	-1.038	-0.628	-0.970	0.402	1.504	1.478
	(1.39)	(0.21)	(0.76)	(0.99)	(0.54)	(0.88)	(0.59)	(1.11)	(0.75)
Observations	599	599	599	599	599	599	599	599	599
countries	47	47	47	47	47	47	47	47	47
Instruments	41	41	41	42	41	41	41	41	43
AR(1) (p-value)	0.002	0.003	0.001	0.001	0.002	0.001	0.001	0.001	0.002
AR(2) (p-value)	0.117	0.071	0.084	0.103	0.092	0.092	0.100	0.115	0.166
Hansen (p-value)	0.255	0.531	0.594	0.597	0.623	0.566	0.362	0.182	0.530

Note: The estimation method is two-step system GMM with Windmeijer (2005) small sample robust correction.
L.*Publication* is the lagged dependent variable.
The values in parentheses are absolute value of z-statistics.
The null hypothesis of the AR tests is that the errors exhibit no second order serial correlation.
***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 5. Africa excluding South Africa: Dependent Variable, log(1+ Scientific and technical journal articles)

	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9
L.*Publication*	0.813***	0.635***	0.703***	0.740***	0.699***	0.738***	0.800***	0.913***	0.848***
	(7.81)	(5.63)	(7.02)	(8.15)	(6.06)	(8.64)	(4.73)	(4.66)	(8.10)
Income	-0.350	-0.568***	-0.312**	-0.270*	-0.312*	-0.336**	-2.446***	-0.230	-0.291
	(1.60)	(3.31)	(2.33)	(1.86)	(1.92)	(2.42)	(3.47)	(0.50)	(1.17)
ICT	-0.557*	-0.728**	-0.771**	-0.730***	-0.692*	-0.710**	1.237*	-0.192	-0.193
	(1.66)	(2.14)	(2.28)	(2.91)	(1.73)	(2.31)	(1.89)	(0.48)	(0.97)
FDI	-0.202***	-0.146**	-0.131**	-0.131**	-0.144**	-0.139**	-0.016	-0.262**	-0.166*
	(2.92)	(2.38)	(1.96)	(2.24)	(2.23)	(2.42)	(0.12)	(2.54)	(1.82)
Enrolement	1.625**	1.936***	1.700***	1.556***	1.422**	1.703***	1.536**	-1.487	-0.589
	(2.19)	(2.86)	(3.13)	(3.36)	(2.43)	(3.06)	(2.32)	(1.21)	(0.98)
Infrastructure	1.415***	0.802**	0.816**	0.962***	0.890**	0.937***	0.460*	1.501**	1.607***
	(3.41)	(2.09)	(2.20)	(2.62)	(2.02)	(2.70)	(1.80)	(2.47)	(3.11)
BritishD	0.525*	0.727**	0.669***	0.630***	0.647**	0.534**	0.236	0.359	0.433*
	(1.75)	(2.44)	(2.67)	(3.05)	(2.44)	(2.46)	(0.43)	(0.82)	(1.69)
VA	-1.522**								
	(2.53)								
EnrolmentxVA	0.767**								
	(2.17)								
PS		-0.564**							
		(2.31)							
EnrolmentxPS		0.398***							
		(2.61)							
GE			-1.343**						
			(2.31)						
EnrolmentxGE			0.811**						
			(2.39)						
RQ				-1.483***					
				(2.93)					
EnrolmentxRQ				0.895***					
				(3.15)					
RL					-0.964**				
					(2.07)				
EnrolmentxRL					0.573***				
					(2.63)				
CC						-1.645***			
						(2.71)			
EnrolmentxCC						0.932***			
						(2.61)			
polity2							-0.627***		
							(2.81)		
Enrolmentxpolity2							0.343***		
							(2.79)		
POL								-1.136**	
								(2.20)	
EnrolmentxPOL								0.511**	
								(2.04)	
CIL									-0.683**
									(2.29)
EnrolmentxCIL									0.286**
									(2.01)
Intercept	-1.896	1.031	-0.683	-1.139	-0.379	-0.908	12.064***	3.013	1.486
	(1.52)	(0.90)	(0.53)	(0.89)	(0.27)	(0.76)	(3.39)	(1.03)	(0.79)
Observations	586	586	586	586	586	586	586	586	586
countries	46	46	46	46	46	46	46	46	46
Instruments	41	41	41	42	41	41	41	26	43
AR(1) (p-value)	0.001	0.003	0.002	0.001	0.003	0.001	0.036	0.007	0.001
AR(2) (p-value)	0.146	0.062	0.086	0.111	0.091	0.099	0.063	0.269	0.141
Hansen (p-value)	0.304	0.597	0.680	0.689	0.715	0.643	0.357	0.704	0.529

Note: The estimation method is two-step system GMM with Windmeijer (2005) small sample robust correction.
L.*Publication* is the lagged dependent variable.
The values in parentheses are absolute value of z-statistics.
The null hypothesis of the AR tests is that the errors exhibit no second order serial correlation.
***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 6. Sub sample of Sub-Saharan African countries: Dependent Variable, log(1+ Scientific and technical journal articles)

	6.1	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9
L.*Publication*	0.857***	0.783***	0.530***	0.804***	0.781***	0.891***	0.783***	0.917***	0.960***
	(8.27)	(3.89)	(4.74)	(12.26)	(6.11)	(11.27)	(7.01)	(9.47)	(10.46)
Income	-0.345**	-0.881	-0.731***	-0.365***	-0.479**	-0.306***	-1.014***	-0.889**	-0.191
	(2.25)	(1.31)	(3.48)	(3.64)	(2.27)	(2.58)	(2.83)	(2.45)	(1.05)
ICT	-0.261	-0.961*	-1.039**	-0.428*	-0.339	-0.198	0.273	0.295	-0.205
	(0.79)	(1.71)	(2.15)	(1.83)	(0.81)	(0.66)	(0.83)	(0.89)	(0.69)
FDI	-0.159**	0.008	-0.096	-0.044	-0.176*	-0.098*	-0.111	-0.122	-0.148**
	(2.21)	(0.06)	(0.97)	(0.74)	(1.78)	(1.83)	(1.38)	(1.63)	(2.09)
Enrolement	1.362**	3.103**	3.583***	1.665***	2.421***	1.357**	0.460	-1.588	-1.294
	(2.12)	(2.11)	(3.23)	(2.83)	(2.93)	(2.39)	(1.29)	(1.44)	(1.32)
Infrastructure	1.044***	-0.497	0.928***	0.483**	1.352**	0.768**	0.802*	1.343***	1.235***
	(2.65)	(1.25)	(3.01)	(2.20)	(1.97)	(2.55)	(1.89)	(3.44)	(3.21)
BritishD	0.389	0.493	0.980*	0.419*	0.837**	0.264	0.408	0.351	0.292
	(1.40)	(0.86)	(1.88)	(1.79)	(2.57)	(1.37)	(1.13)	(0.93)	(0.92)
VA	-1.244**								
	(2.26)								
EnrolmentxVA	0.663*								
	(1.65)								
PS		-1.218**							
		(2.05)							
EnrolmentxPS		1.307**							
		(2.23)							
GE			-2.949***						
			(2.70)						
EnrolmentxGE			2.036***						
			(2.77)						
RQ				-1.360**					
				(2.46)					
EnrolmentxRQ				0.953**					
				(2.30)					
RL					-2.899**				
					(2.37)				
EnrolmentxRL					1.599**				
					(2.13)				
CC						-1.821***			
						(2.91)			
EnrolmentxCC						0.964***			
						(2.62)			
polity2							-0.470***		
							(2.66)		
Enrolmentxpoli							0.287**		
							(2.46)		
POL								-1.155**	
								(2.40)	
EnrolmentxPO								0.640**	
								(1.98)	
CIL									-0.893**
									(1.96)
EnrolmentxCIL									0.439*
									(1.66)
Intercept	-1.164	3.655	-0.367	-0.174	-2.609	-1.227	4.705***	6.230**	2.174
	(1.26)	(1.04)	(0.23)	(0.28)	(1.27)	(1.12)	(2.63)	(2.01)	(0.94)
Observations	522	522	522	522	522	522	522	522	522
countries	41	41	41	41	41	41	41	41	41
Instruments	41	36	41	41	40	41	41	41	41
AR(1) (p-	0.002	0.004	0.005	0.002	0.009	0.001	0.013	0.005	0.001
AR(2) (p-	0.120	0.085	0.089	0.093	0.139	0.110	0.098	0.201	0.091
Hansen (p-	0.355	0.365	0.285	0.258	0.396	0.282	0.586	0.371	0.417

Note: The estimation method is two-step system GMM with Windmeijer (2005) small sample robust correction.
L.*Publication* is the lagged dependent variable.
The values in parentheses are absolute value of z-statistics.
The null hypothesis of the AR tests is that the errors exhibit no second order serial correlation.
***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 7. Sub-Saharan Africa excluding South Africa: Dependent Variable, log(1+ Scientific and technical journal articles)

	7.1	7.2	7.3	7.4	7.5	7.6	7.7	7.8	7.9
L.*Publication*	0.650***	0.688***	0.757***	0.793***	0.625**	0.854***	0.751***	0.770***	0.681***
	(5.81)	(2.86)	(7.19)	(14.07)	(2.49)	(8.95)	(4.87)	(3.36)	(3.15)
Income	-0.606**	-1.013**	-0.436***	-0.312***	-0.828**	-0.609*	-1.594***	-0.273	-0.442
	(2.02)	(2.05)	(3.32)	(3.10)	(2.03)	(1.69)	(3.21)	(0.42)	(0.60)
ICT	-1.083	-1.123*	-0.531*	-0.435	-0.993	0.076	0.579	-0.302	-0.463
	(1.56)	(1.91)	(1.73)	(1.58)	(1.46)	(0.25)	(1.14)	(0.41)	(0.70)
FDI	-0.277***	-0.001	-0.073	-0.364*	-0.136	-0.345**	-0.204	-0.316**	-0.353**
	(2.70)	(0.01)	(0.41)	(1.95)	(0.95)	(2.08)	(1.59)	(2.29)	(2.56)
Enrolement	3.386**	3.534**	2.577***	1.641***	5.873***	1.545**	0.602	-2.818	-1.692
	(2.53)	(2.34)	(2.62)	(3.46)	(2.65)	(2.41)	(1.09)	(1.39)	(1.48)
Infrastructure	1.558***	-0.532**	0.909***	0.558**	1.476**	0.801***	1.180**	1.416**	1.326*
	(2.61)	(2.42)	(3.58)	(2.46)	(2.21)	(3.25)	(2.26)	(2.05)	(1.89)
BritishD	0.970**	0.565	0.605*	0.430*	1.242*	0.323	0.662	0.764	0.881
	(2.00)	(1.17)	(1.68)	(1.90)	(1.75)	(1.54)	(1.10)	(1.28)	(1.37)
VA	-2.795*								
	(1.90)								
EnrolmentxVA	1.755*								
	(1.69)								
PS		-1.045*							
		(1.65)							
EnrolmentxPS		1.286**							
		(2.13)							
GE			-2.615**						
			(2.33)						
EnrolmentxGE			1.645**						
			(2.15)						
RQ				-1.532***					
				(2.91)					
EnrolmentxRQ				1.010***					
				(2.97)					
RL					-6.715***				
					(2.62)				
EnrolmentxRL					4.014**				
					(2.48)				
CC						-1.926**			
						(2.40)			
EnrolmentxCC						1.006**			
						(2.21)			
polity2							-0.819***		
							(2.89)		
Enrolmentxpolity2							0.501***		
							(2.80)		
POL								-1.558*	
								(1.84)	
EnrolmentxPOL								0.847*	
								(1.76)	
CIL									-1.220**
									(2.03)
EnrolmentxCIL									0.632**
									(2.03)
Intercept	-2.146	4.471	-1.827	-0.193	-5.270	0.550	7.374***	5.482	5.418
	(0.89)	(1.56)	(1.31)	(0.19)	(1.50)	(0.30)	(3.02)	(1.11)	(1.16)
Observations	509	509	509	509	509	509	509	509	509
countries	40	40	40	40	40	40	40	40	40
Instruments	40	36	40	40	35	39	40	25	25
AR(1) (p-value)	0.007	0.007	0.002	0.001	0.035	0.001	0.030	0.008	0.003
AR(2) (p-value)	0.236	0.114	0.098	0.149	0.185	0.146	0.217	0.364	0.129
Hansen (p-value)	0.414	0.425	0.480	0.370	0.239	0.397	0.690	0.831	0.731

Note: The estimation method is two-step system GMM with Windmeijer (2005) small sample robust correction.
L.*Publication* is the lagged dependent variable.
The values in parentheses are absolute value of z-statistics.
The null hypothesis of the AR tests is that the errors exhibit no second order serial correlation.
***, ** and * denote statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 8. Trend of the Scientific and technical journal articles in different region of the World

Regions	1981	1985	1990	1995	2000	2005	2006	2007	2008	2009
European Union	117952	125222	159455	195897	222688	235121	242848	245972	249956	248656
North America	146718	154427	214351	217077	215444	231426	236478	237732	241520	237618
East Asia & Pacific	36706	42911	63365	82586	113881	149540	161523	169109	182046	190579
Latin America & Caribbean			6862	9519	15056	20432	21730	23337	24743	24033
South Asia	11725	9586	9700	9967	10841	15531	17784	19386	20373	21432
Middle East & North Africa			8213	9496	11154	13881	15206	16628	17920	19167
Australia	8138	8247	10664	13125	14589	15972	17217	17834	18776	18923
Russian Federation	0	0		18604	17180	14425	13562	13954	13970	14016
Sub-Saharan Africa			4244	4051	3927	4183	4616	4952	5074	5080
World	331233	351652	475365	564137	629903	709431	739985	758567	783313	788333

Source: National Science Foundation, Science and Engineering Indicators World Development Indicators

Table 9. Scientific and technical journal articles in African countries

Country Name	1986	1990	2000	2009
World	423115	475365	629903	788333
Sub-Saharan Africa	4563	4244	3927	5080
Top Ten				
South Africa	2653	2406	2221	2864
Egypt	1070	1254	1433	2247
Tunisia	76	104	292	1022
Algeria	81	98	211	607
Nigeria	976	815	401	462
Morocco	76	97	466	391
Kenya	238	255	232	291
Ethiopia	45	70	90	175
Tanzania	90	69	96	152
Cameroon	15	46	73	145
Bottom five				
Equatorial Guinea	0	1	0	2
Somalia	7	9	1	1
Comoros	0	0	1	1
Sao Tome and Principe	0	0	1	0
Liberia	5	6	1	0

Source: National Science Foundation, Science and Engineering Indicators World Development Indicators