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A brief future of Time in the monopoly of scientific knowledge

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A brief future of Time in the monopoly of scientific knowledge

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Abstract

This seminal paper provides global empirical evidence on catch-up processes in scientific and technical publications. Its purpose is to model the future of scientific knowledge monopoly in order to understand whether the impressive growth experienced by latecomers in the industry has been accompanied by a similar catch-up in scientific capabilities and knowledge contribution. The empirical evidence is based on 41 catch-up panels which together consist of 99 countries. The richness of the dataset allows us to disaggregate countries into fundamental characteristics based on income-levels (high-income, lower-middle-income, upper-middle-income and low-income), legal-origins (English common-law, French civil-law, German civil-law and, Scandinavian civil-law) and, regional proximity (South Asia, Europe & Central Asia, East Asia & the Pacific, Middle East & North Africa, Latin America & the Caribbean and, Sub-Saharan Africa). Three main issues are investigated: the presence or not of catch-up processes, the speed of the catch-up processes and, the time needed for full (100%) catch-up. The findings based on absolute and conditional catch-up patterns broadly show that advanced countries will continue to dominate in scientific knowledge contribution. Policy implications are discussed.

Keywords: Research and Development; Catch-up
JEL Classification: F42; O10; O30; O38; O57

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1. Introduction

Catch-up has been referred to as the process through which once backward countries successfully narrow the gap in productivity and income with frontier countries.

Accordingly, the process has been historically associated with the adoption and transfer of existing techniques from mature industries in leading countries to backward ones. As a complex process, catch-up entails many different aspects, actors and dimensions of an economic system; among them universities and public research centers have been regarded as central players in recent and past experiences in the catch-up processes (Mazzoleni 2008). These organizations make-up the supporting infrastructure for the acquisition and building of scientific and technological capabilities, provide the general and specialized training, equipment and instrumentation, scientific and technological information and also contribute to the design of new products and processes (Morrison et al., 2009).

Comparative literature on scientific and research productivity of advanced countries has flourished in recent years, depicting how different context and strategies enable countries to mitigate the gap with the frontier countries. Less attention has been paid to the evolution of universities and research organizations in backward regions. Accordingly, we know very little about whether and how cross-country gaps in scientific productivity are narrowing or expanding. This paper intends to contribute to this latter stream of the literature by providing seminal empirical evidence of catch-up processes in knowledge contribution from scientific and technical journal articles publication. The purpose is to understand whether the impressive growth experienced by latecomers in this industry has been accompanied by a similar catch-up process in scientific capabilities.

As far as we have reviewed, there is currently no empirical study that has analyzed or modeled global trends in scientific and technical publications. In this seminal contribution three main issues are investigated: the presence or not of catch-up processes, the speeds of the

catch-up processes and, the time needed for full (100%) catch-ups. The empirical evidence is based on 41 catch-up panels which together consist of 99 countries. The richness of the dataset allows us to disaggregate countries into fundamental characteristics based on income-levels (high-income, lower-middle-income, upper-middle-income and low-income), legal-origins (English common-law, French civil-law, German civil-law and, Scandinavian civil-law) and, regional proximity (South Asia, Europe & Central Asia, East Asia & the Pacific, Middle East & North Africa, Latin America & the Caribbean and, Sub-Saharan Africa).

The rest of the paper is organized as follows. Section 2 provides the intuition for the catch-up framework. Data and methodology are discussed and outlined respectively in Section 3. Section 4 covers the empirical analysis while we conclude with Section 5.

2. Catch-up processes in scientific publications

Since the 1990s, there has been growing emphasis on the relevance of scientific publications in knowledge economy (KE), a phenomenon that has been central in the reports of most influential organizations as the engine for long-term economic prosperity (World Bank, 2007; Weber, 2007). Europe and North America that have mastered the dynamics of scientific publications have been steering development in the global arena. Other regions like East Asia and Latin America have been responding in calculated that underscore the relevance of scientific know-how in their current pursuits of national, regional and local initiatives (Asongu, 2013a). The pattern of Japan has set the course for governments of the Newly Industrialized Asian Economies (China, Korea, Hong Kong, Singapore, Malaysia and Taiwan) that have begun marching towards knowledge-based economies from the product-based economies (Chandra & Yokoyama, 2011). In Africa and the Middle East, KE items have recently been taking a substantial portion of the agenda on development discussions (Asongu, 2013b). Consistent with Wantchékon (2013), of the 258 impact evaluation studies in 2004, only 11% included African authors. He has also stressed that, since the year 2002, only

7% of the 401 African related publications in the Journal of Development Economics are co-authored by Africans. Accordingly, it is still widely disputed whether universities and public research organizations in developing countries should be encouraged to undertake frontier research (Mazzoleni, 2008). There is however consensus that local-focused research is necessary to support indigenous capabilities and to build national absorptive capacity.

The role of universities and public research organizations in catch-up is straight forward. They contribute to development in various ways. First and foremost, their key mission is education and training as shown by the early experiences of Germany in the 19th century and late experiences of Asian countries (Japan, South Korea and Taiwan). The availability of skilled workers and teachers, the migration of technicians from leading countries and the training of students abroad are relevant in enabling conditions for building-up indigenous technological capabilities (Kim & Nelson, 2000; Mowery & Sampat, 2005; Morrison et al., 2009). Moreover, beside education, universities and public research organizations contribute to a country's development by undertaking basic and applied research. Consistent with Morrison et al. (2009), what matters today in the catch-up processes is that basic and applied research represent along with other ingredients, a key determinant for building scientific capabilities which are inputs for innovation and growth (Balconi et al., 2010). This assertion is true today in the context of developing countries more than ever. In line with Mazzoleni & Nelson (2007), two reasons have been advanced to substantiate this claim: (1) the changing nature of technology and science and; (2) the impact of globalization on the diffusion of knowledge and the relative importance of scientific actors.

With respect to the changing nature of technology and science, in line with Morrison et al. (2009), knowledge as well as products and technologies have nowadays a much shorter life cycle. The distinction between what is a scientific input and technology in several scientific domains is not clear-cut, which means that scientific discoveries are often

intertwined with technological development in a manner that the lag between discoveries and the product development is quite of short span. Additionally, new industrial sectors and technologies have stronger scientific underpinnings for the most part. Hence, the two communities are increasingly interacting as substantially documented in the literature (D'Este & Patel, 2007). These studies are consistent with the position that catch-up countries, along with firms and universities therein, need to be well equipped to rapidly adapt to the changing and evolving external environmental conditions. In order to realize this objective, they have to set up a scientific infrastructure which would enable them to renew their repertories or competence and knowledge or at least to identify the relevant sources of knowledge timely. Hence, all these efforts are needed for the nurturing and development of indigenous scientific capabilities, both in terms of research activity and skills formation. On the premise of similar arguments, several approaches have claimed that a third mission of universities is to directly contribute to industrial research (Morrison et al., 2009). In a nutshell, Albuquerque (2000) has pointed four roles of science for the catch-up process: source of technological opportunities, sources of trained researchers, development and improved research techniques and, sources of tacit and public knowledge.

Regarding the other dimension, the forces of globalization have imposed to catch-up countries a new regulatory framework in which they have to operate. Accordingly, the access to knowledge is today more restricted owing to tight intellectual property rights (IPRs) which further constrain the ability of backward countries to catch-up with the technological and scientific frontier. Hence, consistent with Mazzoleni & Nelson (2007), in this stricter regulatory framework the adoption of external technology has become more difficult and costly; similar policies aimed at supporting national industries must comply with more stringent competition rules that prohibit the standardization of industries. In this context, the support for science training, education and infrastructure has become a viable alternative for

the promotion of indigenous technological capabilities. Accordingly, globalization has also meant that the worldwide scientific community is more interconnected that ever. Hence, scientists in less developed countries have higher opportunities to interact with their peers in the frontier countries and this contributes to giving them access to relevant scientific sources.

In light of the above motivations, the present paper seeks to assess whether the gap between less developed and developed countries is reducing in terms of contribution to scientific knowledge.

3. Data and Methodology

3.1 Data

We examine a sample of 99 countries with data from the World Bank Development Indicators (WDI), the Global Market Information Database (GMID) and the World Intellectual Property Organization (WIPO) for the period 1994-2010. The limitations to 99 countries and 17 year annual periodicity are due to constraints in data availability on scientific publications. The dependent variable is the number of scientific and technical journal articles published annually.

3.1.1 Determination of fundamental characteristics and catch-up panels

We now devote space to discussing the determination of fundamental characteristics and corresponding catch-up panels. Consistent with Asongu (2012a), it is unlikely to find catch-up processes within a heterogeneous set of countries. Recent studies have stressed the relevance of a variety of contexts and historical periods (Mazzoleni, 2008; Mazzoleni & Nelson, 2007) and geographical areas (Morrison et al., 2009) in the catch-up process. Accordingly, the determination of fundamental characteristics should be based on factor that naturally determine scientific and technical publications such as research and development budgets, degree of IPRs protections, rate of higher education…etc. However as cautioned by Asongu (2012a), macroeconomic fundamental characteristics have the draw-back of being

time-dynamic. Hence, the same threshold may not be consistent over time, especially in a horizon of 17 years. In accordance with the literature (Narayan et al., 2011; Asongu, 2012a), we shall take a minimalistic approach in the determination of fundamental characteristics and control for fundamental determinants of scientific publications in the estimations. The main fundamental characteristics are based on: legal origins, income-levels and regional proximity while corresponding catch-up panels are derived from the fundamental characteristics.

Firstly, the foundation of legal origin as a fundamental characteristic of scientific publication is based on the emphasis legal origins place on private property rights vis-à-vis those of the state (La Porta et al., 1998) and education (Agbor, 2011). According to Agbor, the educational channel substantially explains variations in economic performance among countries with different legal traditions in sub-Saharan Africa (SSA). In essence, the underlying logic for this segmentation is that the institutional web of informal norms, formal rules and enforcement characteristics affect the educational and research environments. The legal origins include: English common-law, French civil-law, German civil-law and Scandinavian civil-law.

Secondly, assessing scientific publications with income-level dynamics is deeply rooted in the intuition that wealthy nations have the tendency to allocate more funds to research activities. The income-levels include: High-income, Upper-middle-income, Lower-middle-income and, Low-income.

Thirdly, regional proximity is also fundamental in the catch-up process because Morrison et al. (2009) has postulated that differences over time and across geographical areas also explain the catch-up process. Moreover the inclusion of this characteristic is broadly consistent with the empirical underpinnings of the catch-up literature (Narayan et al., 2011; Asongu, 2013c; Andrés & Asongu, 2013). The regions include: South Asia, Europe &

Central Asia, East Asia & the Pacific, Middle East & North Africa, Sub-Saharan Africa and, Latin America & the Caribbean.

From the fundamental characteristics, 41 catch-up panels on which the empirical analysis will be based are derived. These include: 10 on wealth-effects (High-income, High-income and Upper-middle-income, High-income and Lower-middle-income, High-income and Low-income, Upper-middle-income, Upper-middle-income and Lower-middle-income, Upper-middle-income and Low-income, Lower-middle-income, Lower-middle-income and Low-income, Low-income); 10 on legal origins (English common-law, English common-law and French civil-law, English common-law and German civil-law, English common-law and Scandinavian civil-law, French civil-law, French civil-law and German civil-law, French civil-law and Scandinavian civil-law, German civil-law, German civil-law and Scandinavian civil-law and, Scandinavian civil-law) and; 21 on regional proximity (South Asia, South Asia and Europe & Central Asia, South Asia and East Asia & the Pacific, South Asia and Middle East & North Africa, South Asia and Latin America & the Caribbean, South Asia and Sub-Saharan Africa, Europe & Central Asia, Europe & Central Asia and East Asia & the Pacific, Europe & Central Asia and Middle East & North Africa, Europe & Central Asia and Latin America & the Caribbean, Europe & Central Asia and Sub-Saharan Africa, East Asia & the Pacific, East Asia & the Pacific and Middle East & North Africa, East Asia & the Pacific and Latin America & the Caribbean, East Asia & the Pacific and Sub-Saharan Africa, Middle East & North Africa, Middle East & North Africa and Latin America & the Caribbean, Middle East & North Africa and Sub-Saharan Africa, Latin America & the Caribbean, Latin America & the Caribbean and Sub-Saharan Africa and, Sub-Saharan Africa).

3.1.2 Choice of control variables

The choice of control variables is contingent on the theoretical underpinnings of conditional convergence which state that, if countries differ in characteristics that determined

scientific publications, it is possible for conditional convergence to take place. Hence, we control for such factors that determine scientific publications which include: research and development (R&D) expenditure, tertiary school enrolment, internet penetration[2] and protection of IPRs (Main IPRs law and WIPO[3] Treaties). Accordingly, the potential for IPRs to stimulate the diffusion of scientific knowledge is at the heart several contemporary issues: a central agenda is how IPRs over a given piece of knowledge affects the propensity of future researchers to build upon that knowledge in their own scientific research activities (Murray & Stern, 2005). From intuition, R&D expenditure, tertiary school enrolment and degree of internet penetration naturally favor scientific activities. The control variables are broadly consistent with the factors central in the production of knowledge that have recently been identified by Amavilah (2009).

Details about the summary statistics (with presentation of countries), correlation analysis (showing the basic correlations between key variables used in this paper) and variable definitions (with corresponding data sources) are presented respectively in Appendix 1, Appendix 2 and Appendix 3. The descriptive statistics of the variables show that, there is quite some degree of variation in the data utilized so that one should be comfortable and confident that reasonable estimated relationships would emerge. The purpose of the correlation matrix is to mitigate concerns of overparametization and multicolinearity. Based on the correlation coefficients, there do not appear to be any major issues in terms of the relationships to be estimated.

3.2 Methodology

The estimation procedure typically follows modeling of the future of KE by Asongu (2013a). Consistent with recent literature (Asongu, 2012a, 2013a; Andrés & Asongu, 2013),

[2] The rising cost of traditional scientific scholarly communication coupled with the increase of widely available internet communication tools such as the World Wide Web (www) have provided a catalyst for a revolution in the exchange of scientific and technical information (Esler & Nelson, 1998).
[3] World Intellectual Property Organisation.

the estimation approach is based on β-convergence due to constraints in the data set. The use of cointegration and unit roots tests are not convenient due to limited degrees of freedom in homogenous panels or fundamental characteristics. Additionally, the alternative type of convergence (σ-convergence) which is of the view that, a group of economies converge when the cross-sectional variance of the variable under consideration declines, is also inappropriate because the data structure of the paper is panel. Our estimation procedure typically follows the evidence of income convergence across countries that have been investigated in the context of pioneering works in neoclassical growth models (Baumol, 1986; Barro & Sala-i-Martin, 1992, 1995; Mankiw et al., 1992).

In accordance with the convergence literature (Fung, 2009, p. 3; Asongu, 2012a), the two equations below are the standard approaches for investigating conditional convergence if $W_{i,t}$ is taken as strictly exogenous.

$$\ln(Y_{i,t}) - \ln(Y_{i,t-\tau}) = \beta \ln(Y_{i,t-\tau}) + \delta W_{i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (1)$$

$$\ln(Y_{i,t}) = \sigma \ln(Y_{i,t-\tau}) + \delta W_{i,t-\tau} + \eta_i + \xi_t + \varepsilon_{i,t} \quad (2)$$

Where $Y_{i,t}$ is the proxy for the rate of scientific publications in country *i* at period *t*. σ = 1+ β. $W_{i,t}$ is a vector of determinants of publications, η_i is a country-specific effect, ξ_t is a time-specific constant and $\varepsilon_{i,t}$ an error term. According to the neo-classical growth model, a statistically significant negative coefficient on β in Eq. (1) suggests that, countries relatively close to their steady state in 'scientific publications growth' will experience a slowdown in the growth of scientific publications, known as conditional convergence (Narayan et al., 2011, p. 2). In the same line of thinking, according to Fung (2009, p. 3) and recent catch-up literature (Asongu, 2012a, 2013a; Andrés & Asongu, 2013), if $0 < |\sigma| < 1$ in Eq. (2), then $Y_{i,t}$ is dynamically stable around the path with a trend of publication rate the same as that of W_t, and with a height relative to the level of W_t. The variables incorporated in $W_{i,t-\tau}$ and the

individual effect η_i are measures of the long-term level the publications market is converging to. Hence, the country-specific effect η_i emphasizes other determinants of a country's steady state not captured by $W_{i,t-\tau}$.

Conditions for convergence outlined above are valid if and only if, $W_{i,t}$ exhibits strict exogeneity. Unfortunately, this is not the case in the real world because, while R&D, internet penetration, tertiary school enrolment and IPR laws (components of $W_{i,t}$) influence the rate of scientific publication, the reverse effect is also true. Hence, we are faced with the issue of endogeneity in which control variables ($W_{i,t}$) are correlated with the error term ($\varepsilon_{i,t}$). Moreover, country- and time-specific effects could be correlated with other variables in the model, which is very probable with lagged endogenous variables included in the equations. A means of tackling the problem of the correlation between the individual specific-effect and the lagged dependent variables consists of eliminating the individual effect by first differencing. Thus Eq. (2) becomes:

$$\ln(Y_{i,t}) - \ln(Y_{i,t-\tau}) = \sigma(\ln(Y_{i,t-\tau}) - \ln(Y_{i,t-2\tau})) + \delta(W_{i,t-\tau} - W_{i,t-2\tau}) + (\xi_t - \xi_{t-\tau}) + (\varepsilon_{i,t} - \varepsilon_{i,t-\tau}) \qquad (3)$$

However Eq. (3) presents another issue; estimates by Ordinary Least Square (OLS) are still biased because there remains a correlation between the lagged endogenous independent variable and the error term. To tackle this concern, we estimate the regression in differences jointly with the regression in levels using the Generalized Method of Moments (GMM) estimation. Arellano & Bond (1991) has suggested an application of the Generalized Method of Moments (GMM) that exploits all the orthogonality conditions between the lagged dependent variables and the error term. The process employs lagged levels of the regressors as instruments in the difference equation, and lagged differences of the regressors as instruments in the levels equation, therefore exploiting all the orthogonality conditions between the lagged dependent variables and the error term. Between the difference GMM estimator (Arellano &

Bond, 1991) and system GMM estimator (Arellano & Bover, 1995; Blundell & Bond, 1998), we choose the latter in accordance with Bond et al. (2001, pp. 3-4)[4].

The GMM estimation approach has been substantially applied in the catch-up literature. In model specification, we choose the two-step GMM because it corrects the residuals for heteroscedasticity[5]. The hypothesis of no auto-correlation in the residuals is crucial as lagged variables are to be used as instruments for the dependent variables. Accordingly, the estimation depends on the assumption that the lagged values of the dependent variable and other independent variables are valid instruments in the regression. When the error terms of the level equation are not auto-correlated, the first-order auto-correlation of the differenced residuals should be significant whereas their second-order auto-correlation should not be. The validity of the instruments is examined with the Sargan over-identifying restrictions (OIR) test.

In accordance with Islam (1995, p. 14), yearly time spans are too short to be appropriate for studying catch-up processes, as short-run disturbances may loom substantially in such brief time spans. Therefore, considering the data span of 17 years, we are consistent with Asongu (2012a) in using two-year non-overlapping intervals (NOI)[6]. This implies in our analysis, τ is set to 2[7]. We also compute the implied rate of convergence by calculating $\sigma/2$.

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[4] "*We also demonstrate that more plausible results can be achieved using a system GMM estimator suggested by Arellano & Bover (1995) and Blundell & Bond (1998). The system estimator exploits an assumption about the initial conditions to obtain moment conditions that remain informative even for persistent series, and it has been shown to perform well in simulations. The necessary restrictions on the initial conditions are potentially consistent with standard growth frameworks, and appear to be both valid and highly informative in our empirical application. Hence we recommend this system GMM estimator for consideration in subsequent empirical growth research*". Bond et al. (2001, pp. 3-4).

[5] In the *one-step* approach, the residuals are assumed to be homoscedastic.

[6] We have 9 two-year non-overlapping intervals: 1994; 1995-1996; 1997-1998; 1999-2000; 2001-2002; 2003-2004; 2005-2006; 2007-2008; 2009-2010. Owing to data and periodical constraints, the first interval is short of one year.

[7] Consistent with Asongu (2013a), beside the two justifications provided above, we may cite three additional premises on which this choice of the two-year NOI is based. Firstly, NOI with a higher numerical value (say three-year NOI) absorbs more short-run disturbances at the cost of weakening the model. Hence the preference for the two-year NOI over the three/four/five-year NOI is further justified by the need to exploit the time series dimensions as much as possible. Secondly, a corollary to the above point is the positive side of additional degrees of freedom necessary for conditional convergence modeling. Hence, given the time span of 17 years, a higher order of NOI will greatly limit conditional convergence analysis. Thirdly, heuristically from a visual

Accordingly, the estimated coefficient of the lagged differenced endogenous variable is divided by 2 because we have used a two year interval to absorb the short-term disturbances. When the absolute value of the estimated autoregressive coefficient is greater than zero but less than one ($0 < |\sigma| < 1$), we establish evidence of catch-up. The broader interpretation suggests, past variations have a less proportionate impact on future differences, implying the variation on the left hand side of Eq. (3) is decreasing overtime as the country is converging to a steady state (Asongu, 2012a).

4. Empirical analysis

4.1 Presentation of results

This section looks at three principal concerns: (1) investigation of the presence of catch-ups; (2) computation of the catch-up speeds and; (3) determination of the time needed for full (100%) catch-ups. The summary of overall findings is presented in Tables 1-2 in which, the three issues are addressed. Results for absolute (unconditional) and conditional catch-ups are reported in Table 3 and Table 4 respectively.

Whereas, absolute catch-up is estimated with just the lagged difference of the endogenous variable as independent variable, conditional catch-up is with respect to Eqs. (2) and (3) in the presence of control variables. Hence, unconditional convergence is estimated in the absence of $W_{i,t}$: vector of determinants (R&D, internet penetration, tertiary school enrolment and IPRs laws) of scientific publications. To assess the validity of the model and indeed the catch-up hypothesis, we perform two tests, notably the Sargan-test which examines the over-identification restrictions and, the Arellano and Bond test for autocorrelation which assesses the null hypothesis of no autocorrelation. The Sargan-test investigates if the instruments are uncorrelated with the error term in the equation of interest. The null hypothesis is the position that, the instruments as a group are strictly exogenous (do not suffer

analysis, the rate of scientific publications does not show evidence of persistent business cycles (short-term) disturbances that require higher NOI.

from endogeneity) that is needed for the validity of the GMM estimates. The p-values of estimated coefficients are reported in brackets in the line following the reported values of the estimated coefficients. But for a few exceptions, we notice that the Sargan-test statisitics often appear with a p-value greater than 0.10. Hence, its null hypothesis is not rejected for the most part. We also report the second order autocorrelation test and notice that for an overwhelming majority of estimated models, we are unable to reject the null hypothesis for the absence of autocorrelation. Not specifically applicable (nsa) is used where we are unable to model due to issues in degrees of freedom while 'not applicable' (na) is employed in situations of insignificant evidence of catch-up.

Summaries of the results in Tables 3-4 are reported in Tables 1-2. These include results for Absolute Catch-up (AC), Conditional Catch-up (CC), the Speed of Absolute Catch-up (SAC), the Speed of Conditional Catch-up (SCC) and, the rate required to achieve full (100%) catch-up for both AC and CC.

From a general perspective, the following conclusions could be drawn. (1) But for evidence of conditional catch-ups between High-income and other income classes, there is overwhelming absence of catch-ups based on wealth-effects (Panel A of Table 1). (2) There is an isolated evidence of AC among Scandinavian civil law countries and some traces of CC among English common-law countries, between English common-law and German civil-law countries, English common-law and Scandinavian civil law countries, among German civil law countries, between German civil-law and Scandinavian civil-law countries (Panel B of Table 1). (3) There is evidence of AC among countries of the same region (South Asia, Latin American & the Caribbean (LAC), SSA) and between countries of different regions (South Asia and LAC, LAC & SSA); CC between South Asia and Europe & Central Asia on the one hand and, between the latter and all other regions (Table 2). (4) The speed of catch-up hovers between 48-49% with an average time for full catch-up in the neighborhood of 4 years. For

example, with an initial value of 0.973, the rate of convergence is 48.65% ((0.789/2)*100) and the time needed to achieve full convergence is 4.11 years (200%/48.65%). Hence, 4.11 years is required to achieve a 100% convergence for an estimated lagged value of 0.973.

Most of the significant control variables have the expected signs. (1) Internet penetration consistently increases the rate of publications. (2) The negative incidence of R&D funds on publications in LAC and Lower-middle-income countries is contingent on many factors: misappropriation of R&D funds, use of funds for infrastructural projects, use of funds in less frontier research (or for local needs)…etc. (3) The unexpected negative relationship between tertiary school enrolment in some cases could also be explained by a number of factors: firstly, political and socio-economic issues preventing students from pursuing education to the research level; secondly, governments providing less incentives for research purposes; thirdly, academic advancement in some countries may be based on political appointments and not on objective peer assessments and; fourthly, the issue of brain drain preventing students from engaging in indigenous research after completing the first and second stages of tertiary education.

Table 1: Summary of catch-up processes based on income-levels and legal origins

		Panel A: Income Levels							
		High Income		U. Middle Income		L. Middle Income		Low Income	
		AC	CC	AC	CC	AC	CC	AC	CC
	Catch-up	No	Yes	---	---	---	---	---	---
High	Speed of C	na	48.55%	---	---	---	---	---	---
Income	Yrs to F.C	na	4.11 Yrs	---	---	---	---	---	---
Upper	Catch-up	No	Yes	No	No	---	---	---	---
Middle	Speed of C	na	49.05%	na	na	---	---	---	---
Income	Yrs to F.C	na	4.07 Yrs	na	na	---	---	---	---
Lower	Catch-up	No	Yes	No	No	No	No	---	---
Middle	Speed of C	na	49.60%	na	na	na	na	---	---
Income	Yrs to F.C	na	4.03 Yrs	na	na	na	na	---	---
Low	Catch-up	No	Yes	No	No	No	No	nsa	nsa
Income	Speed of C	na	48.55%	na	na	na	na	nsa	nsa
	Yrs to F.C	na	4.11 Yrs	na	na	na	na	nsa	nsa
		Panel B: Legal Origins							
		English Common Law		French Civil Law		German Civil Law		Scandinavian Civil Law	
		AC	CC	AC	CC	AC	CC	AC	CC
English	Catch-up	No	Yes	---	---	---	---	---	---
Common	Speed of C	na	48.15%	---	---	---	---	---	---
Law (L)	Yrs to F.C	na	4.15 Yrs	---	---	---	---	---	---

French	Catch-up	No	No	No	No	---	---	---	---
Civil	Speed of C	na	na	na	na	---	---	---	---
Law	Yrs to F.C	na	na	na	na	---	---	---	---
German	Catch-up	No	Yes	No	No	No	Yes	---	---
Civil	Speed of C	na	48.25%	na	na	na	47.15%	---	---
Law	Yrs to F.C	na	4.14 Yrs	na	na	na	4.24 Yrs	---	---
Scandi.	Catch-up	No	Yes	No	No	No	Yes	Yes	nsa
Civil	Speed of C	na	48.40%	na	na	na	47.85%	40.10%	nsa
Law	Yrs to F.C	na	4.13 Yrs	na	na	na	4.17 Yrs	4.98 Yrs	nsa

C: Catch-up. AC: Absolute Catch-up. CC: Conditional Catch-up. Yrs: Years. F.C: Full (100%) Catch-up. U: Upper. L: Lower
na: not applicable because of absence of significance catch-ups. nsa: no catch-up estimations due to issues in degrees of freedom.

Table 2: Summary of catch-up processes based on regions

		Regions											
		South Asia		ECA		EAP		MENA		LAC		SSA	
		AC	CC	AC	CC	AC	CC	AC	CC	AC	CC	AC	CC
South Asia (SA)	Catch-up	Yes	nsa	---	---	---	---	---	---	---	---	---	---
	Speed of C	48.65%	nsa	---	---	---	---	---	---	---	---	---	---
	Yrs to F.C	4.11Yrs	nsa	---	---	---	---	---	---	---	---	---	---
Europe & CA	Catch-up	No	Yes	No	Yes	---	---	---	---	---	---	---	---
	Speed of C	na	48.25%	na	48.6%	---	---	---	---	---	---	---	---
	Yrs to F.C	na	4.14 Yrs	na	4.11Yrs	---	---	---	---	---	---	---	---
East Asia & the P	Catch-up	No	No	No	Yes	No	No	---	---	---	---	---	---
	Speed of C	na	na	na	48.7%	na	na	---	---	---	---	---	---
	Yrs to F.C	na	na	na	4.10Yrs	na	na	---	---	---	---	---	---
MENA	Catch-up	No	No	No	Yes	No	No	No	No	---	---	---	---
	Speed of C	na	na	na	48.5%	na	na	na	na	---	---	---	---
	Yrs to F.C	na	na	na	4.12Yrs	na	na	na	na	---	---	---	---
LAC	Catch-up	Yes	No	No	Yes	No	No	No	No	Yes	No	---	---
	Speed of C	49.55%	na	na	49.9%	na	na	na	na	49.2%	na	---	---
	Yrs to F.C	4.03 Yrs	na	na	4Yrs	na	na	na	na	4.06 Yrs	na	---	---
SSA	Catch-up	No	nsa	No	Yes	No	No	No	No	Yes	No	Yes	nsa
	Speed of C	na	nsa	na	48.9%	na	na	na	na	49.1%	na	49.05%	nsa
	Yrs to F.C	na	nsa	na	4.08 Yrs	na	na	na	na	4.07 Yrs	na	4.07 Yrs	nsa

C: Catch-up AC: Absolute Catch-up. CC: Conditional Catch-up. Yrs: Years. F.C: Full (100%) Catch-up. ECA: Europe and Central Asia. EAP: East Asia and the Pacific. MENA: Middle East and North Africa. SSA: Sub-Saharan Africa. LAC: Latin America and the Caribbean.
na: not applicable because of absence of significance catch-ups. nsa: no catch-up estimation due to issues in degrees of freedom.

Table 3: Absolute catch-ups

Panel A: Income Levels

	High Income (HI)				Upper Middle Income (UMI)			L M Income (LMI)		Lower I
	HI	UMI	LMI	LI	UMI	LMI	LI	LMI	LI	LI
Initial	**1.015*** **	**1.018*** **	**1.011*** **	**1.015*** **	**1.024*** **	**1.017*** **	**1.023*** **	**1.009*** **	**1.007*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
AR(2)	**0.372**	**0.658**	**-1.202**	**0.776**	**0.586**	**-0.436**	**0.700**	**-1.349**	**-1.198**	nsa
	(0.709)	**(0.510)**	**(0.229)**	**(0.437)**	**(0.557)**	**(0.662)**	**(0.483)**	**(0.177)**	**(0.230)**	
Sargan	**40.372**	54.81**	51.80**	**41.731**	**28.852**	46.593*	**30.196**	**23.466**	**25.375**	nsa
	(0.209)	(0.013)	(0.025)	**(0.170)**	**(0.718)**	(0.073)	**(0.654)**	**(0.912)**	**(0.857)**	
Wald	**82834*** **	**62249*** **	**23020*** **	**82474*** **	**15450*** **	**11936*** **	**15869*** **	**4280*** **	**4065*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Countries	41	70	65	43	29	53	31	24	26	
Obs	328	547	519	344	219	410	235	191	207	

Panel B: Legal Origins

	English Common Law				French Civil Law(CL)			German Civil Law		Scan CL
	English	French	German	Scan.	French	German	Scan.	German	Scan.	Scan.
Initial	**1.019*** **	**1.017*** **	**1.018*** **	**1.018*** **	**1.015*** **	**1.015*** **	**1.014*** **	**1.016*** **	**1.016*** **	**0.802*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
AR(2)	**-0.242**	**-0.440**	**0.087**	**-0.248**	**-0.369**	**-0.175**	**-0.372**	**0.844**	**0.826**	**-0.644**
	(0.808)	**(0.659)**	**(0.930)**	**(0.803)**	**(0.712)**	**(0.860)**	**(0.709)**	**(0.398)**	**(0.408)**	**(0.519)**
Sargan	**24.983**	53.501**	**40.566**	**28.903**	**39.575**	45.753*	**40.824**	**15.884**	**20.999**	**2.779**
	(0.869)	(0.0179)	**(0.203)**	**(0.715)**	**(0.235)**	(0.085)	**(0.195)**	**(0.996)**	**(0.960)**	**(1.000)**
Wald	**31794*** **	**28448*** **	**29526*** **	**36342*** **	**14545*** **	**25286*** **	**15882*** **	**22941*** **	**28685*** **	**7.051*** **

	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Countries	25	75	42	29	50	67	54	17	21	4
Obs	200	592	330	232	392	522	424	130	162	32

Panel C: Regions

	South Asia (SA)						**Europe and Central Asia (ECA)**				
	SA	ECA	EAP	MENA	LAC	SSA	ECA	EAP	MENA	LAC	SSA
Initial	**0.973*** **	**1.02*** **	**1.02*** **	**1.030*** **	**0.99*** **	**1.00*** **	**1.02*** **	**1.02*** **	**1.02*** **	**1.00*** **	**1.01*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
AR(2)	**0.186**	**0.722**	**1.141**	**0.798**	**-0.835**	**-0.182**	**0.720**	**0.803**	**0.965**	**-0.403**	**0.332**
	(0.852)	**(0.470)**	**(0.253)**	**(0.424)**	**(0.403)**	**(0.855)**	**(0.471)**	**(0.421)**	**(0.334)**	**(0.686)**	**(0.739)**
Sargan	**1.865**	**42.090**	**11.472**	**14.902**	**19.999**	**9.740**	**40.148**	45.448*	47.836*	51.69**	45.27*
	(1.000)	**(0.160)**	**(0.999)**	**(0.998)**	**(0.973)**	**(1.000)**	**(0.216)**	(0.090)	(0.058)	(0.026)	(0.093)
Wald	**16.73*** **	**30548*** **	**27751*** **	**17355*** **	**2116*** **	**1059*** **	**27747*** **	**51887*** **	**33704*** **	**10407*** **	**23077*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Countries	2	45	12	15	20	10	43	53	56	61	51
Obs	16	348	96	119	159	80	332	412	435	475	396

	East Asia and the Pacific (EAP)				**Middle East & North Africa**			**LAC**		**SSA**
	EAP	MENA	LAC	SSA	MENA	LAC	SSA	LAC	SSA	SSA
Initial	**1.024*** **	**1.026*** **	**1.004*** **	**1.020*** **	**1.032*** **	**1.003*** **	**1.021*** **	**0.984*** **	**0.982*** **	**0.981*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
AR(2)	**1.120**	**0.986**	**-0.794**	**-0.114**	**0.795**	**-0.654**	**0.086**	**-0.836**	**-0.808**	**-0.173**
	(0.262)	**(0.323)**	**(0.427)**	**(0.909)**	**(0.426)**	**(0.512)**	**(0.931)**	**(0.402)**	**(0.418)**	**(0.861)**
Sargan	**9.798**	**22.996**	**27.787**	**17.596**	**12.337**	**30.822**	**20.472**	**17.982**	**25.923**	**7.964**
	(1.000)	**(0.923)**	**(0.765)**	**(0.990)**	**(0.999)**	**(0.624)**	**(0.967)**	**(0.989)**	**(0.838)**	**(1.000)**
Wald	**35277*** **	**103991*** **	**7175*** **	**47575*** **	**15072*** **	**5135*** **	**30772*** **	**1579*** **	**1819*** **	**35.343*** **
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Countries	10	23	28	18	13	31	21	18	26	8
Obs	80	183	223	144	103	246	167	143	207	64

***,**,*: significance levels of 1%, 5% and 10% respectively. AR(2): Second Order Autocorrelation test. OIR: Overidentifying Restrictions test. Initial: lagged endogenous estimated coefficient. Wald: test for the joint significance of estimated coefficients. HI: High Income. UMI: Upper Middle Income. LMI: Lower Middle Income. LI: Low Income. English: English Common-law. French: French Civil-law. German: German Civil-law. Scan: Scandinavian Civil-law. SA: South Asia. ECA: Europe and Central Asia. EAP: East Asia and the Pacific. MENA: Middle East and North Africa. SSA: Sub-Saharan Africa. LAC: Latin America and the Caribbean. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Wald statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(2) tests and; b) the validity of the instruments in the Sargan OIR test. nsa: no catch-up estimation due to issues in degrees of freedom. Obs: Observations.

Table 4: Conditional catch-ups

Income Levels

	High Income (HI)				**Upper Middle Income (UMI)**			**L M Income (LMI)**		**Lower I**
	HI	UMI	LMI	LI	UMI	LMI	LI	LMI	LI	LI
Initial	**0.971*** **	**0.981*** **	**0.992*** **	**0.971*** **	**1.006*** **	**1.049*** **	**1.006*** **	**1.076*** **	**1.076*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Constant	**0.214*** **	**0.143*** **	**0.086**	**0.214*** **	0.073	-0.138	0.073	-0.271	-0.271	nsa
	(0.000)	**(0.000)**	**(0.453)**	**(0.000)**	(0.525)	(0.313)	(0.525)	(0.410)	(0.410)	
R& D	-0.007	-0.007	-0.013	-0.007	-0.095	**-0.206***	-0.095	-0.308	-0.308	nsa
	(0.000)	(0.438)	(0.258)	(0.529)	(0.327)	**(0.064)**	(0.327)	(0.382)	(0.382)	
Internet	0.025	0.027	0.026	0.025	0.046	0.034	0.046	0.041	0.041	nsa
	(0.216)	(0.100)	(0.162)	(0.216)	(0.245)	(0.248)	(0.245)	(0.370)	(0.370)	
TSE	-0.0003	-0.0008	-0.000	-0.0003	-0.002	-0.002	-0.002	0.0004	0.0004	nsa
	(0.568)	(0.277)	(0.965)	(0.568)	(0.184)	(0.257)	(0.184)	(0.901)	(0.901)	
Main IPL	0.002	0.001	0.0006	0.002	-0.010	-0.005	-0.010	-0.067	-0.067	nsa
	(0.457)	(0.622)	(0.858)	(0.457)	(0.272)	(0.658)	(0.272)	(0.317)	(0.317)	
WIPO	0.005	0.006	-0.008	0.005	0.002	-0.0005	0.002	-0.005	-0.005	nsa
	(0.533)	(0.381)	(0.435)	(0.533)	(0.839)	(0.963)	(0.839)	(0.883)	(0.883)	
AR(2)	**0.481**	**-1.128**	**-0.422**	**0.481**	**-1.280**	**-1.519**	**-1.280**	**-1.044**	**-1.044**	nsa
	(0.629)	**(0.258)**	**(0.672)**	**(0.629)**	**(0.200)**	**(0.128)**	**(0.200)**	**(0.296)**	**(0.296)**	
Sargan	**29.839**	36.240*	**32.425**	**29.839**	**13.301**	**30.000**	**13.301**	**15.143**	**15.143**	nsa
	(0.274)	(0.087)	**(0.179)**	**(0.274)**	**(0.981)**	**(0.267)**	**(0.981)**	**(0.954)**	**(0.954)**	
Wald	**53512*** **	**36056*** **	**8310*** **	**53512*** **	**7289*** **	**7935*** **	**7289*** **	**2053*** **	**2053*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Countries	36	56	53	36	20	37	20	17	17	
Obs	215	328	288	215	113	186	113	73	73	

Legal Origins

	English Common Law				**French Civil Law(CL)**			**German Civil Law**		**Scan CL**
	English	French	German	Scan.	French	German	Scan.	German	Scan.	Scan.
Initial	**0.963*** **	**1.003*** **	**0.965*** **	**0.968*** **	**1.051*** **	**1.010*** **	**1.025*** **	**0.943*** **	**0.957*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Constant	**0.180*** **	0.035	**0.195*** **	**0.182*** **	-0.144	-0.016	-0.093	**0.341** **	**0.264***	nsa
	(0.000)	(0.714)	**(0.000)**	**(0.000)**	(0.288)	(0.912)	(0.508)	**(0.017)**	**(0.091)**	

R& D	-0.0081	-0.033	0.011	-0.009	-0.135	-0.031	-0.038	0.011	-0.0005	nsa
	(0.390)	(0.206)	(0.462)	(0.250)	(0.160)	(0.475)	(0.242)	(0.650)	(0.980)	
Internet	0.050*	0.024	**0.065*** **	0.043	-0.003	0.025	0.012	0.109	**0.092*** **	nsa
	(0.095)	(0.234)	**(0.000)**	(0.173)	(0.917)	(0.336)	(0.636)	(0.000)	**(0.000)**	
TSE	-0.0006	-0.0008	**-0.001** **	**-0.001* **	-0.0015	-0.001	-0.001	**-0.003** **	-0.001	nsa
	(0.377)	(0.406)	**(0.027)**	**(0.063)**	(0.327)	(0.491)	(0.302)	**(0.025)**	(0.183)	
Main IPL	-0.002	-0.002	0.0008	-0.0008	0.006	-0.004	-0.002	0.001	0.003	nsa
	(0.200)	(0.493)	(0.743)	(0.634)	(0.766)	(0.637)	(0.825)	(0.894)	(0.469)	
WIPO T	0.020	0.007	-0.001	0.019	0.007	0.005	0.012	-0.010	-0.015	nsa
	(0.106)	(0.515)	(0.852)	(0.168)	(0.633)	(0.721)	(0.355)	(0.387)	(0.283)	
AR(2)	**-0.851**	**-1.269**	**-1.017**	**-0.860**	**-1.234**	**-1.401**	**-1.270**	**-0.794**	**-0.819**	nsa
	(0.394)	**(0.204)**	**(0.309)**	**(0.389)**	**(0.217)**	**(0.161)**	**(0.203)**	**(0.426)**	**(0.412)**	
Sargan	**11.416**	39.267**	**26.448**	**16.267**	**29.310**	40.846**	**32.737**	**10.096**	**11.291**	nsa
	(0.994)	(0.046)	**(0.438)**	**(0.929)**	**(0.297)**	(0.032)	**(0.169)**	**(0.997)**	**(0.994)**	
Wald	**148953*** **	**11508*** **	**93913*** **	**87536*** **	**9289*** **	**5744*** **	**5910*** **	**11919*** **	**9559*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Countries	16	54	31	20	38	53	42	15	15	
Obs	87	284	178	113	197	288	223	91	117	

Regions

	South Asia (SA)						**Europe and Central Asia (ECA)**				
	SA	ECA	EAP	MENA	LAC	SSA	ECA	EAP	MENA	LAC	SSA
Initial	nsa	**0.96*** **	**1.310* **	**1.073*** **	**1.05*** **	nsa	**0.97*** **	**0.97*** **	**0.97*** **	**0.99*** **	**0.978*** **
		(0.000)	**(0.080)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Constant	nsa	0.144	-2.074	-0.488	-0.174	nsa	**0.123* **	**0.134** **	0.144	0.020	0.103
		(0.064)	(0.700)	(0.683)	(0.628)		**(0.095)**	**(0.049)**	(0.181)	(0.837)	(0.129)
R& D	nsa	0.014	-0.434	-0.086	-0.258	nsa	0.009	0.0006	0.006	-0.015	0.007
		(0.433)	(0.629)	(0.608)	(0.511)		(0.600)	(0.972)	(0.733)	(0.549)	(0.666)
Internet	nsa	**0.07*** **	0.079	0.025	-0.003	nsa	**0.05** **	**0.06*** **	**0.045* **	0.033	**0.054** **
		(0.000)	(0.172)	(0.671)	(0.935)		**(0.000)**	**(0.010**	**(0.063)**	(0.160)	**(0.012)**
TSE	nsa	**-0.001** **	0.005	0.002	0.004	nsa	-0.001	-0.001	-0.0009	-0.0008	**-0.001* **
		(0.028)	(0.701)	(0.768)	(0.490)		(0.112)	(0.167)	(0.347)	(0.381)	**(0.085)**
Main IPL	nsa	0.005	-0.004	---	0.002	nsa	0.005	0.0006	0.007	-0.001	0.005
		(0.314)	(0.857)		(0.960)		(0.233)	(0.833)	(0.164)	(0.894)	(0.269)
WIPO T	nsa	0.001	-0.125	---	-0.015	nsa	0.002	0.0009	0.002	0.002	0.001
		(0.849)	(0.505)		(0.525)		(0.777)	(0.934)	(0.814)	(0.848)	(0.852)
AR(2)	nsa	**-0.563**	**0.050**	**-0.551**	**-0.982**	nsa	**-0.624**	**-0.675**	**-0.763**	**-0.934**	**-1.179**
		(0.573)	**(0.959)**	**(0.581)**	**(0.326)**		**(0.532)**	**(0.499)**	**(0.445)**	**(0.350)**	**(0.238)**
Sargan	nsa	**31.745**	**8.254**	**5.524**	**9.969**	nsa	**29.152**	**33.941**	**32.869**	37.92*	**28.833**
		(0.201)	**(0.999)**	**(1.000)**	**(0.998)**		**(0.304)**	**(0.136)**	**(0.165)**	(0.061)	**(0.318)**
Wald	nsa	**14678*** **	**432.9*** **	**3872*** **	**5691*** **	nsa	**17657*** **	**19742*** **	**7057*** **	**10520*** **	**20742*** **
		(0.000)	**(0.000)**	**(0.000)**	**(0.000)**		**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**
Countries		41	9	9	17		39	46	46	54	40
Obs		249	50	41	75		239	279	270	304	244

	East Asia and the Pacific (EAP)				**Middle East & North Africa**			**LAC**		**SSA**
	EAP	MENA	LAC	SSA	MENA	LAC	SSA	LAC	SSA	SSA
Initial	**1.214*** **	**1.041*** **	**1.094*** **	**1.024*** **	-0.032	**1.086*** **	0.350	**1.086*** **	**1.058*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	(0.984)	**(0.000)**	(0.252)	**(0.000)**	**(0.000)**	
Constant	-1.372	-0.051	-0.303	-0.073	4.187	-0.188	**3.152** **	-0.152	0.007	nsa
	(0.593)	(0.869)	(0.368)	(0.924)	(0.601)	(0.481)	**(0.044)**	(0.612)	(0.976)	
R& D	-0.467	-0.054	**-0.202* **	-0.097	0.222	-0.099	0.209	-0.398	-0.270	nsa
	(0.587)	(0.185)	**(0.097)**	(0.684)	(0.737)	(0.141)	(0.254)	(0.340)	(0.201)	
Internet	**0.071* **	0.009	-0.017	**0.053** **	0.736	-0.065	-0.011	-0.039	-0.012	nsa
	(0.076)	(0.801)	(0.674)	**(0.049)**	(0.715)	(0.243)	(0.908)	(0.556)	(0.834)	
TSE	0.0008	-0.0001	0.0002	---	-0.052	0.001	**0.034** **	0.002	0.001	nsa
	(0.918)	(0.955)	(0.934)		(0.783)	(0.811)	**(0.022)**	(0.642)	(0.831)	
Main IPL	---	-0.009	-0.006	-0.014	-0.871	0.002	0.028	0.008	0.003	nsa
		(0.273)	(0.549)	(0.151)	(0.602)	(0.956)	(0.842)	(0.819)	(0.933)	
WIPO T	---	-0.023	-0.003	0.003	1.619	-0.004	-0.076	-0.024	**-0.028* **	nsa
		(0.509)	(0.911)	(0.954)	(0.134)	(0.873)	(0.659)	(0.327)	**(0.094)**	
AR(2)	**-0.768**	**-0.752**	**-1.265**	**-1.010**	**-0.092**	**-0.967**	**-0.157**	**-1.231**	**-1.199**	nsa
	(0.442)	**(0.451)**	**(0.205)**	**(0.312)**	**(0.926)**	**(0.333)**	**(0.874)**	**(0.218)**	**(0.230)**	
Sargan	**5.718**	**11.777**	**18.67**	**9.945**	**0.000**	**17.675**	**0.368**	**7.595**	**10.421**	nsa
	(0.999)	**(0.992)**	**(0.850)**	**(0.998)**	**(1.000)**	**(0.887)**	**(1.000)**	**(0.999)**	**(0.997)**	
Wald	**441.25*** **	**3180*** **	**4759*** **	**5727*** **	**3252*** **	**6348*** **	**8674*** **	**1434*** **	**3247*** **	nsa
	(0.000)	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	**(0.000)**	
Countries	7	14	22	11	7	22	8	15	16	
Obs	40	71	105	63	31	96	36	65	70	

***,**,*: significance levels of 1%, 5% and 10% respectively. AR(2): Second Order Autocorrelation test. OIR: Overidentifying Restrictions test. Initial: lagged endogenous estimated coefficient. Wald: test for the joint significance of estimated coefficients. HI: High Income. UMI: Upper Middle Income. LMI: Lower Middle Income. LI: Low Income. English: English Common-law. French: French Civil-law. German: German Civil-law. Scan: Scandinavian Civil-law. SA: South Asia. ECA: Europe and Central Asia. EAP: East Asia and the

Pacific. MENA: Middle East and North Africa. SSA: Sub-Saharan Africa. LAC: Latin America and the Caribbean. R & D: Research and Development expenditure. TSE: Tertiary School Enrolment. IPL: Intellectual Property Law. WIPO T: World Intellectual Property Organization Treaties. The significance of bold values is twofold. 1) The significance of estimated coefficients and the Wald statistics. 2) The failure to reject the null hypotheses of: a) no autocorrelation in the AR(2) tests and; b) the validity of the instruments in the Sargan OIR test. nsa: no catch-up estimation due to issues in degrees of freedom. Obs: Observations.

4.2 Discussion of results

Before diving into the discussion of results, it is important to understand the economic intuition motivating absolute and conditional catch-ups in scientific publications. Absolute catch-up in publications takes place when countries share similar fundamental characteristics with regard to factors governing scientific publications such that, only variations across countries in initial levels of publications exist. Absolute catch-up therefore results from factors such as: the formulation of laws protecting scientific IPRs within a legal system; wealth-effects (or income-levels) expressing how the prosperity of nations influences their orientation towards research for more development; regional proximity, since cross-regional differences determine scientific activity (Morrison et al., 2009); among others. Absolute catch-up also occurs because of adjustments common to the fundamental characteristics of scientific publications. Hence based on intuition, differences in initial conditions may significantly affect the absolute catchi-up processes due to the following. Firstly, the beginning of the catch-up process has a precondition: a certain level of scientific internal development which may significantlty differ across countries within the same homogenous panel; (2) the diffusion of legal cultures transmitted by colonial powers over time through regionalization and globalization such that, the legal origin fundamental holds less ground; (3) high growth low-income countries allocating significantly more budget to scientific activities than some of their middle-income counterparts and; (4) non-uniformity of scientific publications within a country as well as variations from city to city, industry to industry and, demography to demography. Hence, the overwhelming absence of absolute catch-up in the findings is traceable to the above factors.

On the other hand, conditional catch-up is that which depends on structural characteristics that determine scientific publications. It depicts the type of catch-up whereby, one's own long-term steady state (equilibrium) is contingent on structural characteristics of the economy. Hence, within a fundamental characteristic (say Low-income countries), cross-country differences in factors that explain scientific publications could facilitate conditional convergence. Accordingly, in our models conditional convergence has been contingent on characteristics that determined scientific publications, notably: R&D expenditure, internet penetration, tertiary school enrolment and, IPRs laws. Therefore the findings are contingent on the variables we choose and empirically test. Unfortunately, owing to constraints in degrees of freedom, we have not been able to employ more than five components of the conditional information set in modeling the fundamental characteristics. This is not much of a concern because as far as we have reviewed, some models in the literature are not conditioned beyond two macroeconomic control variables (Bruno et al., 2012).

Our results have shown overwhelmingly absence of absolute catch-up in the processes. While we have already discussed possible reasons for the outcome in the first paragraph of this section, it is interesting to discuss the findings in relation to the traditional catch-up processes in per capita income. The role of science in the periphery may not fit the classical catch-up per capita income model because the interplay between science and technology at the periphery indicates that from the beginning of the catch-up process, investment should be made in scientific infrastructure. Accordingly, as a focusing device, the scientific infrastructure could spot the avenues of technological development that are feasible to the country, given the international and national conditions. Owing to the wasteful nature of 'blind research', this is very relevant in less developed countries with huge resource scarcity. This view is consistent with the position of Albuquerque (2000) who strongly thinks that, given the scarce resources for scientific activities, catch-up countries might concentrate their

scientific development in key disciplines, especially in scientific fields that are sources of industrial development and that have high impact upon industrial firms. Hence, the distribution of scientific activities before and during catch-up processes might be more concentrated than in other stages of development.

4.3 Policy implications

4.3.1 Encouraging indigenous scientific research and fighting brain drain

Though there is consensus that local-focused research is necessary to build national absorptive capacity and support indigenous capabilities, it will be interesting to require the locally tailored research to be of publishable scientific standard. This would facilitate publication and hence, the catch-up process. Moreover, external peer-review should provide some checks on the scientific rigor and thus, validate the soundness of local-focused policy implications. In the same vein, incentives should be provided to researchers from developing countries to be more involved in the contribution to scientific knowledge, especially on that directly targeting the development of these countries. For instance, Wantchékon (2013) has postulated that, of the 258 impact evaluation studies in 2004, only 11% included African authors. He has further stressed that since 2004, only 7% of the 401 African related publications in the Journal of Development Economics are co-authored by Africans.

If observations on scientific publications used in this study were to be based on authors' region/country/continent of origin, the dynamics of the results might have changed in favor of catch-up evidences. Unfortunately, it is hard to verify this hypothesis because of brain drain. Most scientists are fleeing developing countries in search for greener pastures and better working conditions abroad. A great proportion of students from poor countries trained

abroad in fields that lead to scientific publications never return after obtaining their diplomas. We propose the following measures in the fight against brain drain.

Firstly, we present some recommendations for *source-countries*: improve job security and researcher planning by easing re-entry for researchers seeking temporary employment abroad; improve registration, examination and deployment procedures for foreign-trained researchers; ensure the training curricula meet local needs and develop mid-level researchers capable of meeting local needs and less likely to migrate; ameliorate retention incentives in academic institutions by providing benefits (extra pay for instance), better management and career paths; decrease political factors that determined academic promotions and; increase public-good contribution from the Diaspora through tax incentives.

Secondly, recommendations for *receiving countries* include: creation of bilateral agreements to regulate the recruiting process, ensure that the cost of migration are borne by the receiving and not the source country and take measures to improve country-of-origin development contribution of the Diaspora; adoption and enforcement of ethical codes of conduct in the recruitment of imported researchers; improve self-sufficiency in researchers through increased training and better use of existing researchers; increased contributions to educational systems of source countries through guaranteed salaries for remaining researchers and sustained targeting of educational aid; bilateral agreements creating new tax measures through which public-good remittance can improve financing of educational training systems; and improve 'return' or two-way human resources flows through time-limited visas or guaranteed return privileges for emigrants returning home after service-leaves[8].

Thirdly, recommendations for *regional and international institutions* include: ensure the monitoring of human rights and political instability factors pushing researchers to

[8] Equality in the two-way staff flow will ensure the source countries do not experience a loss of staff and at the same time would benefit from new knowledge brought by research professionals from recipient countries. This will minimize the negative externalities of professionals' flows from source to receiving countries.

emigrate; support for global research workforce alliances that seek to identify and resolve issues surrounding researcher professional migration; re-examine macroeconomic conditions that may impede local-focused research in developing countries and; develop cross-border public research agreements.

4.3.2 Support for regional research and innovation

The absence of absolute catch-up in 'technical and scientific journals' means fundamental characteristics enabling countries with lower levels of publications to catch-up with their counterparts of higher levels are dissimilar. Hence, there should be *encouragement and validation activities targeting local and regional initiatives to promote development of new innovating businesses and 'transfer and exchange' of best practices as well as the establishment of an environment more conducive to innovation*. The focus should preferably be on: trans-regional cooperation to facilitate the development of research and innovation; strategies and initiation of programs involving local actors and corresponding activities should be developed in close coordination with inclusive regional policies and; particular attention should be focused on the participation of sampled countries' regions, notably in relation to the transfer of schemes that have been successful at local and national levels.

The development of research and innovation strategies, as well as inter-regional technology transfer could greatly benefit less developed countries. This should include, *supporting the development of regional scientific infrastructure*. Thus, specific attention should be paid to the development and valorization of new scientific infrastructure in the regions, in collaboration and synergy with activities of the regional investment banks (funds). The example of the European Union has shown that modern scientific infrastructure is a key enabler of regional economic development. For researchers within the regions to be able to cooperate under state-of-the-art conditions with their counterparts in advanced regions as well as with the rest of the world, much needs to be considered (for instance, technical and

scientific parks for efficient cooperation and clustering between academia and industry, or high-speed electronic networks and related facilities as a key gateway to the information economy). A good example is the broadband electronic interconnection backbone that could link various regional electronic research and education networks.

As far as the context of research training networks and knowledge transfer is concerned, fellowships could be *developed to target more and better scientific and technical human resources*. Hence, more opportunities should be offered to researchers originating from less favored countries. This will ease the catch-up processes. Special attention should also be devoted to the number of factors affecting socioeconomic conditions of researchers, notably linguistic balance, gender equity and career structure. Ultimately, in view of further reinforcing the human potential for research in regions, human resource and mobility actions should target the best and most promising researchers from undeveloped countries, promote the training of regional researchers abroad and stimulate the return of scientists established outside, especially state-funded researchers who have a patriotic duty towards nation building after receiving tax payers funds.

Last but not the least, *improving communication between experts and policymakers* by supporting the establishment of joint work and communication platforms between them at the regional level. Clear statistical indicators: able to describe the structure, characteristics and performance of knowledge-based economy should be developed at national and regional levels.

4.4 Caveats and future research directions

Two main caveats have been retained: draw-backs in the methodology and, doubts about the 'legal origin and property rights theory' on which one of the fundamental characteristics is based. Firstly, as already discussed in Section 3.2, the choice of the catch-up approach (which is constrained by the data structure) has some drawbacks. Consistent with

Apergis et al. (2010), critics of β-convergence argue that if countries converge to a common equilibrium with identical internal structures, then the dispersion of the variable under consideration should disappear in the long-run as all countries converge to the same long-run path. More so, if countries converge to 'convergence clubs' or to their own unique equilibrium, the dispersion of this measure will not approach zero (Miller & Upadhyay, 2002). Accordingly, in the latter case of country-specific equilibrium, the movements of the dispersion will be contingent on the initial distribution of the variable under investigation with regard to their final long-run outcomes. Secondly, in accordance with Asongu (2012b) some doubts have been documented about the 'law and property rights theory' which postulates that British common-law supports innovative development to a greater extend than civil-law systems. However, this drawback does not pose much of an issue because of the plethora of catch-up panels employed.

In light of the above, it will be interesting to use the alternative approach of convergence to assess catch-up processes in scientific publications. Another future research direction could be to replicate the analysis in the context of innovations with the growth rates in patents and trademark applications as dependent variables.

5. Conclusion

This seminal paper has provided global empirical evidence on catch-up processes in scientific and technical publications. Its purpose has been to model the future of scientific knowledge monopoly in order to understand whether the impressive growth experienced by latecomers in the industry has been accompanied by a similar catch-up in scientific capabilities and knowledge contribution. The empirical evidence is based on 41 catch-up panels which together consist of 99 countries. The richness of the dataset has allowed us to disaggregate countries into fundamental characteristics based on income-levels (high-income, lower-middle-income, upper-middle-income and low-income), legal-origins (English

common-law, French civil-law, German civil-law and, Scandinavian civil-law) and, regional proximity (South Asia, Europe & Central Asia, East Asia & the Pacific, Middle East & North Africa, Latin America & the Caribbean and, Sub-Saharan Africa). Three main issues have been investigated: the presence or not of catch-up processes, the speed of the catch-up processes and, the time needed for full (100%) catch-up. The findings which are based on absolute and conditional catch-up patterns broadly show that advanced countries will continue to dominate in scientific knowledge contribution. Policy implications have been discussed.

Appendices

Appendix 1: Summary statistics and presentation of countries

Panel A: Summary statistics

	Variables	Mean	S.D	Min.	Max.	Obs
Dependent Variable	Scientific and Technical Journal Articles (STJA)	6.312	2.471	-0.051	12.261	851
Control Variables	Research & Development (R & D)	1.050	0.955	0.000	4.811	481
	Internet Penetration	20.409	24.219	0.000	93.887	840
	Tertiary School Enrolment (TSE)	37.879	21.798	0.000	94.577	703
	Main Intellectual Property Rights Law (Main IPL)	2.081	2.518	0.000	20.000	882
	WIPO Treaties (WIPO T)	3.396	1.849	0.000	7.000	882
Fundamental Characteristics	High Income (HI)	0.438	0.496	0.000	1.000	882
	Upper Middle Income (UMI)	0.295	0.456	0.000	1.000	882
	Lower Middle Income (LMI)	0.243	0.429	0.000	1.000	882
	Low Income (LI)	0.020	0.141	0.000	1.000	882
	English Common Law (English)	0.275	0.447	0.000	1.000	882
	French Civil Law (French)	0.509	0.500	0.000	1.000	882
	German Civil Law (German)	0.173	0.378	0.000	1.000	882
	Scandinavian Civil Law (Scandi)	0.040	0.197	0.000	1.000	882
	South Asia (SA)	0.030	0.172	0.000	1.000	882
	Europe and Central Asia (ECA)	0.438	0.496	0.000	1.000	882
	East Asia and the Pacific (EAP)	0.102	0.302	0.000	1.000	882
	Middle East and North Africa (MENA)	0.132	0.339	0.000	1.000	882
	Sub-Saharan Africa (SSA)	0.081	0.273	0.000	1.000	882
	Latin America and the Caribbean (LAC)	0.192	0.394	0.000	1.000	882

Panel B: Presentation of countries

Albania, Algeria, Argentina, Armenia, Australia, Austria, Azerbaijan, Bahrain, Belgium, Bolivia, Bosnia, Botswana, Brazil, Bulgaria, Cameroon, Canada, Chile, China, Colombia, Costa Rica, Croatia, Cyprus, Czech Republic, Denmark, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Finland, France, Germany, Greece, Guatemala, Honduras, Hong Kong, Hungary, Iceland, India, Indonesia, Ireland, Israel, Italy, Japan, Jordan, Kazakhstan, Kenya, Kuwait, Latvia, Lebanon, Lithuania, Luxembourg, Macedonia, Malaysia, Malta, Mauritius, Mexico, Moldova, Montenegro, Morocco, Netherlands, New Zealand, Nicaragua, Nigeria, Norway, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Poland, Portugal, Puerto Rico, Qatar, Romania, Russia, Saudi Arabia, Senegal, Serbia, Singapore, Slovakia, Slovenia, South Africa, South Korea, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, Ukraine, UAE, United Kingdom, United States, Uruguay, Venezuela, Vietnam, Zambia.

S.D: Standard Deviation. Min: Minimum. Max: Maximum. ICT: Information and Communication Technology. Scandi: Scandinavian. Obs: Observations. WIPO: World Intellectual Property Organization.

Appendix 2: Correlation analysis

R& D	Internet	TSE	Main IPL	WIPO T.	STJA	
1.000	0.436	0.566	0.200	0.068	0.631	R&D
	1.000	0.506	0.351	0.335	0.631	Internet
		1.000	0.394	0.355	0.576	TSE
			1.000	0.328	0.349	Main IPL
				1.000	0.181	WIPO T.
					1.000	STJA

R&D: Research & Development. Internet: Internet Penetration. TSE: Tertiary School Enrolment. Main IPL: Main Intellectual Property Law. WIPO T. World Intellectual Property Organization Treaties. STJA: Scientific and Technical Journal Articles.

Appendix 3: Variable definitions

Variables	Signs	Variable definitions (Measurement)	Sources
Journal Articles	STJA	Logarithm of number of Scientific and Technical Journal Articles	World Bank (WDI)
Research and Development	R & D	Research and Development Expenditure (% of GDP)	World Bank (WDI)
Internet Penetration	Internet	Logarithm of Internet Users per 1000	GMID
Literacy	TSE	Tertiary School Enrolment (% of Gross)	GMID
IPRs Law	Main IPL	Main Intellectual Property Law	WIPO
WIPO Treaties	WIIPO T	World Intellectual Property Organization	WIPO

WDI: World Bank Development Indicators. GMID: Global Market Information Database.. Log: Logarithm. WIPO: World Intellectual Property Organization. IPRs: Intellectual Property Rights.

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