# Digitalization of research: do ICT improve scientific production in developing countries?

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## Abstract

The aim of this paper is to analyze the effects of the diffusion of ICTs in general and the internet penetration in particular on scientific production in developing countries. We capture the scientific production by the number of scientific journals papers published and the number of patents filed by residents of these countries. The panel of data collected on 70 developing countries over the period 2000-2016, allowed us to estimate a model by the method of generalized moments in system. The results show that improving the access to internet in countries increases the productivity of researchers. Also, the results suggest that democracy and transparency of administrations increase researchers' productivity, while corruption, conflicts and mining rents reduce it.

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## 1. Introduction

There are significant inequalities between developed and developing regions. According to the World Bank (2020), the United States of America, the European Union and China account for nearly 65% of the total global wealth produced during that year. These inequalities can be partly explained by the gap between these regions in terms of innovation and research and development (R&D). The relationship between the quality of R&D and economic growth is the subject of several empirical studies in the literature. From these works, a consensus emerges on its positive effect. Indeed, R&D through the improvement of knowledge production and the acceleration of innovations affects growth and explains the differentials observed between the different countries of the world (Josifidis and Supic, 2021; Laverde-Rojas and Correa, 2019 and Bernard, 2017). More specifically, for endogenous growth theorists, mainly Romer (1990), Aghion and Howitt (1992, 1997) R&D is an important determinant of economic growth. The main channels through which innovation impacts growth are, without being exhaustive, the accumulation of human capital (Lucas, 1988) and the expansion of markets through the production of new goods (Barro, 1990).

Moreover, an analysis of the facts shows that there is a positive correlation between research efficiency and economic performance. Indeed, developed countries still dominate about 70% of the production of scientific papers globally and nearly 90% of patents (UNESCO, 2016). As an illustration, the world's top two economies (the United States and China) produce nearly 40% of scientific output. Europe accounts for about 21% of the production of scientific articles (UNESCO, 2016). The main evolution has occurred with the economic progress of some emerging countries. India, Iran or even Brazil has experienced a rapid increase in their share of global knowledge production. India is now the 5th largest scientific power in the world. Brazil is now the 14th largest producer of scientific knowledge in the world having moved up 8 places from 14871 scientific articles published in 2000 to 81742 in 2018. With 25150 scientific articles published in 2018, South Africa ranks as the 29th largest knowledge producer in the world and the largest producer in Africa (World Bank, 2018).

This knowledge development in developed and emerging countries is not generally observed in Sub-Saharan Africa (SSA) except for South Africa and other developing countries. In terms of SSA, it accounts for less than 5% of global scientific output (UNESCO, 2016). The countries producing the least scientific knowledge are Sao Tome and Principe and Somalia. These poor performances of African countries can be explained in part by the differences in the modes of recruitment and promotion of researchers between advanced and developing countries. For example, according to Heckman and Sidharth (2020), a teaching position in a prestigious economics faculty in the United States is conditional on the number of articles published in the main journals in the field (American Economic Review, Econometrica, the Quarterly Journal of Economics, the Journal of Political Economy and the Review of Economic Studies). On the other hand, in many African countries, the recruitment and promotion of researchers is often based on criteria that are not necessarily based on research performance. This imbalance is more marked in the case of Francophone African countries. Indeed, there seems to be a correlation between the legal origin of African countries and their performance in terms of scientific production. The Anglo-Saxon countries have better performances than the Francophone ones.

On the theoretical level, the seminal work on scientific production is attributed to Lokta (1926) who established an inverse relationship between the volume of scientific production and the number of researchers in a Walrasian model. According to the author, it is observed in many fields that most scientific articles are published by a very prolific minority of researchers, whereas the distribution of productivity is asymmetrical to the left, especially for the number of quality publications. Subsequently, an explanation in terms of the research life cycle was provided by Taylor et al. (2006) and states that early career researchers tend to be more productive until they reach their desired level of career advancement (Morrisey and Cawley, 2008). Theoretical work by Carayol (2006), Lesueur (2012), Gay et al. (2008), Lissoni et al. (2011), Rauber and Ursprung (2008), Weisbrod (2009) emphasize the mechanisms of cooperation among researchers through developments by game theory (Neumann and Morgenstern, 1944) as an explanatory factor for researcher productivity.

With the emergence of North's work (1990) on institutions as explanatory factors of the development delay of countries, some authors (Sadeh et al., 2019; Jacq et al., 2015) have analyzed the role that a good quality of institutions can play on knowledge production. Indeed, they hypothesize that democratic systems with freedom of expression and thought are associated with a rapid rise of general knowledge. Also, Robin (2017) argues that the implementation of a protective system of property rights strengthens inventions and discoveries in both the "hard" and "soft" science.

Empirically, despite some dissonant work, there seems to be a consensus on the positive effect of institutions on scientific production. Indeed, while in developed countries the results converge (Jacq et al., 2015), this is not the case in developing countries. According to Ebeke et al. (2015), the education systems of developing countries in general and African countries in particular are oriented towards training to capture a share of the rent to the detriment of training in science and technology.

One of the most rapid innovations in developing countries is the diffusion of ICTs and the analysis of their impact at the macro level has been the subject of many empirical studies, specifically in developing countries. Yet, from the beginning of the decade 2000, these countries have experienced a rapid penetration of ICT. Also, statistically, this ICT penetration seems to be correlated with the increasing evolution of scientific production in these countries.

This study analyzes the role of ICTs in explaining the productivity of researchers in the context of developing countries. ICTs in general and the internet in particular, allows for an international convergence of human capital levels. ICTs can play an important role in the accumulation of human capital of learners (and thus future researchers) and researchers. Acemoglu, Laibson and List (2014) proposed a theoretical model showing how the diffusion of ICTs in general, and the internet in particular, increases the human capital of learners and teachers in countries with low human capital endowments. On the learners' side, they would benefit from the teachings and knowledge coming from all over the world. They no longer depend solely on the teachings of their teachers. Students from all over the world have access to the teachings of the "best" teachers in the world. On the teachers' side, they can improve their knowledge and their teaching, as ICTs offers them the possibility to access the most recent and relevant works in their fields. All of this would promote the "democratization" of knowledge and an international convergence of human capital levels. This work by Acemoglu et al. (2014) deals with the knowledge economy in general, and may refer more immediately to the research sector. Indeed, it shows in particular the impact of the internet on the dissemination and popularization of the work of the greatest specialists in all fields of knowledge.

ICTs can contribute to improving the productivity of researchers in developing countries through two main channels. First, by facilitating access to information and global knowledge, they can increase the level of knowledge of researchers in these countries. Thus, access to international data and to articles published in the best scientific journals increases the human capital of researchers in developing countries. The second channel is access to funding. A major problem faced by researchers in developing countries is that of research funding, with the majority of these countries devoting less than 1% of their budget to research funding. In this context, ICTs facilitate access to and the search for external funding. Information on mobility grants, direct funding, and participation in international conferences is facilitated by the Internet.

This paper is an extension of studies on the determinants of scientific production with a particular emphasis on developing countries. It is innovative in at least two respects. First, it goes beyond the determinants traditionally discussed in the literature and proposes an empirical analysis that focuses specifically on the role of ICTs in explaining the productivity of researchers. As a result, and in contrast to almost all existing studies on the subject, we use macroeconomic data. From this point of view, scientific production is captured by two indicators, namely the number of scientific and engineering articles published and the number of patents filed by residents of a country. This allows us to make international comparisons. Second, this paper tests a hypothesis that is still debated in the existing literature and considers a larger sample. Indeed, to our knowledge, there are very few empirical studies on the determinants of scientific production in developing countries. Moreover, our empirical strategy is based on dynamic panel data, contrary to the cross-sectional analysis usually used. Based on this consideration, we find that the rapid ICTs diffusion in the sample countries increases the scientific production of researchers.

In addition to this introduction, the paper is organized in 3 more sections. Section 2 presents the empirical strategy. Section 3 presents and discusses the econometric results obtained. Finally, section 4 concludes and suggests some policy recommendations.

## 2. Methods and data

### The model

The econometric analyses performed in this paper follow the work of Acemoglu and Verdier (1998), Mawussé (2013), and Ebeke et al. (2015), all of whom present the effects of institutional quality on educational orientation and thus on human capital accumulation in developing countries. This study takes up this idea but instead analyzes the effects of ICT diffusion on researcher productivity in developing countries. As a result, the model we estimate is as follows:

$$\text{Research}_{it} = \sum \beta_i ICT_{it} + \sum \alpha_i X_{it} + \varepsilon_{it}$$

In this equation, the variable $\text{Rechearch}_{it}$ refers to the productivity of researchers and is captured by two indicators: the number of scientific papers published and the number of patents filed. The variables $ICT_{it}$ are proxies of ICT diffusion, including Internet and mobile phones. The X matrix is composed of macroeconomic and historical variables typically used in explaining innovation and research. By introducing all these variables, we obtain the form of the model to be estimated. This model is as follows:

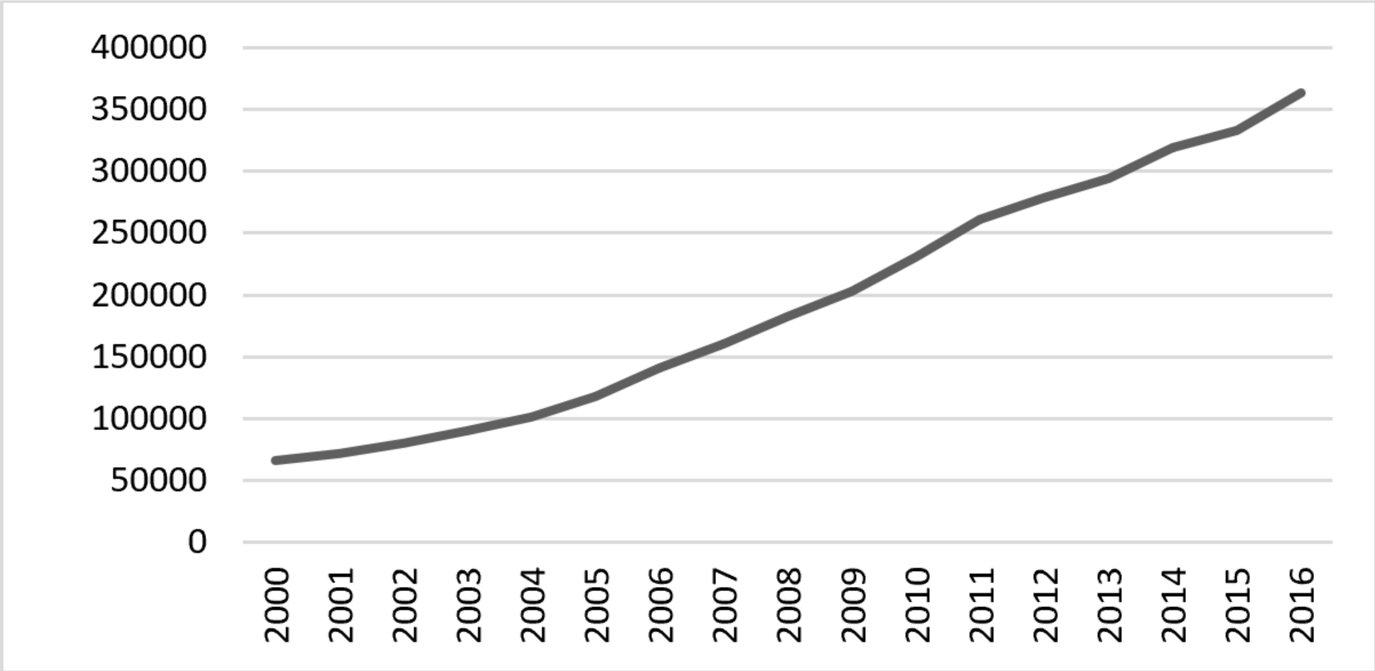
$$\begin{aligned}\text{Rechearch}_{it} &= \beta_0 + \beta_1\text{internet}_{it} + \beta_2\text{corr}_{it} + \beta_5\text{terciary\_educ}_{it} + \beta_6\text{Democracy}_{it}\\ &+ \beta_7\text{ln\_}gdp_{it} + \beta_{12}\text{min\_rent}_{it} + \beta_{13}\,\text{health\_exp}_{\,it} + \varepsilon_{it} \qquad (2)\end{aligned}$$

The variable of interest is Internet diffusion. The institutional variables selected for this study are: democracy and corruption. The macroeconomic series selected are GDP per capita, mining rent, total population, national health expenditure, and the proportion of female university teachers. These variables are described in more detail in the following section.

## Data

The panel consists of 70 developing countries over the period 2000-2016. The list of countries selected is provided in the appendix. The data are mainly taken from three databases: WDI (2018) for the macroeconomic series, ICRG (2017) and the World Happiness Database for the institutional variables (democracy and corruption).

To measure scientific production, the literature distinguishes between volume indicators (number of articles published, number of patents filed) and indicators of research quality (e.g., number of citations). However, since we are working on developing countries, aggregate data on research quality are almost non-existent for several countries. For this reason, we rely on two indicators to measure scientific production: the number of publications of scientific and engineering articles and the number of patents filed. These indicators are taken from the World Bank database (WDI, 2020). Graph 1 plots the evolution of the number of scientific articles published by the 70 developing countries in our sample between 2000 and 2016.




**Graph 1.** Evolution of the number of scientific articles from 70 developing countries

*Source:* authors, based on World Bank data

The main explanatory variable is the use of internet. We capture it by the proportion of individuals using the internet. In relation to democracy and corruption, the indicators used in the literature are not unanimous. A distinction is made between variables that measure the perception of the quality of institutions, obtained by aggregating survey data at the macroeconomic level (e.g., World Happiness database data) and variables that attempt to measure the actual level of institutional quality (ICRG, WGI). In this study, we will use both types of data. First, we will use the democracy and corruption indices provided by the ICRG database. These indices are continuous variables taking their values between 0 and 6. In the robustness analysis, we will use perception data from the World Happiness database. These are continuous variables with values between -3 and 3.

The other variables are all taken from the WDI. These are GDP per capita (in constant dollars), total population, mining rent, domestic health expenditure (as a % of GDP).

The countries used in this work are summarized in Annex 1, while descriptive statistics for all the variables used are provided in Annex 2.

## Estimation techniques

Traditional fixed effects and random effects estimators have been shown to be inappropriate when there is an endogeneity bias. In the case of this study, this bias is pervasive. First, there is a simultaneity bias between certain explanatory variables and the dependent variable. Thus, to take this risk into account, the Generalized Moment Method is more appropriate (Roodman, 2009). Overall, there are two main advantages to using the GMM method. In the case of a dynamic model, this method allows us to take into account temporal dynamics. The second advantage is that this estimation technique allows us to treat all exogenous variables as potentially endogenous (Roodman, 2009).

There are two dynamic GMM estimators: first difference GMM developed by Arellano and Bond (1991) and system GMM (Arellano and Bover, 1995; Blundell and Bond, 1998). However, the literature has identified a problem with the use of difference GMM: in some cases, series lags are not reliable instruments (Bond et al., 2012). As a result, the GMM estimator in system seems better than the one in first difference. We will therefore use this estimator in our empirical analyses. However, there is always the question of validity and multiplication of instrument. We have used the “collapse” command as recommended by Roodman (2009).in order to ensure the validity of the instruments used, we perform two complementary tests: the restriction over identification test and the series correlation test.

## 3. Results and discussions

### Results of the basic model

As a first step, we estimated equation 2 without considering the institutional variables. The results reported in Table 1 account for socioeconomic determinants of the productivity of researchers in developing countries. The first two columns present the results of the estimation of the socio-economic determinants of scientific production while the last two columns are obtained by adding the institutional variables retained.

**Table 1.** Baseline results

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| VARIABLES | Jr_articles | Patents | Jr_articles | Patents |
| ln_gdp | 1.068*** | 1.752*** | 1.198*** | 1.805*** |
| | (0.0262) | (0.0351) | (0.0259) | (0.0410) |
| Internet | 0.0407*** | 0.00659*** | 0.0413*** | 0.00900*** |
| | (0.00131) | (0.00219) | (0.00138) | (0.00269) |
| min_rent | -0.0585*** | -0.0622*** | -0.0850*** | -0.0901*** |
| | (0.00197) | (0.00981) | (0.00325) | (0.0114) |
| tertiary_educ | -0.00306** | -0.00212 | -0.000109 | 0.0107*** |
| | (0.00121) | (0.00254) | (0.00127) | (0.00304) |
| healt_exp | -0.000855*** | 0.00260*** | -0.00163*** | 0.00100*** |
| | (0.000152) | (0.000224) | (0.000155) | (0.000266) |
| democracy_icrg | | | 0.308*** | 0.169*** |
| | | | (0.0144) | (0.0252) |
| Corruption | | | -0.469*** | -0.779*** |
| | | | (0.0244) | (0.0437) |
| Constant | -2.956*** | -8.262*** | -3.200*** | -6.443*** |
| | (0.165) | (0.234) | (0.166) | (0.280) |
| Observations | 427 | 468 | 394 | 416 |
| Number of code | 56 | 57 | 51 | 55 |
| Wald (prob) | 0.0000 | 0.0001 | 0.0000 | 0.0003 |
| AR1 | 0.0001 | 0.0021 | 0.0000 | 0.034 |
| AR2 | 0.2674 | 0.6514 | 0.2915 | 0.7016 |
| Sargan | 0.0146 | 0.0312 | 0.0092 | 0.0104 |

*Note: Values in parentheses are standard deviations. ***, **, * represent significance at 1%, 5% and 10% respectively. Source: authors' construction from Stata 2017.*

How did you handle the issue of missing data? As seen in Table 1, they are missing information. The number of codes is less than 70 and you failed to present the number of instruments.

A quick look at the probability values associated with the Wald and Sargan statistics confirm the quality of these estimates. Overall, the estimates are good. Also, the coefficients have the expected signs and significance.

The results suggest that the socio-economic determinants are identical for the number of scientific articles published and the number of patents filed. These are ICTs, GDP per capita, mining rent, human capital, population, and institutional variables.

The results suggest that the diffusion of ICT in general, and of the internet in particular, positively and significantly (at the 1% threshold) explains both the number of scientific articles published and the number of patents filed. This result is consistent with the theoretical predictions of the Acemoglu et al. (2014) model that, in countries with low human capital endowments (as is the case for most developing countries), access to the internet is a powerful tool for improving the skills of researchers in these countries. Indeed, thanks to the Internet, researchers have access to most of the world's knowledge and to the work of other researchers. This has an undeniable effect on the quantity and quality of their post-internet work.

In relation to per capita income, all coefficients are positive and significant at the 1% level. The productivity of researchers therefore increases with the wealth of the country. This result is firstly consistent with the statistical observation that the richest countries are those that are the most advanced in terms of research and scientific production. It can be explained by the fact that an increase in a country's wealth leads to a natural increase in research funding. However, by way of comparison, the coefficient associated with this variable is more important in explaining the number of patents filed than the number of scientific articles published. This result is not surprising, as innovation from patents sustains economic growth.

Another important result is that the mining rent explains negatively and significantly (at the 1% threshold) both the number of scientific articles published and the number of patents filed. This result confirms the findings of Ebeke et al. (2015), Cavallo and Daude (2011), and De la Croix and Delavallade (2009) that in rentier states there is a talent allocation bias, with the brightest students most often ending up in government in order to capture a portion of the rent. We extend this explanation to the case of researchers. Because of this entry bias, the best students, who would have been better researchers, end up far from research activities. It is therefore the least brilliant students who become researchers.

In relation to human capital, we obtained two main results. First, the quality of public education policies positively and significantly explains the number of patents filed and the number of scientific articles published. Second, national health expenditures negatively explain the productivity of researchers in developing countries. This is because, due to the low life expectancy prevailing in developing countries, these countries still allocate too few resources to health financing.

The estimation results suggest that corruption reduces scientific output in developing countries. Indeed, all coefficients associated with this variable are negative and significant at the 1% level regardless of the column. Thus, corruption reduces both the number of scientific articles published and the number of patents filed. A first explanation of this result is given by the analysis in terms of researcher selection bias. Indeed, Séka (2005) has shown that corruption negatively affects the accumulation of human capital. He argues that very talented students, who might otherwise have continued their studies (and become researchers), suddenly drop out when they compare the welfare level of those who are well educated with those who are not but enriched by corruption. Another explanation can be found in the behaviors of university and research institution faculty in developing countries, who are most often seeking promotion in central government to capture the benefits of their education.

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In the same vein, democracy is positively correlated with scientific production, whatever the indicator used. Indeed, the coefficients associated with this variable are all positive and significant at the 1% level. This suggests that democratic countries tend to be more scientifically productive than others. This result is consistent with the finding that transparency of public policies increases the productivity of researchers in the countries studied. Two explanations can be given here. First, the empirical literature seems to show that democratic countries grow faster than others. This wealth effect leads to an increase in the productivity of researchers. Second, democratic regimes, since they are accountable to the people, have less difficulty controlling corruption than other types of regimes. There is thus a control effect on corruption that reduces the selection bias of researchers. Similarly, the results suggest that political stability reduces scientific production in developing countries. Indeed, in these countries, governments that are long in power (and therefore stable) are generally the least democratic. As a result, a corrupt environment is generally not conducive to research as seen above.

## Sensitivity and robustness tests

In order to test the sensitivity of the previous results to the choice of indicators used, we estimated equation 2 by changing the indicators of democracy and corruption. Previously, we used the indicators provided by the ICRG database. Here, we will use those given by the World Hapiness Database. These are household survey data on their perceptions of their countries' governance and well-being (World Gallup Pool). The following table presents the results of these estimates.

**Table 2.** Sensitivity of results to the choice of indicators

| | (1) | (2) |
|---|---|---|
| VARIABLES | Jr_articles | Patents |
| | | |
| ln_gdp | 2.160*** | 2.799*** |
| | (0.0561) | (0.0908) |
| Internet | 0.0127*** | 0.0238*** |
| | (0.00244) | (0.00466) |
| min_rent | -0.0999*** | -0.0708*** |
| | (0.00280) | (0.0177) |
| tertiary_educ | 0.0147*** | 0.0262*** |
| | (0.00234) | (0.00555) |
| healt_exp | -0.00317*** | -0.00942*** |
| | (0.000484) | (0.000752) |
| democracy_whdb | 0.465*** | 0.517*** |
| | (0.0598) | (0.137) |
| corruption_whdb | -5.071*** | -9.636*** |
| | (0.346) | (0.739) |
| Constant | -4.773*** | -8.179*** |
| | (0.413) | (0.723) |
| | | |
| Observations | 379 | 386 |
| Number of code | 41 | 40 |
| Wald (prob) | 0.0000 | 0.0000 |
| AR1 | 0.0002 | 0.0000 |
| AR2 | 0.4831 | 0.6749 |
| Sargan | 0.0043 | 0.0108 |

*Note: Values in parentheses are standard deviations. ***, **, * represent significance at 1%, 5% and 10% respectively.*

*Source: authors' construction from Stata 2017.*

Overall the results do not vary fundamentally. This proves that the main results are robust to changes in the measurement indicators. In a second step, we analyzed the sensitivity of the results to the introduction of other control variables. We introduced a regional variable. This is a dummy taking 0 if the developing country is outside Africa and 1 in the opposite case. We then cross-reference this variable with democracy and corruption. The aim is to see if the effect of institutions on the effectiveness of research in developing countries varies according to the region. The following table presents the results of these estimations.

**Table 3.** Sensitivity of the results to the introduction of other control variables

| | (1) | (2) |
|---|---|---|
| **VARIABLES** | **Jr_articles** | **Patent** |
| | | |
| **ln_gdp** | 0.666*** | 1.312*** |
| | (0.0353) | (0.0573) |
| **Internet** | 0.0421*** | 0.00341 |
| | (0.00165) | (0.00296) |
| **min_rent** | -0.0604*** | -0.0657*** |
| | (0.00387) | (0.0123) |
| **healt_exp** | -0.000898*** | 0.000982*** |
| | (0.000190) | (0.000302) |
| **tertiary_educ** | -0.0507*** | -0.00300 |
| | (0.00194) | (0.00338) |
| **democracy_icrg** | 0.395*** | 0.111*** |
| | (0.0201) | (0.0279) |
| **Corruption** | -0.513*** | -0.971*** |
| | (0.0378) | (0.0572) |
| **Region** | -2.723*** | -3.902*** |
| | (0.153) | (0.362) |
| **cor_region** | -0.168*** | -0.752*** |
| | (0.0573) | (0.131) |
| **dem_region** | 0.0261 | 0.0771 |
| | (0.0410) | (0.128) |
| **Constant** | 3.425*** | 1.790*** |
| | (0.257) | (0.414) |
| **Observations** | 330 | 362 |
| **Number of code** | 41 | 45 |
| **Wald (prob)** | 0.004 | 0.0009 |
| **AR1** | 0.0000 | 0.0000 |
| **AR2** | 0.5218 | 0.3951 |
| **Sargan** | 0.0021 | 0.0385 |

*Note: Values in parentheses are standard deviations. ***, **, * represent significance at 1%, 5% and 10% respectively.*

*Source: authors' construction from Stata 2017.*

Again, the results remain broadly stable and do not fundamentally change. However, two new facts appear. On the one hand, the results suggest that the region negatively and significantly affects research in developing countries. Thus, African countries have on average a lower rate of scientific production than other developing countries. On the other hand, we observe that these regional disparities in the effect of institutions on scientific production in developing countries are significant in the case of corruption and not in the case of democracy. Indeed, only the cor_region cross variable is negative and significant at the 1% level. This implies that corruption reduces scientific production in African countries more than in the other developing countries considered.

To conclude the empirical analysis, we introduce cross-variables between internet and some socioeconomic variable to study the transmission channels between ICTs diffusion and scientific production. Table 4 summarizes the results of the estimation.

**Table 4.** transmission channels analysis

| | (1) | (2) |
|---|---|---|
| **VARIABLES** | **Articles** | **Brevets** |
| | | |
| **Democracy_icrg** | 0.167*** | 0.192** |
| | (0.0262) | (0.0890) |
| **Corruption** | -0.309*** | -0.635*** |
| | (0.0529) | (0.0122) |
| **Gov_stability** | 0.444*** | -0.204*** |
| | (0.0271) | (0.0726) |
| **Internal_conflict** | -0.204*** | -0.299*** |
| | (0.0412) | (0.102) |
| **Internet** | 0.130*** | 0.231** |
| | (0.0303) | (0.0936) |
| **Min_rent** | -0.0157*** | -0.0263 |
| | (0.00506) | (0.0335) |
| **Healt_exp** | -0.0216*** | 0.0176** |
| | (0.00327) | (0.00792) |
| **Lgdppc** | 1.085*** | 0.936*** |
| | (0.0905) | (0.362) |
| **Lop** | 1.124*** | 1.066*** |
| | (0.0550) | (0.160) |
| **Internet_gov** | 0.0112*** | 0.0157*** |
| | (0.00247) | (0.00522) |
| **Internet_KH** | 0.0297*** | 0.1328*** |
| | (0.00682) | (0.0243) |
| **Constant** | -3.39*** | -2.98*** |
| | (0.991) | (4.070) |
| | | |
| **Observations** | 680 | 448 |
| **Number of code** | 55 | 42 |
| **Wald (prob)** | 0.000 | 0.000 |
| **AR2** | 0.865 | 0.652 |

*Note: Values in parentheses are standard deviations. ***, **, * represent significance at 1%, 5% and 10% respectively.*

*Source: authors' construction from Stata 2017.*

The results remain globally stable and do not fundamentally change. The cross-variables internet and government stability on the one hand, and internet and human capital on the other hand, are all significant and positive. This suggests that ICT amplifies the effects of good governance and human capital on research quality in developing countries.

## 4. Conclusion

This study proposes to analyze the role of ICTs in explaining the productivity of researchers in the context of developing countries. ICTs in general and the internet in particular, allows for an international convergence of human capital levels by increasing the human capital in countries with low human capital endowments. To do so, we compiled data on 70 developing countries over the period 2000-2016. These data come from the World Bank and the ICRG and World Happiness databases. Using a panel model estimated by the GMM method, we obtained the result that internet diffusion is positively correlated with scientific production in selected countries. Also, we find that democracy and transparency in government increase researcher productivity, while corruption, conflict, and mining rents reduce it.

As a result, we recommend that the governments of these countries continue to take steps to improve governance. In particular, they should continue with the democratization of these countries.

## Appendix

### Appendix 1: List countries

Afghanistan, Angola, Bangladesh, Bhutan, Brazil, Benin, Burkina Faso, Burundi, Cap-Vert, Cameroon, Chad, CAR, Comoros, Congo, Côte d'Ivoire, Djibouti, Eritrea, Swaziland, Ethiopia, Estonia, Gambia, Ghana, Guinea, Guinea-Bissau, Equatorial Guinea, Haiti, Yemen, Cambodia, Tuvalu, Myanmar, Colombia, Uganda, Fiji, Gabon, Guatemala, Hungry, Iran, India, Indonesia, Kenya, Korea, Lesotho, Liberia, Madagascar, Mali, Malaysia, Mozambique, Mongolia, Namibia, Mauritania, Nepal, Niger, Nigeria, Pakistan, Philippines, Peru, Senegal, Seychelles, Sao-Tomé et Principe, Somalia, Sierra-Leone, South Soudan , Soudan, Togo, Tanzania, Thailand, Vietnam, Zambia and Zimbabwe.

### Appendix 2: Descriptive Statistics

| Variables | Observations | Mean | Sd | Minimum | Maximum |
|---|---|---|---|---|---|
| **Papers** | 1190 | 2660.764 | 10490.49 | 0 | 112167.3 |
| **Patents** | 415 | 6024.66 | 25482.65 | 1 | 167275 |
| **Ln_GDP** | 1140 | 7.331064 | 1.078756 | 5.272348 | 10.14581 |
| **Internet** | 1152 | 11.65162 | 16.73004 | .0002893 | 92.84303 |
| **Min_rent** | 1158 | 1.777855 | 4.977882 | 0 | 46.62465 |
| **Tertiary_edu** | 445 | 28.19718 | 16.75275 | 1.22511 | 82.21014 |
| **health_exp** | 832 | 8.259265 | 1.589765 | 3.166667 | 11.58333 |
| **Democracy** | 833 | 3.308974 | 1.420283 | 0 | 6 |
| **Corruption** | 833 | 2.002451 | .734672 | 0 | 5 |

### Appendix 3: Correlation matrix

| Variables | papers | patents | ln_gdp | Internet | min_rent | tertiary_edu | health_exp | Democracy | Corr |
|---|---|---|---|---|---|---|---|---|---|
| **Papers** | 10.000 | | | | | | | | |
| **Patents** | 0.5288 | 10.000 | | | | | | | |
| **Ln_gdp** | 0.2912 | 0.4293 | 10.000 | | | | | | |
| **Internet** | 0.4027 | 0.5414 | 0.6512 | 10.000 | | | | | |
| **Min_rent** | -0.0481 | -0.0865 | -0.0543 | -0.0474 | 10.000 | | | | |
| **Tertiary_edu** | 0.2007 | -0.0889 | 0.5398 | 0.4338 | -0.0953 | 10.000 | | | |
| **Healt_exp** | -0.1556 | -0.0013 | -0.0843 | -0.2510 | -0.1686 | -0.0198 | 10.000 | | |
| **Democracy** | 0.1030 | -0.5098 | 0.0269 | 0.0388 | 0.1086 | 0.1752 | -0.1286 | 10.000 | |
| **Corr** | -0.0010 | -0.2974 | 0.1076 | 0.1092 | 0.0522 | 0.1076 | 0.1955 | 0.3846 | 10.000 |

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