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Scientific knowledge production and economic catching up: an empirical analysis

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Scientific knowledge production and economic catching up: an empirical analysis[1]

Abstract:

This paper aims to investigate the relationship between scientific knowledge production in universities and academic institutions and countries' income level. We argue that scientific performance could be considered as a manifestation of the improvements of the educational and technological capabilities within an economy. We use academic publications in refereed journals as a proxy of scientific performance. We also look for the specific effects of per capita engineering publications and of the academic specialization of a country in engineering. The impacts of scientific publications on middle income countries are also analysed, as well as their different effects in Asian and Latin America countries. The results show that academic publications are consistently and positively correlated with income per capita, for both middle and high income countries. In addition, we find nonlinear effects, suggesting the presence of decreasing returns of academic performance. This means that middle income countries could benefit more than for high income countries from just improving their scientific base. Finally, we find that Asian countries have benefited more from academic production in engineering than their Latin American peers.

Resumen

El objetivo de este trabajo es investigar la relación entre la producción de conocimiento científico en universidades e instituciones académicas y el nivel de ingreso de los países. Argumentamos que el rendimiento científico podría considerarse como una manifestación de las mejoras de las capacidades educativas y tecnológicas dentro de una economía. Usamos publicaciones académicas en revistas con referato como un proxy del desempeño científico. También indagamos sobre los efectos específicos de las publicaciones en el área de ingeniería, n términos per cápita y con relación a la especialización académica de un país en dicha área del conocimiento. También se analizan los impactos de las actividades científicas en los países de ingresos medios, así como sus diferentes efectos en Asia y América Latina. Los resultados muestran que las publicaciones académicas se correlacionan de forma consistente y positiva con el nivel de ingreso per cápita de los países, tanto para aquellos de ingresos medios como altos. Además, encontramos efectos no lineales, lo que sugiere la presencia de rendimientos decrecientes asociados a la producción de conocimiento científico. Esto significa que los países de ingresos medios podrían beneficiarse más de una mejora de su desempeño científico que los de ingresos altos. Finalmente, encontramos que los países asiáticos se han beneficiado más de la producción académica en ingeniería que sus pares latinoamericanos.

JEL Code: O30, O47 C23
Keywords: Academic Research, Nonprofit Research, Economic Development, Economic Catch-up, Panel Data

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1. Introduction

It is widely accepted that technological change is a key factor behind economic development processes. However, there is less emphasis on the role of scientific knowledge. In fact, as technological change may stem from different sources and developing countries could borrow knowledge from abroad through different channels, it could be seemingly the case that the availability of domestic scientific capabilities is a factor of low importance for developing countries aiming to catch up with high income nations.

However, there are at least two reasons that could lead us to think that academic research could be relevant for developing countries: i) training on specific scientific skills or advanced scientific education could enrich human capital quality; ii) academic research, specially in science and engineering, could contribute not only to monitor and adapt foreign technologies, but also to create domestic innovation capabilities.

This paper aims to investigate the relationship between scientific knowledge production in universities and academic institutions and economic development. Following studies by Cohen *et al.* (2002), Mazzoleni and Nelson (2007) and Fagerberg and Srhole (2008), we argue that scientific performance could be considered as a manifestation of the improvements of the educational and technological capabilities within an economy. In this venue, Inglesi-Lotz and Pouris (2013) argue that academic research activities, including developing and learning new methods and technics, could enhance human capital. In turn, Kumar *et al.* (2016) and Solarin and Yen (2016) have shown that academic research publications have a positive effect on economic growth.

The impacts of scientific research could differ according to the stages of the economic development process in which each country is located. For instance, it could be argued that academic research could have a large impact for middle income economies who are struggling to catch up with the technological and production frontier insofar those countries have the challenge to strengthen their human capital and technological capabilities base.

For scientific research to have an impact on economic growth strong linkages among the organizations that are involved in the so-called “National Innovation System” (NIS) are also needed. The NIS comprises the network of public and private institutions, and the interactions among them, from which the capabilities to develop, import, modify and adopt new technologies emerge (Nelson, 1993; Lundvall, 1995; Freeman, 1995; Malerba, 2002; Edquist, 2005). In this regard, there is a wide literature comparing East Asian and Latin American NIS, suggesting that the former are more efficient and have contributed more to economic growth, in part because of the stronger networks of cooperation and interactions among the agents of the system vis a vis the Latin American cases (Lee and Kim; 2017).

With this background, our research aims at understanding the impacts of scientific knowledge production, and specially of engineering research, on economic development. Accordingly to the discussion above, we distinguish those impacts for high and middle income countries, and for two specific regions: East Asia and Latin America.

We use academic publications in refereed journals as a proxy of scientific knowledge production within a country. We conduct a comprehensive panel data analysis and we estimate two models: one based on the number of total and engineering scientific publications per capita and the other on the relative specialization of scientific research in the engineering field (measured as the proportion of engineering publications on the total number of academic publications).

The results show that scientific knowledge production is consistently and positively correlated with the level of income per capita, for both developed and developing countries. This finding goes in the same direction as those emerging from studies by Inglesi-Lotz and Pouris (2013), Kumar *et al.* (2016) and Solarin and Yen (2016), which find that scientific production has a positive effect on economic growth. Moreover, we find that both the number of academic publications and engineering publications per capita had a positive effect on economic development. We also find nonlinear effects, suggesting the presence of decreasing returns. However, these decreasing returns effects were much lower for developing countries than for developed countries. This means that economic catch-up in the developing world may be fostered by boosting scientific knowledge production in universities and academic institutions. However, after a turning point countries should also enhance other sources of economic development, such as scientific quality, patenting activities and/or institutional quality.

Moreover, specializing in engineering research is positively correlated with economic development for middle income countries but not for high income countries. Finally, Asian economies reaped higher benefits from scientific knowledge production than Latin American ones. This would suggest that even though complex knowledge production has positive effects on economic development in general, for these effects to be observed there is a need to foster interactive channels for knowledge transfer –as Asian countries did more efficiently than Latin American countries (Lee and Kim, 2018; Dahlman and Nelson, 1993; Albuquerque, 2001).

The work is structured as follows. The next section presents a brief literature review regarding the effects of scientific knowledge production on economic development. In section three we explain the data and methodology used. Section four shows the results of our estimations. Finally, section five concludes.

2. Scientific production and economic development

There is an extensive literature that discusses the impact of science and technology activities on economic development. This impact if channelled through a number of complex and dynamic processes, which involve a broad number of actors, and is heavily influenced by each countries' specific characteristics and capabilities.

The first approach to this subject, which was later on named as the "linear model", conceived the innovation process as a linear path from invention (which was the outcome of scientific research), to innovation (the first practical application of a new product or process) to diffusion (the dissemination of the new technologies throughout the economy and the society as a whole). Here there is a clear cut distinction between basic research (leading to discoveries and inventions) and applied research (leading to innovations). The larger the inputs applied to basic and applied research, the larger the outcomes obtained in terms of new technologies and hence economic development (see Kline and Rosenberg, 1986).

Later on an alternative model emerged, the so-called "interactive model of innovation" (Kline and Rosenberg, 1986). In this approach, the innovation process is characterized by the existence of continuous interactions and feedbacks between the different stages and activities that are involved in it, namely, the perception of a potential market and/or a technological opportunity, analytical design, tests and redesigns, production and marketing. Here the relationships between "science" and "technology" are two-way, with mutual feedback in the different stages of the innovation process.

Finally, within the realm of evolutionary economics, a more comprehensive analysis of the relations between innovation and development emerged under the "National Innovation System" concept. In this case the focus is on the set on public and private organizations which are involved and interact in the creation, diffusion and use of new and economically useful knowledge (Lundvall, 1992; Freeman, 1995; Malerba, 2002; Edquist, 2006).

Pari passu, there is an ever growing body of literature that shows that technological progress in developing countries, far from being a free ride phenomenon, requires, jointly with other complementary factors, the existence of a set of assets which are critical for monitoring, understanding, adopting, adapting and improving knowledge created abroad, and that may eventually lead to the development of capabilities for creating new knowledge (Fagerberg and Srholec, 2008). A large stream of theoretical and empirical studies have analysed the role played by "social" (Abramovitz, 1986), "absorptive" (Cohen and Levinthal, 1990) or "technological" (Kim, 1997; Archubugi and Coco; 2005) capabilities as key elements for economic development. Hence policies aimed at promoting economic development should foster the creation of indigenous technological and scientific capabilities (Dahlman and Nelson, 1995).

As discussed by Mazzoleni and Nelson (2007), the development of those capabilities at the firm and country level is to a large extent dependant on the existence of effective systems of scientific research and higher education. Hence, research institutions, specially public ones, as they are more prone to diffuse the results of their activities through academic publications and are closer to the higher education system, are highlighted by these authors as a key part of the institutional infrastructure required for catching up.

Apart from the creation of social, absorptive or technological capabilities, other authors, such as Jaffe (1989), find that knowledge production in universities has crucial spillover effects as they contribute to the generation of commercial innovations in the private sector. In the same venue, Mowery and Rosenberg (1979) highlight the role of "basic science" research as the main entrance to the development of networks of technological and scientific information. Some other studies focus on the linkages between public research institutions and private enterprises as the main source from where scientific and technical knowledge production done in universities would impact on innovation and economic productivity (Arza, 2010; Freitas *et al.*, 2013; Giuliani and Rabellotti, 2012).

Lee and Kim (2017) point out that the impacts of scientific and technological research on economic development could also be dependent on the orientation of science and technology policies. They show that East Asian countries chose a "technologically-oriented" approach, while Latin American countries policies were more "science-oriented". Thus, whereas the first bunch of policies is directly connected with the needs from the private sector, the last does not necessarily attend those concerns. This could help to understand the divergent innovative and economic performance between Asian and Latin American countries.

In turn, Albuquerque (2001) pinpoints the different roles of scientific production on technological progress. Scientific knowledge is: i) a source of technological opportunities; ii) a source of trained researchers; iii) key to the development of improved research techniques and of; iv) technical instruments, and; v) a main source of tacit and public knowledge. In the case of developing countries (characterized by less "mature" NIS), instead of being a direct source of technological opportunities, as it happens in high income countries, science production helps to identify opportunities generated abroad. Hence, the promotion academic research in developing countries could contribute to engage developing countries in international scientific and technological flows.

Finally, Inglesi-Lotz and Pouris (2013), and Solarin and Yen (2016) argue that local scientific knowledge production is crucial to enhance human capital within a country. In turn, Kumar *et al.* (2016) show that non-profit scientific research activities could boost countries' labour force potential and attractiveness for domestic and foreign investment of high tech companies.

3. Data and methodology

In order to test the effects of scientific knowledge production on economic development we built a number of different models and we run several regressions in order to check the robustness of our findings. As the results were consistent in all cases, we report here the results of the most representative estimations, but the estimations not reported in the paper are available at request from interested readers.

We measure scientific knowledge production in a country through the number of academic publications in refereed journals. For this purpose, we used data on the number of published academic articles provided by SCOPUS, the most authoritative international scientific database. SCOPUS also provides a classification of the scientific papers in different fields, from which we took the data of engineering publications. As mentioned above, we tested two different specifications, one base on the number of total and engineering scientific papers per capita and the other on the relative specialization of scientific production in engineering.

In both cases, our dependent variable is GDP per capita measured in purchasing power parity (constant 2011, in international $) as informed in the World Bank database. In the first model our independent variable is the logarithm of the per-capital total number of academic publications as well as the logarithm of the per capital number of engineering publications[2]. For the second model we ran the regressions considering the logarithm values of the proportion of engineering publications among the total number of academic publications.

Additionally, we have considered nonlinearities in the impact of knowledge production by including squared variables. We have also included interactive dummies for testing the impact of scientific research in medium income countries. Interactive dummies were also used in the second model for testing the different impact of engineering specialization in Asian and Latin American countries.

We have included different variables to control for the effects of other factors that could influence economic development, which are typically used in the current literature. Following Mankiw *et. al.* (1992) we employ secondary school enrolment (as informed by the World Bank database) as a proxy of human capital –a tertiary school enrolment variable is also introduced in our case. We also included the squared value of those variables to test for the presence of nonlinearities in the impact of human capital.

As a proxy for institutional quality (see Acemoglu and Robinson (2010)), we use data from the Freedom House database. In this case we expect the respective coefficient to be negative due to the ranking system adopted[3]. As in the case of human capital, we also included squared values to check for the existence of nonlinear effects. Finally, we included the logarithm value of total capital gross formation as a percentage of GDP (the data was taken from World Bank database).

Additionally we also control for the differential effect of the quality of scientific research using the number of citations per paper published in refereed journals, which was provided by SCOPUS. Finally, to report the specific impact of domestic technological capabilities we use the (per capita) number of patents granted to the residents of the countries included in our sample by the United States Patents and Trademarks Office (USPTO). In this case we also included an additional squared variable to analyse the presence of nonlinear effects from patenting activities.

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[2] As these two variables were highly correlated, we estimated the effect of these on economic development in different regressions.

[3] The ranking from Freedom House's database includes two types of countries' institutional system features: political rights and civil rights. In this ranking each characteristic is considered individually and scored from 1 to 7 –in decreasing order. Thus, by adding this two variables, countries could be scored from 2 to 14.

Table 1 summarizes the dependent and independent variables, its labels used and the respective data sources. Table A.1 of the Appendix displays the summary statistics.

Table1. Description and information sources

Variable	Label	Source
Per capita GDP in PPP (2011 international $)	log_GDP	WB database
Publication in all scientific areas in per capita values	log_pub_tot_percap	SCOPUS database
	sq_log_pub_tot_percap	SCOPUS database
Publications in engineering (per capita)	log_pub_eng_percap	SCOPUS database
	sq_log_pub_eng_percap	SCOPUS database
Engineering publications as a % of publications in all scientific areas	log_eng_spe	SCOPUS database
	sq_log_eng_spe	SCOPUS database
Patents in per capita values	log_patent_percap	USPTO database
	sq_log_patent_percap	USPTO database
Citations in refereed journals for all scientific areas in per capita values	log_cit_percap	SCOPUS database
Institutional quality	Sum	Freedom House database
	sq_sum	Freedom House database
School enrolment, secondary (% gross)	secu_enr	WB database
	sq_secu_enr	WB database
School enrolment, tertiary (% gross)	ter_enr	WB database
	sq_ter_enr	WB database
Gross capital formation as % of GDP	ln_gcap	WB database

We use data from 54 countries from 1996 to 2015. Countries were classified as high or medium income according to the classification of the World Bank database.

We have estimated the different models using fixed effects (FE). As a robustness check for the first model, we use dynamic panel data estimators –first-differenced GMM (Arellano and Bond, 1991) adjusted by heteroscedasticity, autocorrelation[4] and with the "collapse" method suggested by Roodman (2009)[5].

The advantage of FE regressions is that they account for countries fixed effects and provide a highly consistent estimator of the coefficients cleaned from the endogeneity problem[6]. On the other hand, the GMM estimation provides consistent estimators with the presence of a lagged dependent variable. In fact, as income per capital levels generally present serial correlation we consider relevant to include in our analysis this autoregressive model as a robustness check.

The genera structure of the estimated equations for our different models is as follows:

General Model

FE specification

$$\log\_GDP_{i,t} = \beta_0 + \beta_1 \log\_pub\_tot\_percap_{j,i,t} + \beta_2 sq\_\log\_pub\_tot\_percap_{j,i,t} + \rho\beta_1 + \tau\beta_2 + \gamma X_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \quad (1)$$

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[4] In particular, we run the GMM models with the "xtabond2" Stata command with the addition of "noleveleq" and "robust" commands for autocorrelation and heteroscedasticity adjustment. The "robust" command specifies the robust estimator of the covariance matrix of the parameter estimates. The resulting standard-error estimates are consistent in the presence of any pattern of heteroscedasticity and autocorrelation within panels. On the other hand, the "noleveleq" specifies that the levels equation should be excluded from the estimation, yielding difference rather than system GMM (StataCorp, 2015).

[5] The Roodman (2009) "collapse" method specifies that xtabond2 should create one instrument for each variable and lag distance, rather than one for each time period, variable, and lag distance. In large samples, collapse reduces statistical efficiency; but in small samples, it can avoid the bias that arises as the number of instruments climbs towards the number of observations (StataCorp, 2015).

[6] We have not included a lagged dependent variable for the fixed-effects regressions.

$$log\_GDP_{i,t} = \beta_0 + \beta_1 log\_pub\_eng\_percap_{j,i,t} + \beta_2 sq\_\log\_pub\_eng\_percap_{j,i,t} + \rho\beta_1 + \tau\beta_2 + \gamma X_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \quad (2)$$

GMM specification

$$log\_GDP_{i,t} = \beta_0 + \beta_1 log\_GDP_{i,t-1} + \beta_2 log\_pub\_tot\_percap_{j,i,t} + \beta_3 sq\_\log\_pub\_tot\_percap_{j,i,t} + \rho\beta_1 + \tau\beta_2 + \gamma X_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \quad (3)$$

$$log\_GDP_{i,t} = \beta_0 + \beta_1 log\_GDP_{i,t-1} + \beta_2 log\_pub\_eng\_percap_{j,i,t} + \beta_2 sq\_\log\_pub\_eng\_percap_{j,i,t} + \rho\beta_1 + \tau\beta_2 + \gamma X_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \quad (4)$$

Engineering Specialization Model

FE specification

$$\log\_GDP_{i,t} = \beta_0 + \beta_1 \log\_eng\_spe_{j,i,t} + \beta_2 sq\_\log\_eng\_spe_{j,i,t} + \rho\beta_1 + \tau\beta_2 + \gamma X_{i,t} + \alpha_i + \alpha_t + \varepsilon_{i,t} \quad (5)$$

The coefficients ρ and τ in all five equations are the interactive dummies for middle income countries.

In the first stage of our research, aimed at studying the effects of scientific knowledge production on economic development, we run equations (1) –where publications in all scientific areas are included- and (2) –where only engineering publications are considered- in three different steps. First, we conducted the analysis without dummies for middle income countries. Second, we interact the dummies for those countries with the coefficients that represent the linear and non linear effects of scientific production ($\rho\beta_1 + \tau\beta_2$). Third, we perform the same analysis excluding from the sample China and the US, which are the main producers of scientific research publications. In addition, we run equations (3) and (4) as an extra robustness check for the model. The same three steps were followed in the case of our *engineering specialization model* (equation (5).

In the second stage of this research, we deepen the analysis within the group of middle income countries. In particular, we focus on possible differences on the impacts of *engineering specialization* between Asia and Latin American countries. Thus, we run equation (5) including interactive dummies for these two regions.

Figure 1 illustrates the evolution of academic publications through 1996 to 2015. The box plot displays the distribution of the data in four quartiles. The upper and lower edges show the logarithm of the publications –for all areas in the left box and only in engineering in the right box- for the higher and lower percentile countries. In the boxes of the middle, we observe the two and third quartiles. The horizontal mark is the median value and the dots are the outliers. The illustration shows that for both, high income and middle income countries, academic publications have a growing trend, considering all scientific areas and only engineering publications as well. However, as expected, high income economies had a better academic performance through the whole period.

Figure 1 Evolution of academic publications per-capita (all areas and only engineering).

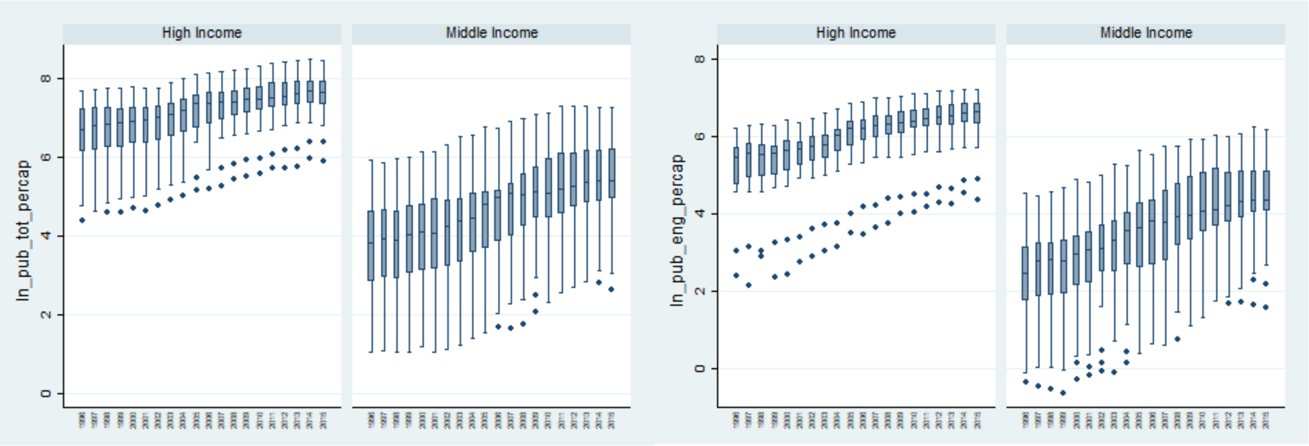
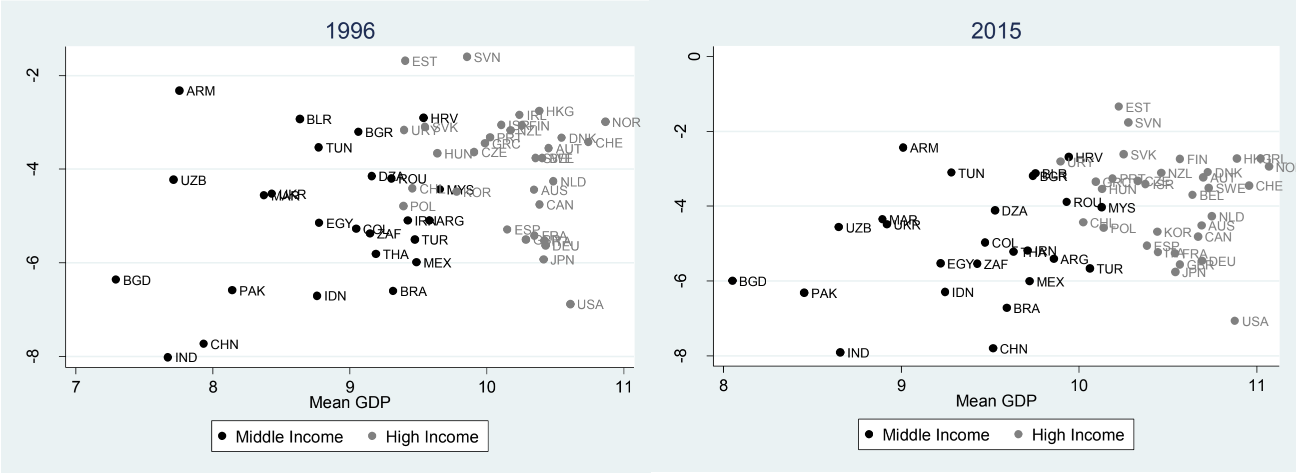


Figure 2 illustrates the relationship between a country specialization in engineering publications and its per-capita GDP for years 1996 and 2015. Middle income countries were painted in black, while high income countries in grey. All high income countries as well as East Asia economies are located in the upper right corner. By the contrary, poorest countries are located in the opposite corner.

Figure 2 Engineering specialization and GDP per-capita



4. Estimation results

In subsection 4.1 we present and discuss the effects of scientific knowledge production on economic development. In section 4.2 we deepen the analysis for the case of middle income countries.

4.1 Scientific knowledge production and economic development

Table 2 reports the results from the general model where all scientific areas are being considered.

Table 2. Results of the General Model for academic publication in all areas

VARIABLES	(A)	(B)	(C)	(D)

	FE – Basic model	FE – with middle income dummy	FE – with middle income dummy & without China and US	GMM – with middle income dummy & without China and US
ln_pub_tot_percap	0.323***	0.672***	0.701***	1.789**
	(0.0332)	(0.0966)	(0.0930)	(0.841)
sq_ ln_pub_tot_percap	-0.0313***	-0.0619***	-0.0633***	-0.123**
	(0.00301)	(0.00734)	(0.00708)	(0.0500)
1.middle_income#c. ln_pub_tot_percap		-0.451***	-0.501***	-1.619**
		(0.102)	(0.0981)	(0.716)
1.middle_income#c.sq_ ln_pub_tot_percap		0.0418***	0.0445***	0.104***
		(0.00788)	(0.00763)	(0.0382)
ln_gcap	0.139***	0.125***	0.126***	0.142***
	(0.0141)	(0.0140)	(0.0135)	(0.0116)
ln_cit_per_doc_tot	0.381***	0.347***	0.296***	0.0215
	(0.0234)	(0.0235)	(0.0240)	(0.0154)
Sum	-0.0425***	-0.0351***	-0.0465***	0.00327
	(0.0116)	(0.0119)	(0.0116)	(0.00674)
sq_sum	0.00401***	0.00358***	0.00431***	-0.000199
	(0.000788)	(0.000802)	(0.000783)	(0.000494)
ln_patent_percap	0.295***	0.358***	0.263***	0.0190
	(0.0392)	(0.0400)	(0.0400)	(0.0298)
sq_ln_patent_percap	0.00826***	0.0105***	0.00768***	0.000678
	(0.00139)	(0.00142)	(0.00141)	(0.000981)
sch_enr	0.00397**	0.00453***	0.00166	-0.000599
	(0.00174)	(0.00171)	(0.00168)	(0.00118)
sq_ sch_enr	-1.88e-05**	-2.13e-05***	-9.97e-06	2.26e-06
	(7.54e-06)	(7.39e-06)	(7.24e-06)	(4.85e-06)
se_ter_enrr	0.00516***	0.00329***	0.00241*	0.00158
	(0.00126)	(0.00127)	(0.00125)	(0.00138)
sq_se_ter_enrr	-3.05e-05***	-1.73e-05*	-8.93e-06	-9.75e-06
	(9.45e-06)	(9.54e-06)	(9.45e-06)	(1.32e-05)
L.ln_pbi_percap				0.593***
				(0.165)
Constant	9.382***	9.475***	9.073***	
	(0.264)	(0.351)	(0.344)	
Observations	970	970	931	809
R-squared	0.830	0.838	0.829	
Number of countries	56	56	54	54
Year	YES	YES	YES	YES
AR1				0.378
AR2				0.448
Sargan				0.843
Country				54
Intruments				48
Hansen				

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

First, results from Table 2 show that scientific knowledge production is consistently and positively correlated with economic development. This relationship emerges in all the specifications: the basic FE estimation, the FE estimation with dummies for middle income countries, excluding China and the US from the sample and from the estimation obtained by using the GMM methodology. Second, in all specifications scientific knowledge production shows nonlinear effects, which could be representing decreasing returns of research on economic development. In other words, countries in early stages of scientific knowledge production, which have a low number of per capita publications, would reap higher benefits from improving their academic research performance.

Third, there are consistent differences between high income and middle income countries regarding the effects of scientific production on economic development. Equations (B), (C) and (D) show that even though scientific knowledge production has a positive effect for middle income countries, these countries have lower decreasing returns. This means that economic catch-up in the developing world may be fostered by boosting scientific knowledge production in universities and academic institutions.

Finally, all the variables included to control for the effects of other factors that could impact economic development performance show the expected signs. In addition, we find that the per capita number of patents and institutional quality variable have nonlinear effects on economic development (except in the case of the GMM estimation).

Table 3 reports the results from the general model where only engineering publications are being considered.

Table 3. Results of the General Model for academic publication in engineering

VARIABLES	(A) FE – Basic model	(B) FE – with middle income dummy	(C) FE – with middle income dummy & without China and US	(D) GMM – with middle income dummy & without China and US
ln_eng	0.112***	0.240***	0.249***	0.452**
	(0.0219)	(0.0539)	(0.0516)	(0.176)
sq_eng	-0.0155***	-0.0327***	-0.0330***	-0.0372***
	(0.00225)	(0.00491)	(0.00472)	(0.0129)
1.middle_income#c.ln_pub_eng_percap		-0.171***	-0.161***	-0.348**
		(0.0556)	(0.0533)	(0.158)
1.middle_income#c.sq_pub_eng_percap		0.0255***	0.0228***	0.0301**
		(0.00532)	(0.00512)	(0.0137)
ln_gcap	0.149***	0.130***	0.127***	0.126***
	(0.0145)	(0.0144)	(0.0138)	(0.0122)
ln_cit_per_doc_tot	0.360***	0.326***	0.280***	0.0430**
	(0.0250)	(0.0247)	(0.0250)	(0.0187)
sum	-0.0274**	-0.0292**	-0.0453***	-0.000604
	(0.0119)	(0.0120)	(0.0117)	(0.00551)
sq_sum	0.00303***	0.00323***	0.00426***	0.000127
	(0.000809)	(0.000816)	(0.000796)	(0.000393)
ln_patent_percap	0.219***	0.311***	0.234***	0.0403*
	(0.0400)	(0.0411)	(0.0404)	(0.0227)
sq_ln_patent_percap	0.00532***	0.00866***	0.00649***	0.00135*
	(0.00141)	(0.00145)	(0.00142)	(0.000778)
sch_enr	0.00672***	0.00629***	0.00236	-0.00169
	(0.00181)	(0.00178)	(0.00176)	(0.00118)
sq_ sch_enr	-2.97e-05***	-2.87e-05***	-1.32e-05*	6.48e-06
	(7.83e-06)	(7.69e-06)	(7.54e-06)	(4.87e-06)
se_ter_enrr	0.00619***	0.00351***	0.00250*	-0.000814
	(0.00129)	(0.00131)	(0.00129)	(0.00125)
sq_se_ter_enrr	-4.08e-05***	-2.09e-05**	-1.06e-05	9.71e-06
	(9.72e-06)	(9.84e-06)	(9.71e-06)	(1.04e-05)
L.ln_pbi_percap				0.540***
				(0.170)
Constant	9.319***	10.08***	9.884***	
	(0.284)	(0.327)	(0.318)	
Observations	970	970	931	809
R-squared	0.819	0.830	0.822	
Number of countries	56	56	54	54
Year	YES	YES	YES	YES
AR1				0.197
AR2				0.606
Sargan				0.755
Country				54
Intruments				48
Hansen				

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Both developed and developing countries reap positive effects from promoting engineering scientific activities. Again, we find that these effects are nonlinear, suggesting the presence of decreasing returns. We also find in this case that middle income countries have lower decreasing returns in relation to high income countries. The control variables have the expected signs and the nonlinear effects highlighted in the previous model are also present here.

In order to learn about the total effect of scientific knowledge production on GDP per capita we need to add both linear and non-linear effects. Doing the partial derivatives in equations (1) and (2), we get the following equations:

$$\beta_1 + \beta_2 * 2 * \log\_pub\_tot\_percap_{j,i,t} \qquad (6)$$

$$\beta_1 + \beta_2 * 2 * \log\_pub\_eng\_percap_{j,i,t} \qquad (7)$$

By using β_1 and β_2 from Table 2, Figure 3 shows the marginal effect for the general model for academic publication in all areas, where Figure 3A shows the shape from equation (6) for country's total number of publications in mean value and Figure 3B shows the curve shape from equation (1) by using again the mean value for each country total number of publications. Meanwhile, by using β_1 and β_2 from Table 3, Figure 4 shows this same effect but for the general model for academic publications in engineering areas, where 4A and 4B follow the same scheme from 3A and 3B. To see if there is a "catching up" effect, we split this total β value for high and middle income countries.

Figure 3. Linear and non-linear effect for academic publication in all areas on per capita GDP.

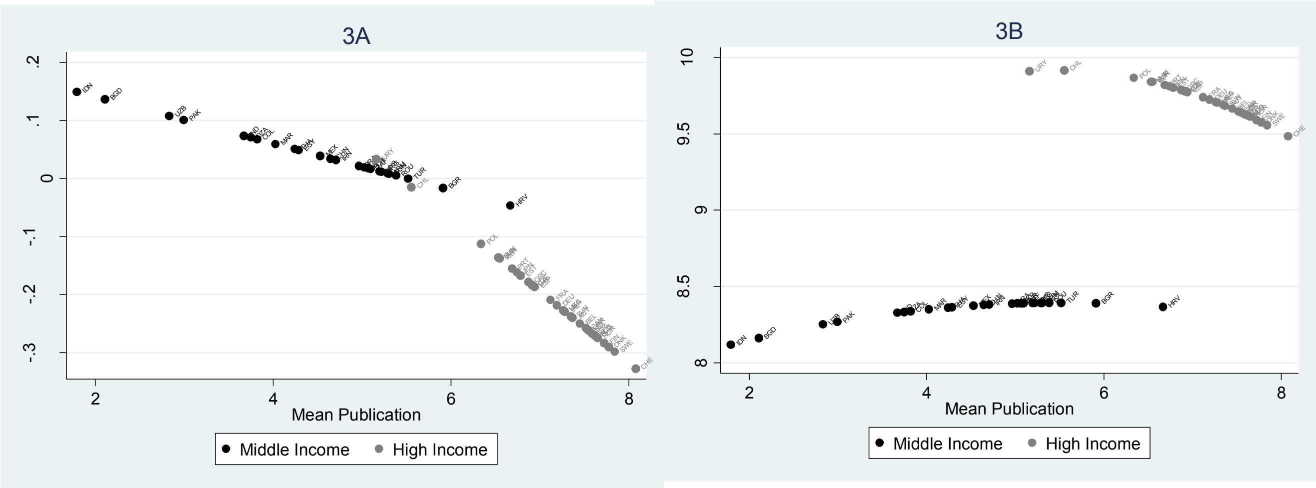
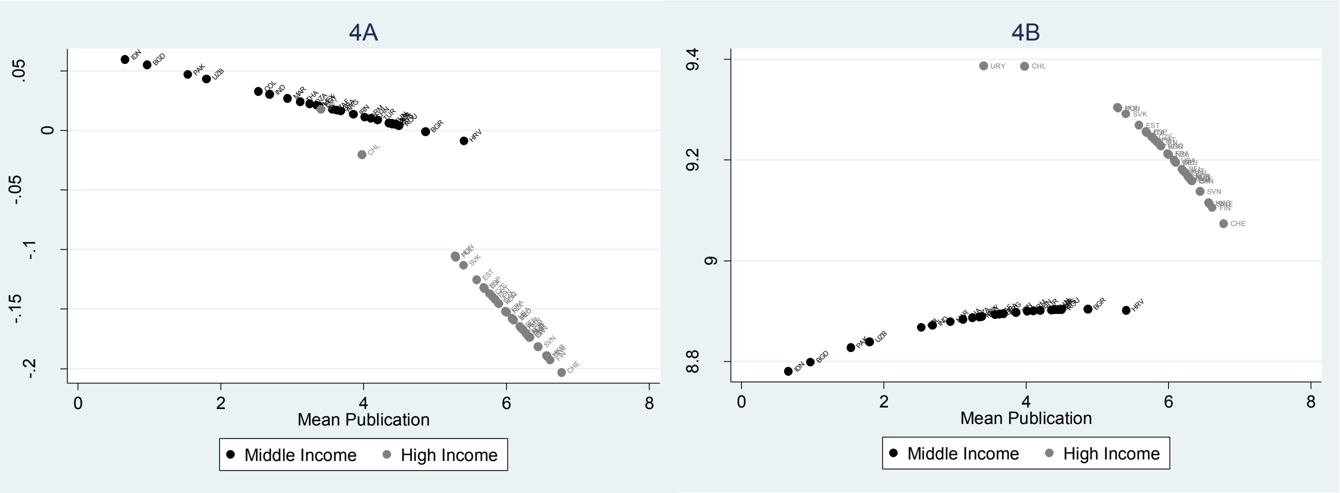


Figure 4. Linear and non-linear effects of academic publication in all areas on per capita GDP



Hence, Figures 3A and 4A show the marginal effect from scientific knowledge production on per capita GDP –considering both all areas and only engineering areas-. These graphs show that there are decreasing returns, as it was previously said, but they are lower in middle income countries. Likewise, being a country with a high average of per capita publications tends to reduce the impact on per capita GDP. Indeed, mostly all high income countries have a negative marginal effect from increasing the number of per capita publications. The results of our estimations show that for these countries there are other factors that may have a positive effect on growth, such as increasing patenting activity or the quality of scientific publications (measured by the citations of academic papers).

In turn, middle income countries, which have a relatively weak academic performance and therefore a low publication average, would face positive effects on per capita GDP by only increasing their publications (both in all areas as well as in engineering). However, those countries within this group with higher average publications face a similar situation than high income countries (i.e. after some level positive effects on economic development dwindle). This situation is also illustrated in figures 3B and 4B. In both cases it is shown that the effect from publication activity takes the typical decreasing returns inverted U-shape.

Our results go in the same direction as Mazzoleni and Nelson (2007), who argue that at the first stages of the economic development process scientific research institutions are vital as institutional infrastructure for building indigenous technological capabilities. However, the contribution of scientific research tends to vanish as countries make progress in their income levels and other factors, such as increasing the quality of scientific research or improving the technological performance become more relevant.

4.2 Differences within middle income countries from scientific knowledge production

In Table 4 we show the results of the estimations based on the percentage of engineering publications over the total number of publication from all scientific areas (what we call the “engineering specialization” model).

Table 4. Results of Engineering Specialization Model

VARIABLES	(A) FE – Basic model	(B) FE – with middle income dummy	(C) FE – with middle income dummy & without China

			and US
log_ eng_spe	0.379***	-0.0795	-0.0191
	(0.114)	(0.174)	(0.170)
sq_log_ eng_spe	0.187***	0.0159	0.0329
	(0.0427)	(0.0607)	(0.0591)
1.middle_income#c.ln_ eng_spe		0.986***	0.675***
		(0.238)	(0.238)
1.middle_income#c.sq_ln_ eng_spe		0.397***	0.258***
		(0.0908)	(0.0913)
ln_gcap	0.170***	0.165***	0.163***
	(0.0144)	(0.0144)	(0.0140)
ln_cit_per_doc_tot	0.320***	0.336***	0.291***
	(0.0258)	(0.0259)	(0.0266)
Sum	-0.0245**	-0.0288**	-0.0432***
	(0.0118)	(0.0118)	(0.0117)
sq_sum	0.00284***	0.00317***	0.00410***
	(0.000801)	(0.000803)	(0.000797)
ln_patent_percap	0.0709**	0.0532	-0.0117
	(0.0344)	(0.0352)	(0.0354)
sq_ln_patent_percap	0.000332	-0.000167	-0.00202
	(0.00121)	(0.00124)	(0.00124)
sch_enr	0.0103***	0.0105***	0.00660***
	(0.00174)	(0.00181)	(0.00182)
sq_ sch_enr	-4.37e-05***	-4.46e-05***	-2.91e-05***
	(7.62e-06)	(7.82e-06)	(7.83e-06)
se_ter_enrr	0.00627***	0.00589***	0.00478***
	(0.00126)	(0.00125)	(0.00125)
sq_se_ter_enrr	-4.30e-05***	-3.98e-05***	-2.96e-05***
	(9.54e-06)	(9.48e-06)	(9.54e-06)
Constant	8.446***	8.224***	8.141***
	(0.246)	(0.254)	(0.249)
Observations	970	970	931
R-squared	0.815	0.819	0.804
Number of country	56	56	54
Year	YES	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Regression (A) shows a significate and positive effect from the specialization in engineering on per capita GDP. The non-linear effects are also positive, suggesting that, differently from the evidence of previous models, we are in presence of increasing returns from specializing in engineering. However, when we include the interactive dummies for middle income countries, the abovementioned effect only remains for that group of countries. This means that middle income countries are the only group which profit from being specialized in engineering publications. As the nonlinear coefficient is significant and positive, boosting the specialization on engineering publications would lead to increasing returns.

Finally, we perform an additional regression by distinguishing the impact of engineering specialization in Asian and Latin American countries, following the arguments of Lee and Kim (2017) discussed above. Thus, we run equation (5) with interactive dummies for these two regions (results are shown in Table 6).

Table 5. Results within middle income countries for the Engineering Specialization Model

VARIABLES	(B) FE – with regional dummies	(C) FE – with regional dummies & without China and US
log_ eng_spe	0.157	0.252
	(0.181)	(0.178)

sq_ log_ eng_spe	0.145*	0.175**
	(0.0747)	(0.0734)
1.as#c.ln_ing_wei	1.358***	0.936***
	(0.251)	(0.259)
1.la#c.ln_ing_wei	-0.577	-0.518
	(0.378)	(0.369)
1.as#c.sq_ln_ing_wei	0.434***	0.261**
	(0.102)	(0.105)
1.la#c.sq_ln_ing_wei	-0.233*	-0.223*
	(0.127)	(0.124)
ln_gcap	00.165***	0.163***
	(0.0139)	(0.0136)
ln_cit_per_doc_tot	0.333***	0.293***
	(0.0250)	(0.0257)
sum	-0.0333***	-0.0469***
	(0.0115)	(0.0115)
sq_sum	0.00331***	0.00420***
	(0.000774)	(0.000772)
ln_patent_percap	0.106***	0.0362
	(0.0341)	(0.0346)
sq_ln_patent_percap	0.00186	-0.000207
	(0.00121)	(0.00122)
secu	0.00844***	0.00500***
	(0.00174)	(0.00175)
sq_secu	-3.61e-05***	-2.25e-05***
	(7.57e-06)	(7.59e-06)
se_ter_enrr	0.00640***	0.00521***
	(0.00123)	(0.00124)
sq_se_ter_enrr	-4.21e-05***	-3.15e-05***
	(9.32e-06)	(9.44e-06)
Constant	8.671***	8.564***
	(0.259)	(0.255)
Observations	970	931
R-squared	0.830	0.814
Number of countries	56	54
Year	YES	YES

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results show that only Asian countries experiment positive effects from the specialization on engineering knowledge production. Positive nonlinear effects also appear for these countries, suggesting that this specialization shows increasing returns. These differences suggest that only fostering academic research in engineering is not enough for economic development objectives, and the need of complementary assets and policies aimed at facilitating and promoting the use of scientific knowledge for innovation purposes.

5. Conclusions and final remarks

Our results show that scientific knowledge production is positively correlated with economic development, confirming arguments advanced by Mazzoleni and Nelson (2007) and Fagerberg and Srhole (2008). Academic research activities are a key element for economic development specifically at early stages, as it contributes not only to improve the capacity to monitor, adopt and adapt foreign knowledge, but also to generate new products or production methods. Moreover, as the specific kind of scientific knowledge production that we have considered mostly takes place in universities and public research institutions, it also plays a fundamental role to enrich human capital, beyond generating knowledge spillovers that may diffuse throughout the economy as a whole.

In particular, promoting engineering research activities could have a positive impact for middle income countries. We also find nonlinear effects of academic progress, meaning that there is a turning point after which the positive effects from increasing the number of academic publications decline. For this reason, only countries that have relatively low scientific activities could enhance their economic performance by just fostering academic activities. Thus, high income countries as well as some middle income countries should also focus on improving other areas also related to economic development, for example scientific knowledge quality –measured by article citations-.

We also show that that some developing regions have been taking more advantages from scientific production. Confirming the findings of different previous studies, the impacts of academic research outputs, now focused on engineering, are stronger in Asia than in Latin America. This highlights the need of fostering linkages between scientific research institutions and public and private organizations developing applied technological activities, as well as of enjoying key complementary assets that are required for improving the technological performance of a country (Lee and Kim (2017).

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7. Appendix

Table A.1. Statistics Summary

Lable	Obs	Mean	Std. Dev.	Min	Max
log_GDP	1140	9,805271	0,811353	7,293635	11,08342
log_pub_tot_percap	1140	5,952834	1,659057	1,03308	8,482294
sq_log_pub_tot_percap	1140	38,18629	17,86204	1,067253	71,94931
log_pub_eng_percap	1140	4,821942	1,670563	-0,6399983	7,233358
sq_log_pub_eng_percap	1140	26,03945	14,07947	0,0003993	52,32147
log_eng_spe	1140	-1,179689	0,3087695	-2,469914	-0,4152459
sq_log_eng_spe	1140	1,48692	0,7327622	0,1724291	6,100474
log_patent_percap	1107	-11,56034	2,877836	-18,82917	-6,969033
sq_log_patent_percap	1107	141,916	69,46106	48,56742	354,5377
log_cit_percap	1140	2,666027	0,6549532	0,2623643	3,78009
Sum	1120	4,85625	3,55524	2	14
sq_sum	1120	36,21161	49,60699	4	196
schol_enr	1140	94,68976	22,03006	22,85859	166,8085
sq_schol_enr	1140	9451,048	4110,221	522,5151	27825,07
ter_enr	1140	49,19552	23,691	2,73015	113,8718
sq_ter_enr	1011	3081,455	2382,134	7,453719	12966,78
ln_gcap	1140	3,162431	0,2669844	-1,208503	3,925708

Table A.2. List of countries

High income countries		Middle income countries	
Australia	Italy	Algeria	Iran
Austria	Japan	Argentina	Malaysia
Belgium	Netherlands	Armenia	Mexico
Canada	New Zealand	Bangladesh	Morocco
Chile	Norway	Belarus	Pakistan
Czech Republic	Poland	Brazil	Romania
Denmark	Portugal	Bulgaria	South Africa
Estonia	Slovakia	China	Thailand
Finland	Slovenia	Colombia	Tunisia
France	South Korea	Croatia	Turkey
Germany	Spain	Egypt	Ukraine
Greece	Sweden	India	Uzbekistan
Hong Kong	Switzerland	Indonesia	
Hungary	United Kingdom		
Ireland	United States		
Israel	Uruguay		

Note: World Bank classification