When Size Matters: Trends in Innovation and Patents in Latin American Universities

Luis Fernando Ramirez-Hernandez[1], Jairo Guillermo Isaza-Castro[2]*

Abstract: This paper characterizes the trends in technological innovation and intellectual property in four Latin American countries (Chile, Colombia, Mexico, and Peru). Toward this aim, we collected a database of patents granted at the national and university levels in combination with information from a variety of sources to construct a set of plausible explanatory variables. Based on panel data at the national level, we verify that the number of patents granted to universities is strongly associated with the share of resources, as a percentage of GDP, invested in science and technology. At the university level, we find that institutions with more scientific publications and larger enrolment size tend to be granted more innovation patents. To some extent, the evidence presented in this paper indicates that both the absolute and relative sizes of resources invested in scientific and technological research at the university level are subject to economies of scale: a greater amount of resources invested in technological research is associated with increasing levels of innovation and patenting activity.

Keywords: innovation; patents; R&D policy; universities; Latin America

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1. Introduction

A political concern in the agenda for governments and universities alike has been the relationship between science and technology and the corresponding link between universities and industries. Globally, as a key element of their institutional missions, universities search to find the most efficient way to transfer the outcomes of their research to society and to industries. One important basis of this concern is the 1945 Bush Report called: *Science, The Endless Frontier*. The basic principle of the report is that discoveries resulting from research through technology transfer must support economic development and social welfare. Technology licensing, patents, and publications in high-impact journals are materialization of such transfer.

The linear model of innovation was the first analytical framework to explain the relationship between science and technology (Godin, 2006). This model proposes that innovation begins with basic research, continues with applied research, and ends with production and transference. To support the final stage at the policy level, efforts to diffuse and commercialize the innovation outcomes of scientific research have been supported at the legislative level in many countries (Bradley, Hayter & Link, 2013). In the United States, the Bayh–Dole Act of 1980 allowed universities to retain intellectual property and to appropriate the proceeds of licenses from patents obtained through federal research funding (Fish, Hassel, Sander & Block, 2015). European and East Asian nations have emulated the US by enacting domestic legislation specifying that intellectual property be privileged at the institutional level; this is evident in Finland, Germany, Spain, the UK, Korea, and Singapore, among others (Geuna & Rossi, 2011).

Hayter and Rooksby (2016) recently stated that research on technology transfer has now broadened its field of action generating links to the theory of economic development and providing a vision of growth and prosperity related to the creation, diffusion, and marketing of new knowledge. The impact of this new knowledge depends on its ability to flow within societies, fostering social and economic development.

According to Rodeiro, Lopez, Otero and Sandias (2010), there is a wide range of possibilities for interaction between universities' science and technology output and industries, including entrepreneurship, recruitment of graduates, technology diffusion and transfer, specialized consulting, collaborative projects, the use of patents and licenses, and the creation of spin-off companies. In this regard, the study on university technology transfer elaborated by Bradley et al. (2013) found universities' interest in obtaining patents has grown rapidly in the last decade; there has been a significant increase in licensing activities and the creation of university spin-off companies, both inside and outside the United States.

Much of the literature has emphasized the transfer of innovation and technology from the university sector to the rest of the economy in the industrialized world. This topic has received less attention regarding developing countries, particularly in Latin America. Consequently, the purpose of this paper is to answer two questions. First, to what extent can the amount of resources invested in research and development by the innovation systems at the national level be associated to technology transfer activity as measured by the number of patents granted to universities? Second, what is the relationship between the technology transfer from universities to society in terms of granted patents to both their enrolment size and their scientific publications? We aim to answer these questions with an empirical application based on quantitative data from four Latin American countries: Chile, Colombia, Mexico, and Peru. For this aim, we assembled a database of granted patents at the national and university levels in combination with information from a variety of sources to construct a set of plausible explanatory variables. Based on panel data at the national level, we verify that the number of patents granted to universities is strongly associated with the share of resources as a percentage of GDP invested

1) CENTRUM Graduate Business School, Pontificia Universidad Católica del Perú. Alamos de Monterrico, Lima, Perú. 110231, (51)1-6267100.
2) Facultad de Ciencias Económicas y Sociales, Universidad de La Salle, Colombia. Carrera 5 No. 59-91, Bogotá, Colombia.
*Corresponding author: a20165447@pucp.edu.pe

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in science and technology. At the university level, we find that those universities with more scientific publications and higher enrolment size tend to obtain more granted innovation patents. To some extent, the evidence presented in this paper indicates that both the absolute and relative size of the resources invested in scientific and technological research are subject to scale economies whereby a larger size of resources invested in technological research is associated with an increasingly larger innovation and patenting.

The rest of this paper is organized as follows. Section II presents a literature review, which includes a theoretical framework for the study, a review of the innovation systems in Latin America, and a review of previous research in the field of patents and innovation. The third section explains the data sources for the data presented in this paper. Section IV displays the statistical and econometric results and discusses them in the light of the existing literature. Finally, the fifth section makes a summary of the findings and puts forward some limitations and considerations for further research.

2. Literature Review

2.1 Theoretical Framework of the Study

From a theoretical perspective, Audretsch (2014) presents an interesting review of how and why the role of the university in society has evolved over time, arguing that the forces shaping economic growth have influenced the corresponding role of the university. He stated, "As the economy has evolved from being driven by physical capital to knowledge, and then again, to being driven by entrepreneurship, the role of the university has evolved over time" (p. 313).

In this sense, he makes a comparison between the influences of the so-called Solow economy (popularized by Robert Solow) and the Romer economy (introduced by Paul Romer). The Solow model puts "emphasis on physical capital and unskilled labor as the twin factors shaping economic performance. Despite the preeminent contributions to social and political values, the economic contribution of universities [is] modest" (Audretsch, 2014, p. 315). Meanwhile, in the Romer economy, knowledge is considered particularly potent as a driver of economic growth. Audretsch states, "As the Romer economy replaced the Solow economy, a new role for the university emerged, as an important source of economic knowledge" (Audretsch, 2014, p. 316).

In a related stream of research, Kesan (2015) examined several theories that explain and justify the role of patents in today's knowledge-based, technology-intensive economy, stating, "patents reduce transaction costs, help convert inventions into transferable assets, promote disclosure, provide a system of certification and standardization, and allow greater divisibility of technology" (p. 903). In relation to the marketing of innovations, Kesan (2015) assured, "All of these functions make transactions in the marketplace for inventions more efficient, to the benefit of both inventors and consumers" (p. 903). In this context, acquiring patents helps a university bring in revenue, and allows for technology transfer offices and corporate firms interested in commercializing innovations to be connected to the universities through industrial property.

These theoretical approximations indicate that universities' scientific and technological development is a source of economic growth through offering new technologies to the market and providing basic support to nations' innovation systems. In sum, the university today has a role that goes beyond teaching and involves the transference of research knowledge to society.

2.2 Innovation Systems in Latin America

In the last decade, innovation has gained increasing importance in Latin America. Most of the countries in the region now have national strategies for innovation and have created governing institutions for this purpose. While these countries have accumulated experience in designing innovation policies, they still sometimes struggle to articulate industrial policies and domestic production from the generation of scientific knowledge and technological capabilities (Primi, 2014).

When the concept of National Systems of Innovation (NIS) gained importance in the region in the mid-1990s, the main concern was how to articulate cooperation between the public sector and the private sector to boost efforts of science and technology (Edquist & Hommen, 1999; Lundvall, 1992; Nelson, 1993). At the time, most countries suffered from a lack of industrial transformation and limited development of technological capabilities. This was due to the growing specialization that guided nations' development models according to the comparative advantages they exhibited for international trade.

A national innovation system can be described as the flow of technology and information among the actors of the system—companies, universities, and government—that generates processes of innovation at national level (Russo-Spena, Tregua & Bifulco, 2017). In the case of Latin American countries, this concept has been used to design policies and instruments to establish organizational infrastructures to facilitate the connections between the different actors, to promote knowledge networks that generate innovation at the firm level. National innovation systems, therefore, define the basic conditions for this research, like mechanisms for protecting inventions, incentives for promoting scientific research, mechanisms for financing projects, conditions for licensing of patents, and aligning universities and businesses for innovation.

However, other innovation scholars have identified different contexts to conceptualize national innovation systems. Specifically, they refer innovation by clusters, regions, and within technological areas, rather than by a national system (Russo-Spena, *et al.*, 2017).

Later, toward the middle of the 2000s, along with an increase in the prices of commodities worldwide, new financial opportunities emerged for countries in Latin America, sparking a relaunch in public policies for innovation. At that time, innovation policies redirected emphasis on (i) sectorial differentiation, (ii) the generation of incentives for science and technology, and (iii) the definition of new priorities for social and territorial inclusion and environmental sustainability (Primi, 2014).

Latin American institutions have different policies in relation to the governance of innovation policies. Developments in the four countries in this study are as follows. In Chile, the Ministry of Science, Technology, Knowledge and Innovation was created in 2018; it reports directly to the Presidency of the Republic. In Colombia, the agency responsible for innovation is Colciencias, which in 2009 was declared an autonomous department and was recently elevated to the Ministry of Science, Technology and Innovation, which begin operation in 2020. In Mexico, the agency in charge is the CONACYT, which reports to the Ministry of Economy. In Peru there are two entities, CONCYTEC, which depends on the Ministry of Education, and the National Council for Competitiveness, which reports to the Ministry of Economy and Finance.

Each country differs in the magnitude of resources applied to the promotion of innovation and in the way that the resources are assigned. However, for all Latin American countries, progress has been made in at least three areas: (i) institutional strengthening, with the creation of bodies charged with guiding the innovation policy with sufficient autonomy and capabilities, (ii) new funding sources for innovation programs through the collection of royalties for the production of commodities and through the establishment of sectorial funds for technological development, and (iii) improvements in the legal framework for innovation, through the establishment of clear policies on industrial property, and the simplification of procedures for access to resources and the promotion of technology-based companies (OECD, 2016)

Finally, from an analysis of the innovation systems in Latin America, it can be concluded that they have the following features in common:

- Almost all of them have an overarching plan for science, technology, and innovation that identifies the challenges and goals, establishes programs, and defines the plans of action.

- The programs tend to be similar in terms of priority areas (nanotechnology, biotechnology, alternative energies, health, and agricultural production).

- Most countries today have a territorial perspective in their national innovation strategies. In the case of Chile, Colombia, and Peru, this perspective is closely related to the funding structures from taxes associated with the exploitation of natural resources, where territorial authorities have great influence on the allocation of resources for science, technology, and innovation.

It is undeniable that the governments of the region have improved policies for innovation, especially in the last decade. Today, institutions are empowered, available budgets have been increased to finance programs for innovation, and regulatory frameworks support industrial property and encourage the creation of companies based on innovation. An adequate alignment of innovation policies with efforts for productive transformation will generate new development opportunities for these countries in the immediate future.

2.3. Previous Research

An industrial property is the legal framework that protects the interests of innovators, giving them rights over their creations. This legislation is part of the wider body of law known as intellectual property (IP) (WIPO, 2016). These rights confer to the inventor(s) an exclusive monopoly on exploitation, after completing some formalities. Patents of invention intended to protect innovations of a technical nature fit in this category.

In this sense, Savescu (2017) stated, “Industrial property rights are outlined in Article 27 of the Universal Declaration of Human Rights, which states that everyone should enjoy the protection of moral and material interests resulted from any scientific, literary or artistic production of which is the author” (p. 136). An efficient patent system contributes to the stimulation of innovation, because is a condition for economic growth, through the design and implementation of new products.

On the 30th anniversary of the enactment of the Bayh–Dole Act in the US, Grimaldi, Kenney, Siegel, and Wright (2011), considered the rationale for academic entrepreneurship and described the evolving role of universities in the commercialization of research. They considered that the Act “was both an outcome of and response to the changing climate, by enhancing incentives for firms and universities to commercialize university-based technologies. Specifically, the legislation instituted a uniform patent policy across federal agencies and removed many restrictions on licensing” (p. 1046). Several European (Wright et al., 2008) and Asian (Kodama, 2008) countries adopted similar legislation (Grimaldi et al., 2011).

In a similar vein, Drivas, Economidou, Karamanis, and Zank (2016) conducted a study to determine whether university patents are licensed over their enforceable lifecycle and at what point in time the licensing occurs. Based on an analysis of over 20,000 university patents granted between 1990 and 2000, they stated that since the Bayh–Dole Act was enacted, “most research universities have established their own Offices of Technology Transfer to undertake these commercialization and patent monetization activities. These academic technology transfer entities use a wide range of exclusive and non-exclusive licensing agreements to monetize the IP they own.” (p. 46).

Using an external change in German Federal law Czarnitzki, Doherr, Hussinger, Schliessler, and Toole (2016) examined how entrepreneurial support and the ownership of patent rights influence academic entrepreneurship. They carried out a study on the impact of the Federal Government regulations in Germany since 2002, following the objectives of the US Bayh–Dole Act. The German reform called Knowledge Creates Markets generates subsidies, supports technology transfer, and assigns patent rights that result from university inventions from the individual level to the university level. An empirical analysis showed a strong relationship between patents and the creation of university companies. The evidence then suggests the existence of a high dependence on academic entrepreneurship regarding industrial protection granted by patents.

Fisch, Hassel, Sandner, and Block (2015) conducted a research from an international perspective, examining patents at the top 300 universities worldwide from 32 different countries, indicating a predominance of US universities. They found that "18 of the top 25 universities are located in the US, with the Massachusetts Institute of Technology ranked as first" (p. 318). They concluded that the propensity to apply for patents is very high in universities in the US and Asia; comparatively, it is lower in European universities. Their international comparison shows profound differences between countries that equally affect licensing, the creation of university spin-offs and other technology transfer mechanisms.

Additionally, Chang (2017) employed a two-mode network analysis method (using countries and fields of technology) to highlight the pivotal role of various countries in technology networks. He found that "the key technologies in the more recent UIC (University-Industry collaboration) technology network were largely in the fields of measurement and chemistry, which are characterized as basic sciences with cross-disciplinary traits" (p. 107).

Chang concluded, "Patents directly reflect innovative output. Therefore, they can serve as an indicator for measuring national technology output. The country-technology network analysis results revealed that Japan and the United Stated played crucial roles in the UIC technology network" (Chang, 2017, p. 107).

As demonstrated, the emergence of the Bayh–Dole Act in the U.S marked a milestone in the granting of university patents. This act generates an environment conducive to research and the commercialization of the results. The legal protection offered to the innovations encourages more university research and the transfer of the results to society.

For Latin America countries, Sargent and Matthews (2014) examined the efforts of elite universities in Chile, Mexico, and Brazil to transfer faculty inventions to the marketplace. Based on statistical information about patents filing, they found, for this sample, that a "significant percentage of the new knowledge produced by researchers employed at universities has commercial value. Universities can take this knowledge, file for patents or other forms of IP protection, and then license the IP to existing or spinout companies" (p. 169).

These authors recognized that there are clearly weaknesses in the Latin American NIS. However, "in cities such as Sao Paulo, Campinas, Santiago, and Monterrey, elite universities have established well designed systems to both create and commercialize knowledge in S&T fields. In general these initiatives have significant financial support from state and federal governments" (Sargent and Matthews, 2014, p. 184). They recommended exploring how legal barriers in Latin America affect the evolution of licensing efforts and university spin-offs, and analyzing the support received by the industry in the success or failure of university commercialization systems.

For its part, the recent study prepared by Fischer, Schaeffer, Vonortas, & Queiroz (2018), empirically assesses the extent to which institutional openness in universities toward UIC linkages affect the generation of knowledge-intensive spin-offs and academic patenting activity in the context of the State of Sao Paulo, Brazil. They concluded that in terms of science and technology policy, it is necessary to promote deeper linkages between companies and universities, saying "a stronger coordination between industrial policy, regulation of the competitive environment and the institutional framework of UIC is needed to build an environment conducive to the deep links we are discussing" (p. 280).

In a similar way, a study by Guerrero, and Urbano (2017) tried to provide a better understanding of the influence of Triple Helix agents on the performance of entrepreneurial innovations in emerging economies. They analyzed the effects on innovation performance resulting from the links of enterprises with other enterprises, with universities, and with government. The study concluded that it is necessary in these countries to reinforce both the innovation system and the entrepreneurial ecosystem.

On the other hand, Jefferson, Maida, Farkas, Alandete-Saez, and Bennett, (2017) focused on comparing the structure and operation of programs for IP management and technology transfer, and the mechanisms through entrepreneurship is fostered in five high-profile research institutions across the Americas. Their study, based on five universities in three countries found that there were "common goals and core activities, shared and implemented in similar ways among all five institutions. However, some divergent areas within the structure and operation of the technology transfer and entrepreneurial support programs […] represented significant differences between the five institutions" (p. 1307).

Finally, in relation to the business models that can be derived from the Intellectual Property of the innovations, a good part of the universities have chosen to establish Technology Transfer Offices (TTO), which are responsible for the orientation of the mechanisms for the commercialization of patents. Some studies suggest (Siegel & Wright, 2015) that different types of business models applied by universities can be associated with the characteristics of their corporate governance and this directly influences the ability of TTOs to achieve their objectives. In addition, the longitudinal study conducted at 60 US universities by Baglieri, Baldi and Tucci (2018) found that "business models that leverage high-quality research (ie, catalyst) and startup creation (ie, orchestrator of local buzz) are associated with higher economic performance" (p. 51). Therefore, the way technology transfer is guided is key for value creation and rent capture, according to the university strategic goals.

3. Data Sources

To achieve a better understanding of the dynamics of university patenting in Latin America, we carried out a comparative analysis based on the number of patents granted to universities from four Latin American countries: Chile, Colombia, Mexico, and Peru. These countries are the signatories of the Pacific Alliance (Alianza del Pacífico), a regional integration initiative to promote economic and social development in the region, and are where countries innovation activities have gained importance in recent years (OECD, 2014).

The information for the present analysis comes from secondary sources through the consultation and systematization of public data that are available in electronic databases held by national agencies in the field of IP. These institutions are as follows: the Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); and the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe). For each of them, information was collected regarding invention patents granted to universities from these countries over the period of 2008 to 2017.

Given that this work seeks to correlate the conditions of the innovation systems with the evolution of granted patents, we gathered information related to the total amount of resources invested in research and development as a percentage of GDP. For this purpose, we consulted the annual reports of the Global Innovation Index Database (www.globalinnovationindex.org). In addition, we consulted information from UNESCO's Science, Technology and Innovation database to identify the capacity to mobilize resources for innovation activities in each one of the four selected countries. To control for the overall level of economic development in each country, we gathered information on the national GDP per capita at purchasing power parity (PPP) at constant prices for 2011 expressed in US dollars from the World Bank's World Development Indicators database.

Because one of the two central questions of this study aims to correlate the institutional capabilities of universities with obtaining patents, we collected information for a sample of 165 higher education institutions that have received patents in the period of the study. To have an indicator of the production of knowledge derived from research in each university, we found the number of scientific publications registered on two platforms, Scopus® and Web of Science® -WOS, between 2013 and 2017. To identify the size of each institution as a proxy of its capacity to mobilize resources over the same years, we compiled information about the number of students enrolled by consulting the Statistical Yearbooks in the Ministries of Higher Education of each country. Similarly, in order to control for the research institutional capacity, we collected the number of researchers with a PhD degree for a subsample of the universities available at QS University Rankings database.

This entire battery of information was used to organize the descriptive statistics and perform the econometric analyses, whose results are presented below.

4. Descriptive Statistics and the Results

4.1 Descriptive Statistics

Table 1 presents some descriptive statistics on innovation outcomes in the four countries in this study: Chile, Colombia, Mexico, and Peru. Clearly, Mexico reports the highest average number of patents granted per year (69) from 2008 to 2017; this is more than twice the average for Chile and more than three times the average for Colombia. At the other extreme, Peru averages only nine patents per year. These results are somewhat correlated with the average expenditure of R&D as a percentage of GDP. Mexico reports the highest average value (0.52%), which is more than double the average for Colombia and Peru and 1.4 times that observed for Chile. Although GDP per capita in Chile is nearly double that of Colombia and Peru, the size of the Mexican economy and its R&D expenditure might entail some advantages in terms of scale economies that could explain its superior performance in terms of patents granted.

The superior performance of Mexico over the other three countries deserves some qualification. In absolute terms, Mexico's average budget in R&D is 7.6 times that reported in both Chile and Colombia and 34 times that of Peru. Although such a level of expenditure should entail some scale economies in terms of technological research and development for Mexico, it is in Chile where the expenditure in R&D is the most effective in materializing innovation patents between 2008 and 2017. Every registered patent in that country required an average investment of US $1.25 million dollars over this period, a figure that is just 43% the average for Mexico, 46% that of Colombia, and 33% that of Peru. However, variations in the required investments in R&D might be quite diverse across scientific fields or economic sectors and our data lacks the required details to disentangle the nature of such differences.

Table 1. Descriptive statistics on innovation trends in Chile, Colombia, Mexico, and Peru (average values for 2008–2017)

Average values	(1) Colombia	(2) Chile	(3) Mexico	(4) Peru
Number of granted patents to Universities	20.7	29.3	68.6	8.7
	(6.4)	(4.7)	(12.3)	(3.8)
GDP per capita at constant prices of 2011	11,977	21,088	16,412	10,905
	(333)	(506)	(209)	(345)
R&D expenditure % of GDP	0.24	0.37	0.52	0.09
	(0.01)	(0.01)	(0.01)	(0.01)
Observations	10	10	10	10

Source: own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); and the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe).

In Table 2, we report some additional descriptive statistics based on a database of 165 universities from the four countries selected for this study. The averages displayed in Table 2 show the (arithmetic) annual average of the total number of granted patents, enrolment and publications reported by each university in the sample over the period 2013-2017. For instance, the table indicates that each one of the 39 Chilean universities included in the sample reported an average of 0.94 granted patents per year between 2013-2017. According to these statistics, Mexico not only reports the highest number of universities in the sample but also records the highest average annual number of granted patents per university over 2013 to 2017. The scale effects mentioned above in relation to Mexico could be explained at least in part, by the larger size of the universities in this country, with an average enrolment of 28.4 thousand students per institution, which is 1.3 times higher that Peru and about 1.8 times higher than Chile and Colombia.

The same figures reveal that both Chilean and Mexican universities report a similar average number of scientific publications per institution in Scopus (with 359 and 354 publications, respectively) for 2013 to 2017, while Colombian universities report about half of that average and Peruvian schools, one fourth. With the smallest visible sample, Peruvian universities were able to obtain an average of 0.76 granted patents per institution, not far from their Chilean counterparts (0.94) and above the average for the Colombian ones (0.60) although such differences are not statistically significant.

Table 2. Innovation statistics in universities from Chile, Colombia, Mexico, and Peru (average annual values per university for 2013–2017)

VARIABLES	(1) Chile	(2) Colombia	(3) Mexico	(4) Peru
patents	0.95	0.60	1.70	0.76
	(0.19)	(0.10)	(0.33)	(0.25)
enrollment	15,609	16,124	28,438	22,131
	(697)	(589)	(2,012)	(1,585)
Publications in Scopus	359	177	354	83
	(41)	(21)	(51)	(12)
Publications in WOS	270	110	257	52
	(31)	(13)	(37)	(7)
Observations	195	255	290	85

Source: own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe); Scopus® and, Web of Science® -WOS.

4.2. Econometric Results

Table 3 displays the results of a preliminary econometric analysis of panel data for the four countries included in this study over the period 2008 to 2017. Given the limited number of ($i \times t = 10 \times 4=$) observations, only 40, for this stage of research, it is necessary to interpret these results with caution. In this analysis, the dependent variable is the natural log of the annual number of registered patents in each one of the four countries. As explanatory variables, we have the natural logarithm of GDP per person at PPP values (*lnpibpc*) and the overall expenditure of the country in R&D as a percentage of GDP (*gerddelpib*). Other variables, such as the number of researchers per million people in the country and FDI as a percentage of GDP were not statistically significant and, therefore, were excluded from the results presented here.

The results in Table 3 display different estimation techniques: ordinary least squares (*OLS*), random effects (*RE*), fixed effects (*FE*), fixed effects with robust standard errors (*FE_robust*), and FE with cluster-robust standard errors (*FE_cluster_robust*). According to the results of a Hausman type test for fixed versus random effects, there is strong evidence to reject the null hypothesis of non-systematic differences between coefficients from these two models. Therefore, we conclude that the appropriate estimator is the fixed effects model.[1] For this reason, we further elaborate on the fixed effects results and display alternative estimates of the standard errors for this model in columns (4) and (5) to control for either general serial autocorrelation or country (cluster) specific autocorrelation of the error term.[2] According to these results, we validate, under all five specifications, a positive relationship between a country's GDP per capita and its number of registered patents annually. Such a relationship is statistically significant at the 1% level under the FE specification with uncorrected standard errors (see column 3 in Table 9); however, its precision diminishes to 10% significance with robust standard errors (in columns 4 and 5). Given the small

[1] The test yields a Chi-squared statistic = 50.08 with an associated p-value = 0.000. We computed the Hausman test in Stata 13.0 with the Hausman command.

[2] The robust standard errors and the cluster-robust standard errors implemented in this application are a generalization of White's (1980) procedure for the estimation of the robust covariance matrix with panel data. Chapters 8 and 9 on Cameron and Trivedi (2009) provide an overview of procedures to obtain robust standard errors, which are serially correlated in the context of panel data.

number of observations for each combination of year and country, this loss of precision is not a surprising result. We also verify a positive relationship between public expenditure as a percentage of GDP and the log of annual number of registered patents, with the same loss of precision when adjusted robust standard errors are applied.

Table 3. Regression coefficients from panel data models for the (log) number of granted university patents in Chile, Colombia, Mexico, and Peru (2008–2017)

Variables	**(1)** **OLS**	**(2)** **RE**	**(3)** **FE**	**(4)** **FE_robust**	**(5)** **FE_cluster_robust**
lnpibpc	0.7461	0.7461	5.1505***	5.1505*	5.1505*
	(0.5396)	(0.5396)	(1.8470)	(2.0279)	(2.0279)
gerddelpib	7.0357***	7.0357***	12.5595***	12.5595*	12.5595*
	(1.2849)	(1.2849)	(4.1936)	(5.0382)	(5.0382)
Constant	−6.6985	−6.6985	−51.7167***	−51.7167*	−51.7167*
	(5.0525)	(5.0525)	(16.9170)	(20.5518)	(20.5518)
Observations	40	40	40	40	40
R-squared	0.5757		0.6334	0.6334	0.6334
Number of countries		4	4	4	4

Own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); and the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe). Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

Given the small number of observations in the models just discussed above, we implemented an alternative approach based on a sample of 165 universities in the four countries. We initially gathered data on the annual number of patents granted, the number of scientific publications in both Scopus and WOS and the enrolment size.[3] Table 4 displays the results of panel data coefficients for $i = 165$ universities and $t = 2013$ to 2017. All variables in this analysis are expressed in logs. The results on the top of the table three columns, numbered from 1 to 3, include all regressors for OLS, fixed effects and, random effects. The results in the middle part of the table, numbered from 4 to 6, only control the number of papers using data from WOS in addition to the enrollment size. Lastly, the results in columns 7 to 9 display the number of published papers in Scopus with the enrollment size. All standard errors are robust to serial autocorrelation within universities.

[3] We are grateful for a comment from one of the referees in which it was suggested to include the number of published papers from WOS. It was very satisfying to see that the results obtained from this variable corroborate those derived from the number of papers published in Scopus.

Table 4. Regression coefficients from panel data models between the annual number of granted university patents in Chile, Colombia, Mexico, and Peru, and their number of publications in Scopus and WOS, and the enrollment size, 2013–2017

Variables (All)	**(1)**	**(2)**	**(3)**
	OLS	**Fixed Effects**	**Random Effects**
ln_enrollment	0.1257**	0.1407	0.1472***
	(0.0505)	(0.1333)	(0.0527)
ln_publications	0.1383***	0.0100	0.0792***
	(0.0376)	(0.0218)	(0.0276)
ln_wos	0.0181	0.0472*	0.0407**
	(0.0178)	(0.0263)	(0.0193)
Constant	-1.6840***	-1.3627	-1.7109***
	(0.5329)	(1.2789)	(0.5321)
Observations	825	825	825
R-squared	0.2603	0.0152	
Number of institution		165	165
Variables (only WOS)	**(4)**	**(5)**	**(6)**
	OLS	**Fixed Effects**	**Random Effects**
ln_enrollment	0.1584***	0.1450	0.1745***
	(0.0563)	(0.1367)	(0.0592)
ln_wos	0.1114***	0.0511**	0.0833***
	(0.0216)	(0.0224)	(0.0171)
Constant	-1.7370***	-1.3733	-1.7814***
	(0.5561)	(1.2907)	(0.5637)
Observations	825	825	825
R-squared	0.2355	0.0151	
Number of institution		165	165
Variables (only Scopus)	(7)	(8)	(9)
	OLS	Fixed Effects	Random Effects
ln_enrollment	0.1265**	0.1656	0.1528***
	(0.0508)	(0.1327)	(0.0536)
ln_publications	0.1573***	0.0509**	0.1194***
	(0.0311)	(0.0213)	(0.0242)
Constant	-1.7063***	-1.6021	-1.7875***
	(0.5301)	(1.2756)	(0.5364)
Observations	825	825	825
R-squared	0.2597	0.0110	
Number of institution		165	165

Own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe); Scopus® and, Web of Science® -WOS. Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

The results in Table 4 point to a positive relationship between the size of the institution, measured by the (log) of total enrolment (including undergraduate and postgraduate students), although the significance of the coefficient for this variable is statistically insignificant for this regressor under the fixed effects estimator in all cases. On average and ceteris paribus, the elasticity of the number granted patents with respect to the enrollment size ranges from 0,12 to 0,18.

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The same results point towards a positive and statistically significant relationship between the (log) number of registered patents by a university and the (log) number of scientific publications either in Scopus or in WOS. The elasticity coefficients tend to be less statistically significant, particularly in the case of the fixed effects estimator, when they are included jointly. When included separately, these two variables are statistically significant under all specifications with point estimates ranging from 0,5 to 0,15, on average and ceteris paribus. It is worth to mention that fixed effects estimates for this variable tend to be smaller and, comparatively, less significant than those from pooled OLS and random effects.

According to the results from a robust Hausman test based on a method developed by Wooldridge (2002) for fixed versus random effects models with cluster-robust standard errors, we find sound evidence in favor of the fixed effects model when the variable for the number of published papers is obtained from Scopus.[4] When we use the number of published papers in WOS, the same test does not allow to reject the null hypothesis of differences in coefficients and, therefore, the random effects model could be appropriate.[5]

The random effects model is attractive from an analytical point of view given the fact that this estimator allows to identify the effect of time-invariant regressors such as country effects and the public/private nature of university institutions. Based on this intuition, we further advance the analysis to explore the possible effects of time-invariant regressors: (4-1=), three dummies for Chile, Mexico, and Peru (we leave Colombia as the base category) and a control for public/private universities. We also include the (log) number of enrolled students (in thousands) and the (log) number of published papers in WOS. These results are displayed in Table 5 under two specifications, OLS and RE, both with clustered-robust standard errors.

According to these results, country-specific effects, as well as the private/public nature of the universities, are not statistically significant.[6] As such, these results also confirm that both the enrolment size and the scientific output (measured by the number of publications in WOS) are positively correlated to the annual number of registered patents by universities in the four selected countries of this study. All of this indicates that the relationship between the specific characteristics of an institution and its innovation activity at the university level is of a complex nature. A specific country environment does not emerge as a differentiating factor in determining the innovation activity of universities in Colombia, Chile, Mexico, and Peru, nor the private/public nature. This also suggests that other institutional, managerial or regional factors play a significant role in universities' performance of technological innovation and, probably, justify a qualitative approach to further investigate the behavior of university innovation.

Table 5. Relationship between the annual (log) number of granted university patents in universities from Chile, Colombia, Mexico, and Peru and their (log) number of publications in Scopus and WOS, with dummies for country location and public/private origin, 2013–2017

Variables	(1) OLS_ROB	(2) RE_ROB
ln_publications	0.1762***	0.1272***
	(0.0338)	(0.0256)
ln_enrolment	0.1099**	0.1455***
	(0.0488)	(0.0525)
Chile	−0.0782	−0.0424
	(0.0735)	(0.0733)
Mexico	0.0913	0.0900
	(0.0866)	(0.0873)
Peru	0.1388	0.0940
	(0.1071)	(0.1052)
public_uni	−0.0711	−0.0474
	(0.0742)	(0.0730)
Constant	−1.6252***	−1.7605***
	(0.5164)	(0.5325)
Observations	825	825
R-squared	0.2726	
Number of institutions		165

Own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe); Scopus® and, Web of Science® -WOS. Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1.

[4] The conventional Hausman test requires that the random effects estimator is efficient, an invalid assumption under cluster-robust standard errors. To overcome this difficulty, we implemented in Stata 13.0 a robust version of the Hausman test proposed in Cameron and Trivedi (2009: 261-262) based on a Wald test developed by Wooldridge (2002), which is asymptotically equivalent to the conventional test when the random effects model is fully efficient. The test yields an estimated F-statistic (with 2 and 820 degrees of freedom) =3.55 and an associated p-value= 0.0292; this suggest that differences in the coefficients from fixed and random effects models are systematic. The result of this test is conclusive at the 5% level (but not at the 1%) against the random effects model.

[5] In this case, the estimated F-statistic (with 2 and 820 degrees of freedom) is 2,47 with a probability value of 0,0855, indicating that the null hypothesis of systematic differences in coefficients cannot be rejected by the data at hand.

[6] We obtained a similar result when the log number of published papers in WOS is replaced with the number of papers included in Scopus. However, as explained in the previous footnote, when the log number of papers in Scopus is included in the specification, the random effects model is inappropriate and that is why we prefer not to include it in the table.

Finally, we expand the analysis by including the (log) number of research staff with a PhD, an additional variable which was only available for a subsample of 93 university institutions in 2016 and 2017 in the QS Universities' Database.[7] With such data, we estimated five different comparable models that are displayed in Table 6 where column 1 presents OLS estimates, columns 2 and 3 feature fixed and random effects, respectively, and column 5 shows random effects estimates with dummy variables.

Table 6. Relationship between the annual (log) number of granted university patents in universities from Chile, Colombia, Mexico, and Peru and their (log) number of publications (Scopus and WOS), (log) number of researchers with PhD degrees and with dummies for country location and public/private origin, 2013–2017

VARIABLES	(1) OLS_ROB	(2) FE_ROB	(3) RE_ROB	(4) RE_ROB
ln_enrollment	0.2594**	-0.1708	0.2459**	0.2407**
	(0.1012)	(0.9110)	(0.0971)	(0.1123)
ln_publications	0.2874***	0.1964	0.2761***	0.2560**
	(0.0964)	(0.1489)	(0.0819)	(0.1029)
ln_wos	-0.0355	-0.0898	-0.0351	0.0068
	(0.0783)	(0.1319)	(0.0648)	(0.0785)
ln_staff_phd	0.2469*	0.1255	0.2620**	0.2332*
	(0.1438)	(0.1825)	(0.1158)	(0.1201)
dummy_chl				-0.0621
				(0.2187)
dummy_mx				-0.0591
				(0.2019)
dummy_pe				0.1309
				(0.2629)
public_uni				-0.1187
				(0.1525)
Constant	-4.4394***	0.9731	-4.3143***	-4.1615***
	(1.0702)	(8.8633)	(1.0172)	(1.1319)
Observations	170	170	170	170
R-squared	0.3789	0.0076		
Number of institution		93	93	93

Own estimates based on OECD (2014), Instituto Nacional de Propiedad Industrial de Chile (INAPI) (www.inapi.cl); the Superintendencia de Industria y Comercio de Colombia (SIC) (www.sic.gov.co); the Instituto Mexicano de Propiedad Industrial (IMPI) (www.impi.gob.mx); the Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual de Peru (INDECOPI) (www.indecopi.gob.pe); Scopus®, Web of Science® -WOS and QS World University Rankings (https://www.topuniversities.com). Standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

According to these results, the fixed effects estimates (in column 2) perform poorly as all its coefficients are statistically insignificant and some are even negative. Such a result could be explained, at least in part, by the substantial reduction of the sample size. Conversely, results from the RE model corroborate the statistical significance of all continuous regressors, except in the case of the (log) number of papers published in WOS. The elasticity coefficients for the (log) enrollment size are statistically significant at the one percent level ranging from 0,241 to 0,251 while the (log) number of publications fluctuates between 0,256 and 0,287.

The same results suggest a positive relationship between the (log) number of granted patents and the (log) number of research staff with a PhD degree with an elasticity of 0,262 in the case of the random effects model, a result that is statistically significant at the five percent. With the inclusion of time-invariant regressors, this coefficient decreases in terms of both size and statistical significance at the 10 percent level. Again, the coefficients for the time-invariant regressors reflecting both the country-specific effects and the public/private nature of institutions are not statistically different from cero. To some extent, the limited number of observations for the number of PhD

[7] For more information about this database, see: https://www.topuniversities.com -retrieved: 28 October 2019. We are also grateful for the suggestion from one of the referees to include the number of researchers with PhD as an additional regressor.

entails limitations to present comparable evidence of its effects on the innovation performance in the universities of these four countries. Nonetheless, these results are indicative of the importance of having qualified research staff in the technological innovation performance of universities in the four selected countries of this study.

5. Final Remarks

In the regressions at the country level, we verify a positive relationship between a countries's GDP per capita and its annual number of registered patents. We also verify a positive association between public expenditure as a percentage of GDP and the (log of) the annual number of registered patents. This evidence suggests that the amount of resources invested in research and development at the national level is strongly associated with the performance of innovation systems, measured by the number of patents granted. This evidence is in line with the related literature in this field (see: Ho, Liu, Lu, & Hang, 2014; Hsu, Shen, Yuan, & Chou, 2015; Drivas, et al., 2016). Another related finding is that the level of economic development, measured by the GDP per capita, is an important determinant of the performance of the innovation systems at the national level (Rasmussen, Mosey, & Wright, 2014; Calcagnini, & Favaretto, 2016; Chang, 2017; Guerrero, & Urbano, 2017). Although there are limitations based on the number of observations reported in this four-country study, these results are coherent with the relevant literature in this field.

Looking at university-specific data in the four countries for 2013–2017, we corroborate a relationship of technology transfer from universities to society in terms of granted patents with both enrollment size and scientific publications. We find a positive statistically significant relationship between the (log) number of registered patents at the university level and the (log) number of scientific publications in Scopus. This result was confirmed using WOS as an alternative source of information for the number of scientific papers published annually at the university institutions level. Such a conclusion corroborates the findings in a number of related studies in this field (Hsu, & Ken, 2014; Thompson, Ziedonis, & Mowery, 2016). The same data suggests that larger universities are able to generate larger numbers of registered patents; this suggests the possibility that larger institutions are able to afford certain types of research infrastructure such as specialized laboratories and related facilities that endow them with higher innovation performance (Ho et al., 2014; Moutinho, Au-Yong-Oliveira, Coelho, & Manso, 2016; Cantu-Ortiz, Galeano, Mora-Castro, & Fangmeyer, 2017). The inclusion of the number of research staff with PhD as an additional regressor further confirms that universities with larger research teams tend to produce more granted patents. This line of analysis points to the presence of both scale economies and institutional capacities at play in the generation of technological innovation in the universities of the four countries reviewed in this study. Interestingly, the public/private nature of the university and their country location do not emerge as relevant factors in the determination of innovation performance.

The findings reported so far point to the relevance of investing resources at the national level to achieve higher levels of innovation patents. This coincides with Number Nine of the Sustainable Development Goals set by the United Nations, which seeks to increase the public and private research and development spending (UNDP, 2017). This conclusion is also valid at the university level, where the scientific output of published papers in peer-reviewed journals (measured by publications in both Scopus and WOS) appears to be a significant factor related to the production of scientific innovation. There is also a positive association between both the enrolment size and the number of PhD researchers of a university, on the one hand, and its innovation output, on the other, as measured by the number of registered patents. This again suggests that the size of an institution is a relevant factor in the generation of scientific innovations. Certainly, universities' infrastructure in terms of laboratories, highly trained scientific human resources and related facilities can be more affordable with a large number of students. This could be a possible limitation for small universities where economies of scale do not allow expensive investments in R&D. A way out in this case could be an association among several smaller universities around common scientific innovation agendas in which the pooling of economic resources and scientific capabilities enable the economies of scale to reach higher levels of scientific innovation. Such association among universities could be highly relevant at the regional level for developing countries where infrastructure and scientific expertise are scarce resources.

This present study could be further advanced in several ways. One limitation relates to the number of countries included in the analysis. The collection of data for four countries was certainly a challenging task but we believe that a similar effort with an increase in sample size would certainly enhance the capacity to generalize the conclusions, as well as the recommendations, presented here. Moreover, the measurement of a university's variables related to its innovation capacity, such as the number of published papers and number of researchers in different areas of knowledge, would enable the elaboration of more refined conclusions for innovation policy in the higher education sector. A similar remark applies to other variables related to the production function of university innovation, such as the resources and infrastructure devoted to R&D. We were unable to differentiate between the numbers of scientific patents in different areas of knowledge in which the production function for each of them could be subject of a high degree of heterogeneity. For instance, the infrastructure requirements in diverse fields of knowledge could be highly differentiated; this is an unaccounted factor in this research that could be addressed in the future in discipline-specific studies of innovation for relevant sectors in emerging-market economies such as biotechnology, medicine, agricultural production, and alternative energies.

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