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Research productivity: trend and comparative analyses by regions and continents

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Abstract

Using data for the period 2000 to 2019, the aim of this paper is to: (i) profile and compare research publications in regions and continents worldwide namely Africa, Western Europe, Eastern Europe, Northern America, Latin America, the Asiatic region, the Pacific region and the Middle East; (ii) assess factors associated with research productivity and (iii) verify if African countries are closing the deep gap of research production and by extension, detect factors on which to improve and boost the catch-up process. The empirical evidence is based on the Poisson regression model, quantile regression for counts data and panel negative binomial regression. The findings can be summarised as follows: (i) continuous and linear increasing trends in the production of knowledge are noted in developing regions specifically in Africa even if the contribution of the continent to global research is marginal; (ii) in countries with least production, 'internet users' is not significant but schooling modulates its effect on research production contrarily to countries in the upper part of the distribution and (iii) in Africa, if the number of schooling years increases by one, the number of documents or published works produced is expected to increase by a factor of 1.147.

Keywords: Research productivity; economic development; count data
JEL Classification: F42; O10; O30; O38; O57

1. Introduction

This study is motivated by three main strands in the academic and policy literature, notably: (i) the imperative of catch-up in the globalisation process and the corresponding role of higher institutions of learning in the attendant process; (ii) the challenge of some sustainable development goals in the light of cross-country disparities in research priorities and economic development outcomes and (iii) gaps in the literature. The points are substantiated in turn.

First, with the advent of globalisation, countries have been striving to catch-up their more developed counterparts in many areas of economic development. Within this remit, catch-up represents a phenomenon whereby nations that are backward in terms of economic development reduce the attendant gap in economic development with frontier or the most economically-performing countries (Asongu & Nwachukwu, 2016, 2019). Building on the attendant literature, the process of catch-up was fundamentally linked to the implementation of measures in laggard countries by which techniques from leading nations could engender a more proportionate increase in development outcomes. Mazzoleni (2008) posits that, catch-up entails a complex procedure that embodies a plethora of actors, dimensions and aspects within an economic system. According to the narrative, public research institutions and universities have been acknowledged as key stakeholders for the cross-country catch-up process. Morrison et al. (2009) maintain that such institutions constitute the infrastructure supporting the means by which technological and scientific capacities are built, not least, because higher institutions of learning provide the much-needed instruments, equipments, scientific as well as technical expertise relevant for the conception and development of new commodities.

Second, according to ninth Sustainable Development Goal (i.e. SDG 9), countries have pledged to "*build resilient infrastructure, promote inclusive and sustainable industrialization a foster innovation*". Target 9.5 in particular puts emphasis on the need to boost innovation in the light of substantially improving the number of researchers as well as private/public spending on research and experimental development (R&D). However, when the selected indicators are considered to assess the underlying targets (i.e. R&D expenditure and full-time researchers), it is apparent that the findings are very skewed. For instance, in 2017, according to the World Bank statistics, no African country managed to allocate 1% of its GDP to research (South Africa and Kenya capped at 0.8%, Burkina Faso at 0.67%, Ghana 0.38% and Madagascar, 0.01%). At the same time, France and the United States invested 2.19% and

2.71% of their GDPs in research, respectively. Indeed, the number of researchers per million inhabitants in Africa was 35 while in France and the United States, the corresponding numbers stood at 2500 and 4000, respectively.

In the light of the above, it is not surprising that northern America and Western Europe dominate in research publications worldwide. However, in recent years, there has been a surge in research productivity in developing countries. For example, according to Olalekan et al. (2014), there has been a substantial boost in health-oriented research in the African region since 2000.

Third, while the extant literature on trends in research productivity is discussed in Section 2, the closest study in the literature to the present exposition is Asongu and Nwachukwu (2016). These authors have provided global tendencies on cross-country disparities in technical and scientific publications. Three main concerns are assessed by the study, notably: (i) the presence or absence of a catch-up process; (ii) the speed of such catch-up and (iii) the period of time needed for full catch-up to be realised. Building on evidence from absolute and conditional sigma convergence tendencies, the empirical evidence suggests that more technically-developed countries would continue to dominate in knowledge production by means of scientific publications.

The present study departs from Asongu and Nwachukwu (2016) on many fronts. (i) While the underlying study has used data from World Development Indicators of the World Bank, the present study uses the Scimago Journal and Country Ranking database; (ii) while the underlying study uses data from 99 countries for the period 1994 to 2010, this research builds on data from 161 countries for the period 2000 to 2019. (iii) The empirical approach employed by the underlying study is the generalised method of moments while that from this study entails poisson regressions, quantile regressions for count data and panel negative binomial regressions.

The aim of this paper is threefold: (i) to profile and compare research publications in regions and continents worldwide namely Africa, Western Europe, Eastern Europe, Northern America, Latin America, the Asiatic Region, the Pacific Region, and the Middle East. More specifically, we examine the trends over time by regions/continents; (ii) to assess factors associated with research productivity taking into account the role played by public investment and their interactions; (iii) to verify if African countries are closing the deep gap of research production and by extension to detect factors on which to improve and boost the catch-up process. Such a positioning is also motivated by an apparent gap in the extant literature.

The rest of the study is organised as follows. Changing trends in research productivity are discussed in Section 2 while the data and methodologies are presented in Section 3. The findings and discussion are disclosed in section 4 while section 5 concludes.

2. Changing trends in research productivity

Consistent with the attendant literature (Asongu & Nwachukwu, 2016; Tchamyou, 2017), since the 1990s, there has been increasing emphasis on scientific publications and/or research productivity as a premise for economic development catch-up in the long term. The narrative is also supported by extant non-contemporary studies (Weber, 2011; World Bank, 2007). Asongu (2013a) maintains that the continents with more technological advancements (e.g. North America and Europe) have understood the need to invest in R&D for sound macroeconomic outcomes while Eastern European, Asian and Latin American countries have been tailoring their development policies to follow suit. However, compared to other countries, those in Africa have been substantially lagging behind on this front. The underlying perspective on growing catch-up from developing countries is supported by Chandra and Yokoyama (2011) within the remit of the Industrialised Asian economies (China, Korea, Hong Kong, Singapore, Malaysia and Taiwan) and by Asongu (2013b) on some countries in the Middle East.

While there is still a debate over whether public or private research institutions in developing countries should be the primary producers of knowledge products or scientific publications used to inform policy decision-making in view of boosting economic development (Mazzoleni, 2008), there is a consensus that research and scientific production are worthwhile for economic development (Asongu & Nwachukwu, 2019). Building on the relevant literature, the changing trends in research productivity can be discussed in three main strands, notably: the role of universities, the changing nature of technology and other dimensions such as the influence of globalization. These are chronologically discussed in what follows.

First, the mission of universities and public institutions of research is fundamentally based on their need to produce knowledge that is worthwhile in tailoring development policies for cross-country catch-up (Asongu & Nwachukwu, 2016). Accordingly, such underlying contribution to economic development by universities could be observed from a plethora of perspectives. As apparent in the 19th century in Germany and later experiences from some main Asian countries (Taiwan, Japan and South Korea) on the key role of education, the fact that skilled workers are available, coupled with the migration of workers with more technical expertise from leading industrialised nations as well as the phenomenon of training students abroad, have all contributed to providing conducive conditions for building capabilities for indigenous research (Kim & Nelson, 2000; Mowery & Sampat, 2005; Asongu, 2017a, 2017b; Tchamyou, 2020). As documented in Morrison et al. (2009) and Balconi et al. (2010), in the contemporary era, the catch-up process is contingent on the premise that applied and basic research represent along with other factors, fundamental drivers of scientific capabilities and by extension, crucial innovation inputs required for economic development. This narrative is supported by Asongu and Nwachukwu (2019) in an argument for doctoral degrees to be oriented towards robust and published scientific research in order to boost capabilities for scientific innovation and economic development in Africa. Mazzoleni and Nelson (2007) have further argued that the increasing role of universities in scientific innovation and economic development is traceable to two main factors which are discussed chronologically in the next two paragraphs, notably; (i) the nature of science and technology that is constantly and fast changing and (ii) other external factors such as the importance of globalization in facilitating knowledge diffusion especially within the remit of the scientific sector.

Second, with regard to the changing nature of science and technology, as Morrison et al. (2009) have argued, in the contemporary era, technologies, products and knowledge, *inter alia*, are characterised by shorter life spans compared to the past. It follows that there is still a conflation between a technology within the scientific remit and a scientific input. The implication is that discoveries from science are largely bundled with technological improvements within a very short spell of time. Moreover, novel technologies and sectors of the industry largely engender more robust scientific basis. Therefore, as argued by D'Este and Patel (2007) and Tchamyou (2017), the underlying two communities are growingly interacting with one another. The strand of studies within this remit of research largely builds on the importance of universities being equipped with the latest technologies in order for them to rapidly catch-up with frontier countries in terms of knowledge production and innovation (Puplampu & Mugo, 2020; Broström et al., 2020). Such equipments entail scientific infrastructure that is consistent with the novel repertories and/or competence as well as the insights that are essential in the identification and acquisition of timely knowledge. Accordingly, such efforts are not only important in consolidating indigenous capabilities of science, but are also important in training, acquisition of skills and research endeavours. Building on similar perspectives, it has been argued in some scholarly circles that the role of universities is in directly contributing to research in the industrial sector for economic development (Morrison et al., 2009). Albuquerque (2000) aptly substantiates the point by providing four fundamental roles of science and education in the process of catch-up, notably, as sources of: (i) technological avenues; (ii) teachers that are trained; (iii) development of and improvements in techniques of research and (iv)public and tacit know-how. These are also facilitated by both opportunities and challenges that come with the growing globalisation.

Third, consistent with the underlying literature (Asongu & Nwachukwu, 2016), the ineluctable forces of globalisation that are mostly determined in frontier countries are constraining countries in the periphery to constantly adapt to an evolving and changing environment, especially within the remits of scientific research and knowledge production. In essence, accessing knowledge in the contemporary era could be constrained by restricted intellectual property rights (IPRs) which inhibit the possibilities of peripheral countries to catch-up in terms of knowledge production (Quijano, 2000; Dastile & Ndlovu-Gatsheni, 2013; Mignolo & Walsh, 2018). As posited by Mazzoleni and Nelson (2007), when the regulatory framework for scientific publication is more stringent, the incorporation of technology from frontier countries by peripheral countries can be costly and herculean. Furthermore, similar measures with the aim of boosting industries at the national level must adhere to the competitive rules that are more stringent. Within this framework, supporting infrastructural development, education and training in science is fundamental for promoting indigenous capabilities of technology and scientific production.

3. Data collection and methodology

In this section, we present the data being used and the methodology for the trend analysis and the factors associated with research productivity.

3.1 Data collection

In this paper, two sets of data are employed. The first data were downloaded from the Scimago Journal and Country Ranking database (http://www.scimagojr.com) in November 2020. We collected data from SCImago Journal & Country Ranking (SJCR) for all areas. This portal is an interface through which the bibliometric indicators database of the SCImago Journal & Country Ranking can be accessed.

Eight major world regions are considered namely Africa (51 countries), Western Europe (19 countries), Eastern Europe (22 countries), Northern America (2 countries), Latin America (23 countries), the Asian region (25 countries), the Pacific region (5 countries) and the Middle East (14 countries) during the period 2000-2019. We select data on documents or published works, citable documents, and citations[1]. A document is defined in terms of the number of published works during the selected year. In other words, this represents the country's scientific output. The citable documents are those that are cited for a selected year. Conference papers, reviews and articles are exclusively considered. The citations are the number of citations by the documents published during the source year. The second set of data is countries' characteristics. These are: GDP per capita, governance, government expenditure on education, inequality in education, internet users and mean years of schooling (see Table 1).

3.2 Methodology

In this section, we first present the Average Annual Percentage Changes (AAPC) through a Poisson regression used to estimate the trends in world research production. Secondly, we estimate a quantile fixed effects regression and a panel negative binomial regression to explore factors associated with research productivity.

3.2.1 The trend analysis

The first indicator used for the trend analysis is the percentage share of the world research production per year. It is defined as:

$$PSW_t = \left(\frac{\text{Pub}_t^i}{\text{Pub}_t^w}\right) * 100$$

Pub_t^i is the number of publications from the region *i* and Pub_t^w is the total number of publications from the world.

Trends in the world research production are analysed by Panel Poisson Regression (PPR) models. Since the dependent variable (number of documents) is a non-negative count variable, the standard Ordinary Least Squares is no longer valid. The Poisson regression fits the model of the number of occurrences (research output) of the event (research production) where it is assumed the number of occurrences follow a Poisson regression. This model

[1] Documents and published works are used interchangeably.

allows us to estimate trends across countries and regions in order to obtain the Average Annual Percentage Changes (AAPC). To estimate the AAPC, the following PPR is used:

$$\log(y_{it}) = \beta_0 + \beta_1 x$$

Where $\log(y_{it})$ is the natural logarithm of research production (number of documents, citable documents and number of citations) of the country i in year t, and x the year given as $0,1,2,\cdots,19$ where year 0 corresponds to 2000, year 1 corresponds to 2001 and so on to 2019. We also assume that $log(y_{it})$ is linear over time. Then the AAPC are calculated as follow:

$$AAPC = 100 * (\exp(\beta_1) - 1)$$

3.2.2 The quantile fixed effects regression for counts

To deal with the problem of heterogeneity and in order to take into account the initial level of number of documents produced, we employ the Panel quantile fixed effects regression (Qcount) model.

Let y be a count random variable and their $\alpha - q$uantile defined as:

$$Q_y(\alpha) = \min\left[\eta \,\middle|\, P(y \leq \eta) \geq \alpha\right], \qquad 0 < \alpha < 1$$

The $\alpha -$ quantile has the same discrete support as y and cannot be a continuous function of the covariates. We follow the method of Machado and Santos-Silva (2005). The authors suggested a procedure which is also termed known as "jittering" employed to artificially impose some degree of smoothness by building a continuous auxiliary variable (y^*) whose quantiles have reflected a one-to-one relationship nexus with the quantiles of the count variable of interest. This variable is derived by adding to the count variable a uniform random variable, independent of y an x:

$$y^* = y + u$$

Where

$$u \sim \text{uniform}(0,1)$$

In order to implement the procedures, the authors suggest the following parametric model of the $\alpha -$ quantile of y^*:

$$Q_{y^*}\left(\alpha \,\middle|\, x\right) = \alpha + \exp[x'\beta(\alpha)], \qquad 0 < \alpha < 1$$

The parameter α is added to the right side because y^* is bounded from below at α given the way it is constructed. In count data models, the exponential form is assumed traditionally. We can now present in a more specific way our conditional quantile estimator of the number of documents produced as:

$$Q_{y^*}(\alpha \,|\, x) = \alpha + \exp[\beta_0(\alpha) + \beta_1(\alpha)\text{Schooling} + \beta_1(\alpha)\text{Internet\_us}_\text{i} + \gamma(\alpha)w_i]$$

Where $\text{Schooling}_\text{i}$ and Internet_i represent the average number of years of education received by people aged 25 and older and people with access to the worldwide network in percentage of the total population, respectively. The vector w_i includes all their characteristics that were controlled for in the regression.

3.2.3 The panel negative binomial regression

In this study, we use the negative binomial regression to analyse the relations between the number of produced documents and corresponding determinants. With this method, we can predict the value of the count variable (number of produced documents) from a set of covariates. The negative binomial model represents a variant of the Poisson-based model for count data. The negative binomial regression is used in many studies focused on research productivity (Uthman et al., 2015; Nachega et al., 2012). Following these authors, this model has been shown to employ a more robust method to fit count data in the presence of over-dispersion than the Poisson regression itself. In our case, we note that this propriety is present (see Table 3 for a descriptive summary).

Let y be the dependent variable and its value is $k \in \{0, 1, 2, 3, \cdots\}$, representing the number of produced documents. We also assume $X_1, X_2, \dots., X_n$ are independent variables and:

$$Pr(y = k \,|\, x_1, x_2, \dots., x_n)$$

represents the probability that $y = k$ when $X_1 = x_1, X_2 = x_2, \cdots, X_n = x_n$. Accordingly, the negative binomial regression can generate the following model:

$$Pr(y = k) = \frac{\Gamma(r + k)}{\Gamma(r + k)\Gamma(r)}\left(1 - \frac{\lambda}{r + k}\right)^r \left(\frac{\lambda}{r + \lambda}\right)^k$$

With r is the dispersion parameter, Γ the gamma function and λ the variance of y.

$$\Gamma(m) = (m-1)!$$

$$\lambda = \exp(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n \beta_n)$$

With this representation, we can estimate all parameters of the model by the Maximum Likelihood method.

4. Findings

The findings of the paper are presented in three main sections: the first on the Average Annual Percentage Changes, the second on the determinants of knowledge production base on the quantile regression and the third on the factors based on a binomial negative regression with an attention on African countries.

4.1 Average Annual Percentage Changes results

Figure 1, 2 and 3 show the per cent share of research output during the period 2000-2019. We observe a continuous and linear increase in the per cent share of number of documents produced in Africa. The same result is observed regarding the number of citable documents. The percent share of citable documents per year increased from 1.25% in 2000 to 2.88% in 2019. It follows that Africa represents the highest rate of increase in research production. The same trends are observed for citable documents and citations in other regions such as Latin America, the Asian region, the Pacific region and the Middle East. Contrarily, regarding developed countries such as Northern America and Western Europe, we note a decrease per cent share of worldwide research production for documents. The trend analysis confirms a continuous decrease in citable documents and citations. The relative share of published documents declined from 31.09% in 2000 to 19.61% in 2019 for Northern America and 35.24% in 2000 to 25.63% for Western Europe. The results also reveal that a real phenomenon of catch-up is taking place between developed countries and developing countries.

Table 2 shows the trends in research publications obtained from Poisson regression. The trends are significant at the 1% level in all regions. This result indicates that time explains research production. Also, concerning the number of documents and the number of citable documents, the beta coefficient is positive and significant. This indicates that the number of publications is constantly increasing during the study period. The results confirm the continuous increase in the production of research documents in the World (6.184 for documents, 5.971 for citable documents). Africa earns the highest Average Annual Percent Change (11.182) followed by the Middle East (10.407), the Asian region (8.872) and Latin America (8.654). Northern America and Western Europe present the lowest AAPC (3.562 and 4.812, respectively). The same order is apparent with the citable documents. Regarding citations, only Africa and the Middle East produce positive AAPC, reflecting their domination in terms of trend analysis of research publications. These AAPC results confirm the percent share of world research output that a catch-up phenomenon is taking shape between developed regions (Northern America and Western Europe) and other regions/continents.

4.2 Quantile regression for counts results

Table 4 presents the parameters from the quantile fixed effects regression. The signs of the regressors and their significance do not switch across the different quantiles (except for inequality in education whose effect is positive and significant in all different quantiles). These results strongly support the adoption of quantile regression. In effect, the descriptive analysis reveals that research productivity in the world is highly scattered.

GDP per capita is negative and highly significant in the lower tails of the distribution while its sign becomes positive in the upper tails. The results indicate that economic development leads to research production only in the 25^{th} quantile even if the impact is negligible. Expenditure in education is positive and significant in the lowest quantile but its impact decreases as the quantiles are increasing. The impact is negative at the highest quintile (i.e. 90^{th} quantile). Public investment represented by expenditure on education is very productive in countries where produced documents are least. The physical investment level proxied by the number internet users is significant and positive only from the 50^{th} quintile to the 90^{th} quantile and its impact doubles (0.036 at the 50^{th} quantile to 0.085 at the 90^{th} quantile). Schooling is productive in all different quantiles even if its impact is more important in higher quantiles.

To take into account the combined effect of physical investment and level of education, we create an interaction between schooling and number of internet users. The results show that the variable is positive and significant in the lower tails of the distribution (10^{th} and 25^{th} quantiles). Contrarily to the lower quantiles, the effect becomes negative and strongly significant in upper tails. To analyse the overall effect of the educational level (schooling) and physical investment (internet users) on research productivity, net effects are computed. The net effects are computed only if the three coefficients (coefficients of schooling, internet users and their interaction) are statistically significant. Otherwise, it is not applicable. The computation of net effects is consistent with contemporary literature on interactive regressions (Tchamyou & Asongu, 2017; Tchamyou, 2019). For internet users, net effects (i.e. positive) are apparent only from the 50^{th} quantile. Regarding the schooling variable, the net effects are positive in all quantiles but its value is doubles from the bottom quantile estimates to the top quantile. This result shows that even if 'physical investment', represented by number of internet users is not significant in countries with low levels of research production, its effects become productive if it is cumulated with the level of education proxied by schooling. This finding can be interpreted as follows: in countries with high levels of research production, physical investment proxied by internet users and 'expenditure on education' have a strong impact on the number of documents produced. In countries where the production is least, internet is not significant but schooling can modulate the effect on the production of knowledge.

4.3 The panel negative binomial regression results

To deepen the analysis of the results obtained in the previous section, we use a negative binomial regression with a special attention for African countries. The model estimated here is augmented by variables interacted with Africa. The following findings can be established from Table 5 on the linkages between country-specific features and the productivity indicator. To choose between different models with different number of parameters, a way of doing so is to compute an information criterion such as the Akaike Information Criterion (AIC). With this statistic, the fourth model (i.e. 4^{th} column) is clearly the winner in terms of parsimony. We also provide the log likelihood and Chi^2 statistics. The findings are discussed in terms of Incidence Rate Ratios (IRR) interpretation.

We observed that economic development, inequality in education and the interaction between schooling and internet users are not significant. It is the same for interactions between Africa and education expenditure and internet users. The estimated rate ratio for one unit increase in education expenditure is equal to 1.011, *ceteris paribus*. Hence, if a government were to increase its percentage of the expenditure on education by one point, its research production would be expected to increase by a fraction of 1.011, while holding all other variables in the model constant. Regarding 'internet users' and the schooling, the incidence rate ratios are 1.012 and 1.224, respectively. So, if a country were to increase the proportion of the population with access to worldwide internet by one unit (the mean of schooling years by one year), the number of documents produced would be expected to increase by a factor of 1.012 (1.224). When we introduce the specificity of the African region, the estimated rate ratio is 1.707, compared to other regions and given that the other variables are held constant in the model. This result can be interpreted as follows: Africa, compared to other regions, *ceteris paribus*, is expected to have a rate 1.707 times greater for research production. This finding confirms the AAPC calculated with Poisson regression by region in the previous sections. Finally, when we interact Africa with the average number of years of education received by people aged 25 and older, the incidence rate ratio is 1.147. So, in Africa, if the number of schooling years increases by one, the number of documents produced would be expected to increase by a factor of 1.147.

5. Concluding implications and future research directions

The study complements the extant literature by providing novel tendencies in research productivity across the world. In the assessment, the role of public investments on education and corresponding interactions with other elements of the conditioning information set are considered. Poisson, quantile and negative binomial regressions are employed as empirical strategies. The following main findings are established: (i) continuous and linear increasing trends in the production of knowledge are noted in developing regions specifically in Africa even if the contribution of the continent to global research is marginal; (ii) in countries with least production, 'internet users' is not significant but schooling modulates its effect on research production contrarily to countries in the upper part of the distribution and; (iii) in Africa, if the number of schooling years increases by one, the number of documents or published works produced would be expected to increase by a factor of 1.147.

Overall, the findings show that while regions/continents such as the Middle East and Africa are catching-up frontier regions/continents in terms of knowledge production by means of scientific publications, more R&D investment is needed to improve and speed-up the catch-up process. Improvements in the R&D budgets should also be complemented with measures designed to encourage knowledge products by researchers even if such research is not funded. This can be a subject of future research. To this end, qualitative data and the relevant robust methodologies that are consistent with the attendant qualitative data should be considered and employed.

In addition to the highlighted policy recommendations directly building from the findings, the following recommendations should also be considered by policy makers, *inter alia*, (a) encouraging indigenous scientific research and fighting brain drain in peripheral countries/regions with specific policies for source- and receiving-countries. (b) Improving regional research and innovation by: (i) supporting the establishment of regional scientific infrastructure; (ii) improving technical and scientific human resources and (iii) boosting mechanisms of communication between policy makers and scientific experts (Asongu & Nwachukwu, 2016).

References

Albuquerque, E. M., (2000). "Scientific Infrastructure and Catching-up Process: Notes about a Relationship Illustrated by Science and Technology Statistics", The Latin American and Caribbean Economic Association.

Asongu, S. A., (2013a). "Modeling the future of Knowledge Economy: Modeling the future of knowledge economy: evidence from SSA and MENA countries", *Economics Bulletin*, 33(1), pp. 612-624.

Asongu, S. A., (2013b). "The 'Knowledge Economy'-finance nexus: how do IPRs matter in SSA and MENA countries?", *Economics Bulletin*, 33(1), pp. 78-94.

Asongu, S. A., (2017a). "Knowledge economy gaps, policy syndromes and catch-up strategies: Fresh South Korean lessons to Africa", *Journal of the Knowledge Economy*, 8(1), pp. 211–253.

Asongu, S. A., (2017b). "The Comparative Economics of Knowledge Economy in Africa: Policy Benchmarks, Syndromes, and Implications", *Journal of Knowledge Economy*, 8(2), pp. 596–637.

Asongu, S. A., & Nwachukwu, J. C., (2016). "A brief future of Time in the monopoly of scientific knowledge". *Comparative Economic Studies*, 58(4), pp. 638–671.

Asongu, S.A., & Nwachukwu, J.C. (2019). "PhD by publication as an argument for innovation and technology transfer: With emphasis on Africa". *Higher Education Quarterly*, 72(1), pp. 15-28.

Balconi, M., Brusoni, S., &Orsenigo, L., (2010). "In Defense of the Linear Model: An Essay", *Research Policy*, 39(1), pp. 1-13.

Broström, A., Buenstorf, G. & McKelvey, M., (2020). "The knowledge economy, innovation and the new challenges to universities: introduction to the special issue", *Innovation, Organization& Management*, 23(2), pp. 145-162.

Chandra, D. S., & Yokoyama, K., (2011). "The role of good governance in the knowledge-based economic growth of East Asia – A study on Japan, Newly Industrialized Economies, Malaysia and China", Graduate School of Economics, Kyushu University.

Clegg L. X., Hankey B. F., Tiwari R., Feuer E. J. & Edwards B. K., Estimating average annual per cent change in trend analysis. Stat Med 2009;28:3670–82.

Dastile, N. P., & Ndlovu-Gatsheni, S. J. (2013). "Power, Knowledge and Being: Decolonial Combative Discourse as a Survival Kit for Pan-Africanists in the 21St Century". *Alternation,* 20(1), pp. 105 – 134.

D'Este, P., & Patel, P., (2007). "University-Industry Linkages in the UK: What are the factors underlying the variety of interactions with industry?", *Research Policy*, 36(9), pp. 1295-1313.

Kim, L., & Nelson, R., (2000). Technology, Learning and Innovation: Experiences of Newly Industrializing Economies. Cambridge University Press.

Mazzoleni, R., (2008). “Catching Up and Academic Institutions: A Comparative Study of Past National Expericences”, *The Journal of Development Studies*, 44(5), pp. 678-700.

Mazzoleni, R., & Nelson, R., (2007). “Public research institutions and economic catch-up”, *Research Policy*, 36(10), pp. 1512-1528.

Mignolo, W. D., & Walsh, C. E., (2018). *On Decoloniality*. London: Duke University Press.

Morrison, A., Cassi, I., &Rabellotti, R., (2009). “Catching-up countries and the geography of science in the wine industry”, Copenhagen Business School, 2009 Summer Conference.

Mowery, D. C., &Sampat, B. N., (2005). “Universities and Innovation”, The Oxford Handbook on Innovation Ed. Fagerberg, J. Mowery, D., and Nelson, R., Oxford University Press.

Nachega JB, Uthman OA, Ho YS, et al. Current status and future prospects of epidemiology and public health training and research in the WHO African region. Int J Epidemiol 2012;41:1829–46.

Puplampu; K. P., &Mugo, S. M., (2020). Disruptive Technology and Knowledge Development: African Universities, Human Capital and Educating for Global Citizenship. In: Arthur P., Hanson K., Puplampu K. (eds) Disruptive Technologies, Innovation and Development in Africa. International Political Economy Series. Palgrave Macmillan, Cham.

Quijano, A., (2000). Coloniality of power and Eurocentricism in Latin America. International Sociology. Duke University Press, North Carolina.

Tchamyou, V. S. (2017). “The Role of Knowledge Economy in African Business”. *Journal of the Knowledge Economy*, 8(4), pp. 1189-1228.

Tchamyou, V. S., (2019).“The Role of Information Sharing in Modulating the Effect of Financial Access on Inequality”. *Journal of African Business*, 20(3), pp. 317-338.

Tchamyou, V. S., (2020). “Education, lifelong learning, inequality and financial access: evidence from African countries”, *Contemporary Social Science*, 15(1), pp. 7-25.

Tchamyou, V. S., & Asongu, S. A., (2017).“Information Sharing and Financial Sector Development in Africa”, *Journal of African Business*, 18(7), pp. 24-49.

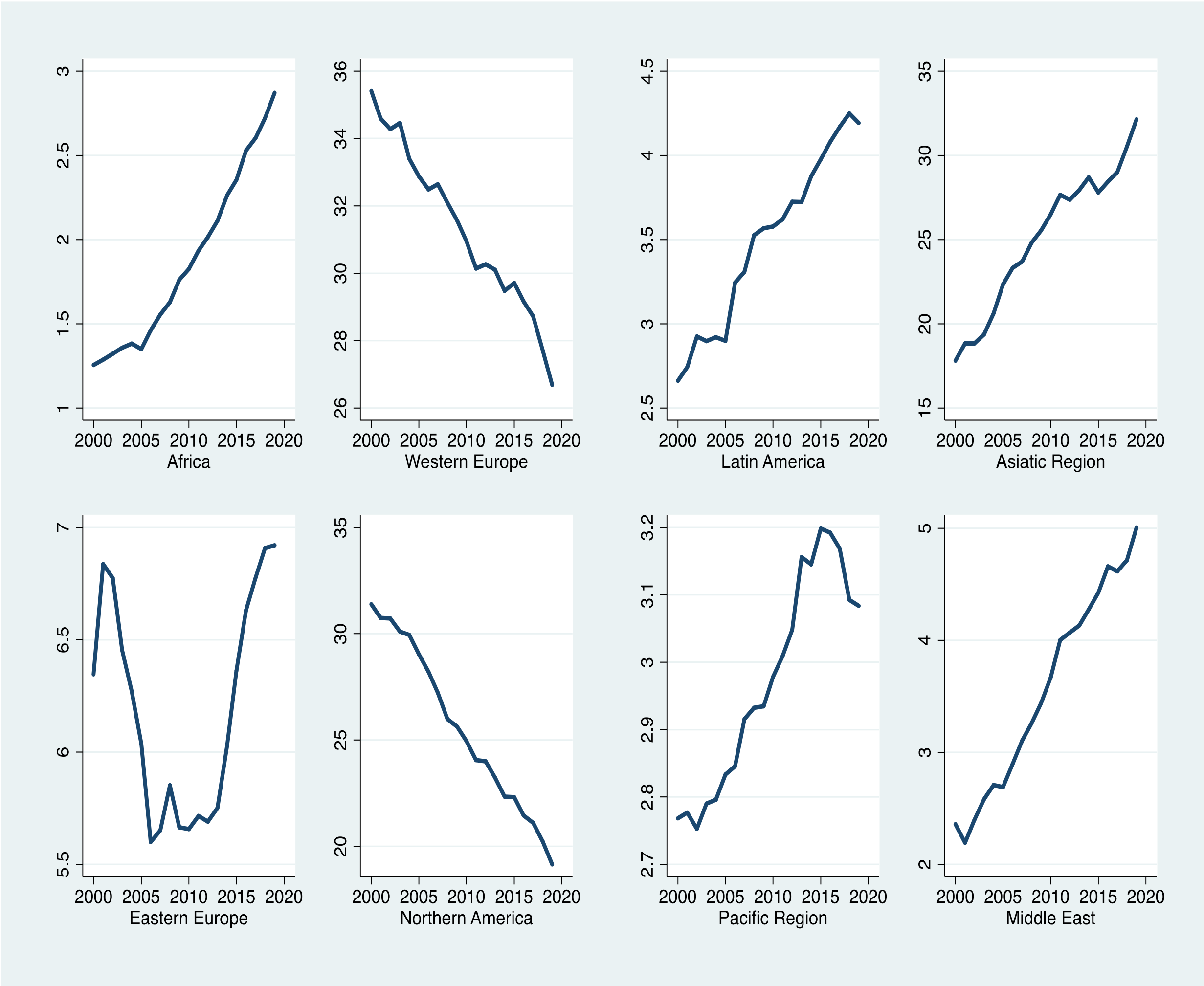
Uthman O. A., Wiysonge C. S., Ota M. O., Nicol M., Hussey G. D., Ndumbe P. M., & Mayosi B. M., (2014).Increasing the value of health research in the WHO African Region beyond 2015— reflecting on the past, celebrating the present and building the future: a bibliometric analysis. BMJ Open 2015;5:e006340. doi:10.1136/bmjopen-2014- 006340.

Weber, A. S., (2011). “The role of education in knowledge economies in developing countries”, *Procedia Social and Behavioral Sciences*, 15, pp. 2589-2594.

World Bank (2007). Building Knowledge Economies. Advanced Strategies for Development. World Bank Institute Development Studies. Washington DC.

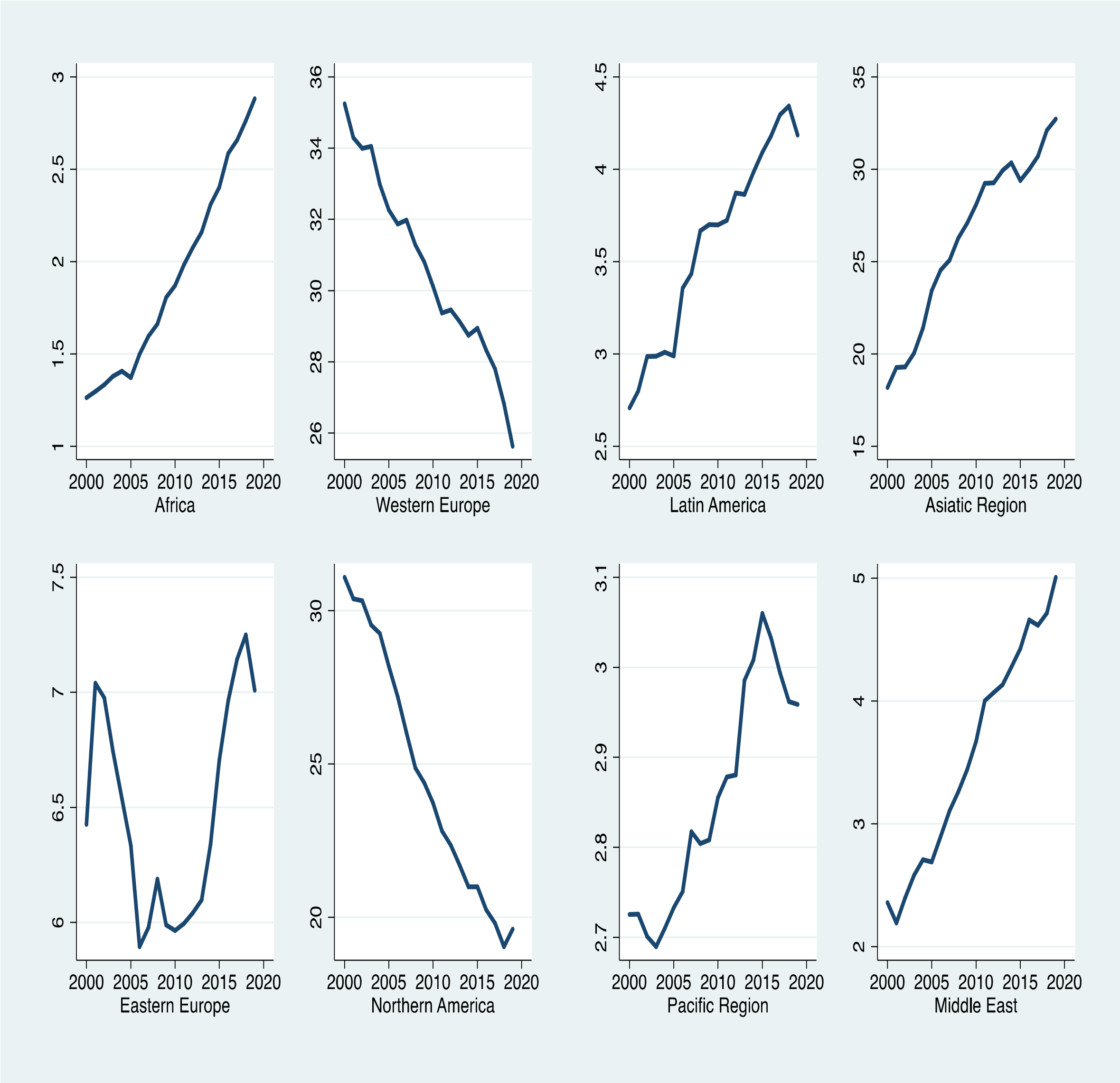
Appendices

Figure 1: Per cent share of world research output (documents or published works)



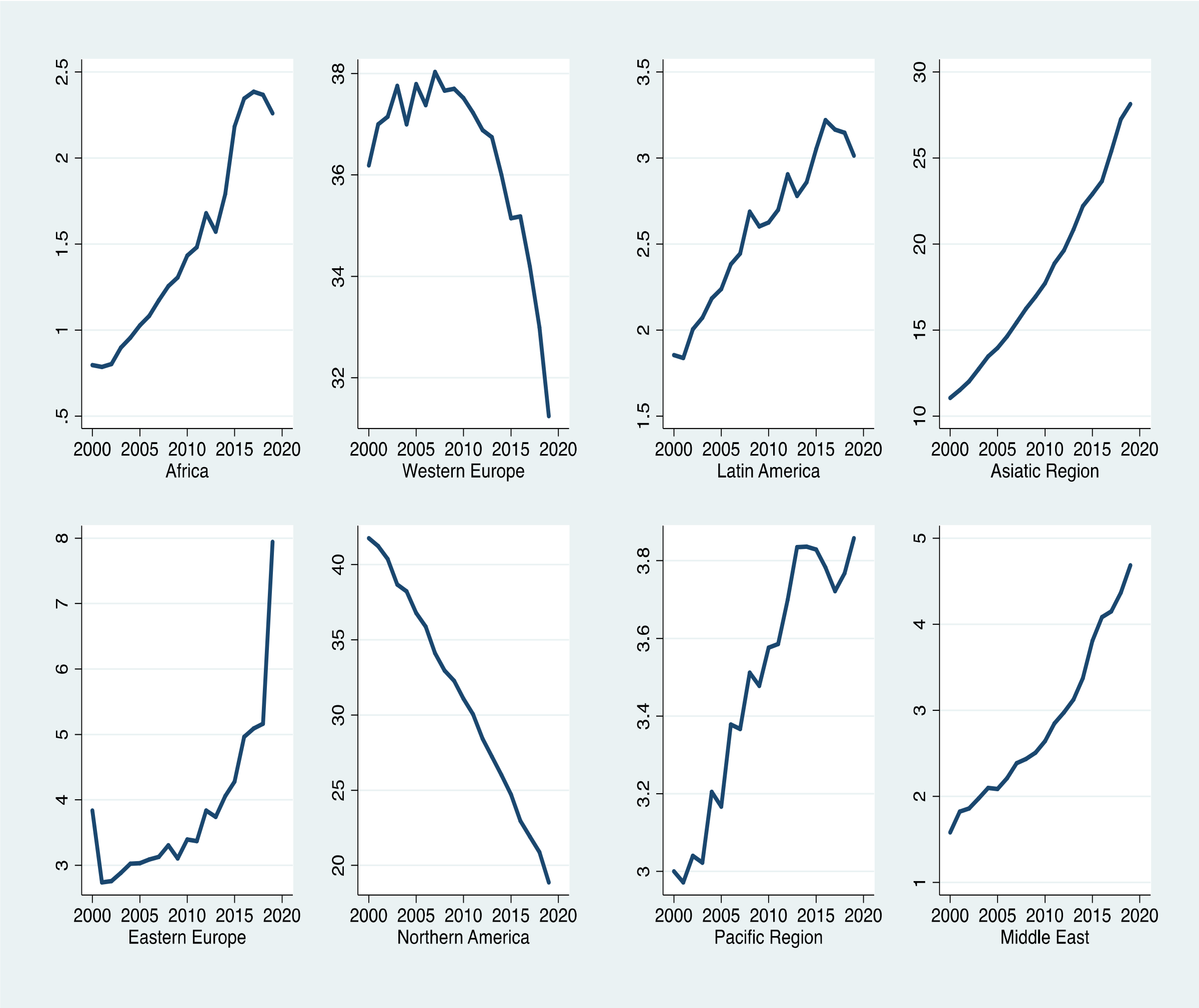
Sources: authors

Figure 2: Per cent share of world research output (Citable documents or published works)



Sources: authors

Figure 3: Per cent share of world research output (Citations)



Sources: authors

Table 1: Variables' definitions

Variables	Abbreviations	Definitions	Sources
Documents	Documents	The document is defined as the number of documents published during the selected year	SCImago
Citable documents	Citable documents	The citable documents are selected year citable documents	SCImago
Citations	Citations	The citations are the number of citations by the documents published during the source year	SCImago
GDP per capita	Gdppc	GDP per capita (current US$)	World Bank (WDI)
Government expenditure on education	Expeducexp	General government expenditure on education is expressed as a percentage of total general government expenditure on all sectors (including health, education, social services, etc	World Bank (WDI)
Internet users	Internet_us	People with access to the worldwide network total (% of population)	UNDP
Inequality in education	Ineq_educ	Inequality in distribution of years of schooling based on data from household surveys estimated using the Atkinson inequality index (in %)	UNDP
Mean years of schooling	Schooling	Average number of years of education received by people ages 25 and older (in years)	UNDP

Table 2: Poisson regression analyses of the AAPC in research production (by region)

Regions	Obs	Documents			Citable documents			Citations		
		β	AAPC (%)	P-value	β	AAPC (%)	P-value	β	AAPC (%)	P-value
Africa	1020	0.106	11.182	0.000	0.104	10.960	0.000	0.014	1.410	0.000
Western Europe	380	0.047	4.812	0.000	0.044	4.498	0.000	-0.039	-3.825	0.000
Eastern Europe	440	0.067	6.930	0.000	0.064	6.609	0.000	-0.009	-0.896	0.000
Northern America	40	0.035	3.562	0.000	0.031	3.148	0.000	-0.063	-6.106	0.000
Latin America	460	0.083	8.654	0.000	0.080	8.329	0.000	-0.012	-1.193	0.000
Asiatic Region	500	0.085	8.872	0.000	0.083	8.654	0.000	0.001	0.100	0.000
Pacific Region	100	0.068	7.036	0.000	0.064	6.609	0.000	-0.023	-2.274	0.000
Middle East	280	0.099	10.407	0.000	0.098	10.300	0.000	0.004	0.401	0.000
World	3220	0.060	6.184	0.000	0.058	5.971	0.000	-0.035	-3.440	0.000

Source: authors. Notes: β represents the regression coefficient (trend), AAPC is the Average Annual percentage changes

Table 1: Descriptive statistics

Variables	Observations	Mean	Std. dev	Min	Max
Documents	1540	21912.380	72789.800	3	699393
GDP per capita	1540	14837.210	20521.11	234.236	118823.600
Government expenditure on education	1540	14.873	4.62367	4.673	37.521
Internet users	1540	44.372	29.2860	0.300	100
Inequality in education	1540	20.546	14.647	0.700	50.100
Mean years of schooling	1540	8.330	3.289	1.400	14.200

Table 2: Determinants of research production (quantile regressions)

	Q10	Q25	Q50	Q75	Q90
gdppc	**-0.000** (0.000)**	**0.000** (0.000)**	**0.000*** (0.000)**	**0.000*** (0.000)**	**0.000*** (0.000)**
expeducexp	**0.058*** (0.003)**	**0.041*** (0.008)**	**0.028*** (0.002)**	**0.006*** (0.001)**	**-0.005*** (0.000)**
Internet_us	-0.023 (0.022)	-0.006 (0.021)	**0.036*** (0.004)**	**0.043*** (0.001)**	**0.085*** (0.000)**
Ineq_educ	**0.055*** (0.012)**	**0.031** (0.013)**	**0.033*** (0.004)**	**0.042*** (0.000)**	**0.044*** (0.000)**
Schooling	**0.333*** (0.086)**	**0.259*** (0.097)**	**0.239*** (0.034)**	**0.423*** (0.006)**	**0.487*** (0.001)**
Schooling#Internet_us	**0.005** (0.002)**	**0.003*** (0.001)**	**-0.000* (0.000)**	**-0.001*** (0.000)**	**-0.006*** (0.000)**
Constant	-0.676 (0.917)	**1.268** (0.639)**	**2.329*** (0.339)**	**2.637 (0.034)**	**3.151*** (0.000)**
Net effect of internet_us	na	na	0.036	0.035	0.035
Net effect of schooling	0.555	0.392	0.239	0.379	0.221
countries	154	154	154	154	154
obs	1540	1540	1540	1540	1540

Notes ; coefficients marked with *,**,*** are significant at 10%, 5% and 1% level. Standard errors are in brackets. The net effects are as follow: ((coefficient of the interaction)×mean of the other variable) +unconditional effect. For instance, at the 90th quantile, the net effect of internet users is 0.035 ((-0.006×8.33) +0.085).

Table 3: Determinants of research production by Negative binomial regressions (Incidence Rate Ratio)

	(1)	(2)	(3)	(4)	(5)
Constant	2.287 (0.000)	0.901 (0.163)	0.867 (0.463)	1.310 (0.217)	1.311 (0.219)
Gdppc	1.000 (0.443)	1.000 (0.754)	1.000 (0.727)	1.000 (0.907)	1.000 (0.906)
Expeducexp	**1.015***** **(0.000)**	**1.009**** **(0.010)**	**1.011**** **(0.037)**	**1.011**** **(0.038)**	**1.011**** **(0.038)**
Internet_us	**1.011***** **(0.000)**	**1.0155** **(0.000)**	**1.015***** **(0.000)**	**1.012***** **(0.000)**	**1.011***** **(0.000)**
Ineq_educ	1.002 (0.258)	1.000 (0.981)	1.000 (0.994)	0.999 (0.740)	0.999 (0.739)
Schooling	**1.159***** **(0.000)**	**1.278***** **(0.000)**	**1.279***** **(0.000)**	**1.224***** **(0.000)**	**1.224***** **(0.000)**
Schooling#Internet_us	**1.000*** **(0.088)**	1.000 (0.229)	1.000 (0.224)	1.000 (0.469)	**1.000***** **(0.000)**
Africa		**3.445***** **(0.000)**	**3.659***** **(0.000)**	**1.707**** **(0.041)**	**1.709**** **(0.042)**
Africa#expeducexp			0.996 (0.583)	0.993 (0.334)	0.993 (0.334)
Africa#schooling				**1.147***** **(0.000)**	**1.146***** **(0.001)**
Africa#Internet_us					1.000 (0.977)
Wald Chi2	1275.810	1396.260	1396.920	1500.800	1501.952
Log likelihood	-10087.705	-10033.260	-10033.436	-10026.953	-10026.952
AIC information	20189.411	20083.174	20084.873	20073.905	20075.904
Countries	154	154	154	154	154
Obs	1540	1540	1540	1540	1540

Notes: coefficients marked with *, **, *** are significant at 10%, 5% and 1% level. P-values are in brackets.