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SCIENTIFIC CAPACITY AND INDUSTRIAL DEVELOPMENT AS LOCOMOTORS OF INTERNATIONAL COMPETITIVENESS IN LATIN AMERICA

Jesús PEÑA-VINCES [1*], Diego SANCHEZ-ANCOCHEA [2], Jorge GUILLEN [3], Luis F. AGUADO [4]

[1]*Department of Business Management, Faculty of Economics and Business, Universidad de Sevilla, Sevilla, Spain*
[2]*Department of International Development, University of Oxford, Oxford, UK*
[3]*ESAN Graduate School of Business, Lima, Perú*
[4]*Department of Economics, Faculty of Business and Economics Sciences, Pontificia Universidad Javeriana, Seccional Cali, Cali, Colombia*

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Abstract. Different bodies of literature emphasise the separate impact of the manufacturing sector and scientific capacity for competitiveness in developing countries. Scientific knowledge can increase productivity and promote innovation, while the manufacturing sector creates spillovers and generates processes of learning-by-doing. Yet, do these two processes complement each other? Do they, together, contribute to even higher international competitiveness? This paper explores these questions, drawing on an eleven-years panel data set for ten South American economies. We develop a moderation hypothesis model based on the congruence between science, industry, and international competitiveness. Our results support our hypothesis that scientific capacity and manufacturing development have a joint impact on international competitiveness that goes beyond their marginal effects and thus calls for future efforts to implement industrial policy.

Keywords: scientific capacity, manufacturing sector, international competitiveness, industrial policy, Latin America.

JEL Classification: O14, O25, O3, O43, L16, F13.

Introduction

How can countries promote sustainable economic growth and higher international competitiveness? A large body of empirical literature highlights the role of scientific capabilities (Audretsch, Hülsbeck, & Lehmann, 2011; Guerrero, Cunningham, & Urbano, 2015; Moaniba, Su, & Lee, 2018) and calls for higher investment in research and development (R&D). Other

*Corresponding author. E-mail: *jesuspvinces@us.es*

authors have emphasised the potential contribution of the manufacturing sector, given its capacity to create more linkages and less volatile demand than other economic activities like agriculture mining (Hall & Lee, 2008; Parteka & Tamberi, 2013; Rehner, Baeza, & Barton, 2014). In the Latin American context, the lack of scientific and manufacturing development has been identified as a significant constraint on economic growth, particularly after the end of the commodity boom (ECLAC, 2016).

Which of those two variables (i.e., scientific capabilities and manufacturing development) is more important? Are they related to each other? This paper tackles these questions through panel data for ten South American economies (see countries list in Table 1). We combine descriptive statistics and a Hayes' Process Method OLS (Hayes, 2013) to explore the relationship between manufacture expansion, scientific capabilities, and international competitiveness. Our study shows a clear connexion amongst the three. More significantly, we find that manufacturing production and scientific capabilities reinforce each other in a virtuous circle. Countries with a higher manufacturing sector that also invest in research and scientific development have more positive effects than those that focus on just one of the two areas.

Our findings have significant policy and analytical implications. Analytically, we show the need to combine the literature on scientific knowledge and industrial policy better. Investment in R&D often takes place in specific sectors of the economy, and we need a better understanding of which sectors can create more virtuous circles and why. Surprisingly, until now few studies have explored the interaction between scientific knowledge and sectoral development, and we show why this gap is problematic–at least in the South American context. In terms of policy, our study is relevant for future development policy in South America and other parts of the developing world. During the last fifteen years, several South American countries used the income generated by the commodity boom to launch new scientific initiatives. Examples include Ecuador with its program to promote science (Prometeo, 2015), Peru's Cienciactiva (Cienciactiva, 2014), Chile's Explora (Explora, 2015), and Brazil's Ciencia sem Fronteiras (Science without Borders, 2015). Most of these programs aimed to create science and technology parks and attract and retain young talent. Yet these efforts were not accompanied by the diversification of the economic structure or the expansion of the manufacturing sector (Martínez Franzoni & Sánchez-Ancochea, 2014). Quite the contrary, primary specialisation increased across the board, thus failing to create the type of virtuous interaction that we found. Our findings also raise some significant questions and open up future research agendas, which we will discuss with detail in our conclusion.

This paper is composed of five sections. The first section addresses the literature review on the topic and develops our conceptual framework. Section 2 defines the key variables and explains how we measure them. Section 3 describes the data, illustrating South America's weaknesses in science and manufacturing as well as regional diversity. Section 4 presents the methodology for the econometric analysis and shows the results. In section 5, we conclude with a set of policy implications and questions for further research.

1. Literature review-conceptual framework

1.1. Scientific capabilities, manufacturing development, and international competitiveness

How can developing countries promote international competitiveness, understood as sustained economic growth, export upgrading and employment growth (Castro-Gonzáles, Peña-Vinces, & Guillen, 2016; Krugman, 1994)? A considerable body of literature emphasises the role of scientific capabilities in promoting international competitiveness (An & Iyigun, 2004; Barge-Gil & Modrego, 2009; Czinkota & Pinkwart, 2012; Mok & Kan, 2013). An effective innovation system can create new opportunities for economic growth and productive upgrading (Cooke, 1992; Czinkota & Pinkwart, 2012; Moaniba et al., 2018; Mok & Kan, 2013; Yaşar & Paul, 2011). Such a system requires an expansion in the number of well-trained researchers and scientists (Bodas Freitas, Marques, & Silva, 2013; Cheung, T. W. W. Yuen, C. Y. M. Yuen, & Cheng, 2011; Peña-Vinces & Urbano, 2014), many of which may be attracted from other regions (Furukawa, Shirakawa, & Okuwada, 2012; Kafouros, Wang, Piperopoulos, & Zhang, 2015; Leten, Landoni, & Van Looy, 2014; Tzeng, 2011). In the same line, Guerrero et al. (2015) suggest that the impact of science on the economy is maximised when universities are capable of generating, attracting, and retaining prestigious researchers.

When evaluating the scientific level of a country, we must take into account the three roles that universities and research centres play (Castro-Gonzáles, Peña-Vinces, Sosa-Varela, & Ruiz-Torres, 2014; Czinkota & Pinkwart, 2012; Kafouros et al., 2015; Leten et al., 2014; Tzeng, 2011). Firstly, they educate and train individuals in areas that are vital for R&D, including natural sciences and engineering (Cooke, 1992; Teixeira & Queirós, 2016). Secondly, they generate new scientific knowledge that might have business applications (Leten et al., 2014; Liyanage & Mitchell, 1994). Third, they produce scientific articles and other outputs (Czinkota & Pinkwart, 2012; Furukawa et al., 2012; Leten et al., 2014). Upgrading a country's scientific knowledge also demands an expansion in the number of researchers working in R&D (Audretsch et al., 2011; Mok & Kan, 2013; Tzeng, 2011; Yaşar & Paul, 2011). In the end, the sustained economic growth depends upon a country's capability to develop knowledge (Moaniba et al., 2018; Teixeira & Queirós, 2016) that is adaptable and commercialise worldwide (Burger, Karreman, & van Eenennaam, 2015; Liyanage & Mitchell, 1994).

Better scientific capabilities should result in higher knowledge transfers. They should also lead to new products and processes (Burger et al., 2015) through various channels, including the patenting and licensing of inventions (Jong & Slavova, 2014; Leten et al., 2014; Moaniba et al., 2018), new ventures and university-industry alliances (Barge-Gil & Modrego, 2009; Cooke, 1992; Jong & Slavova, 2014; Kafouros et al., 2015; Leten et al., 2014).

A series of empirical studies shows that those countries that have fostered science more actively have become global exporters and development successes. For example, well-designed science and technology parks contributed to making China a leading high-tech exporter (Mok & Kan, 2013). At the company level, Lenovo has become a multinational company through the exploitation of know-how and technology coming from a domestic research hub, The Chinese Academy of Science (Peña-Vinces & Urbano, 2014; Tzeng, 2011). Among now-developed countries, there are many cases of successful use of scientific capabilities, including Australia (Liyanage & Mitchell, 1994), Canada (Dufour & Gingras, 1988), Finland (Nilsson et al., 2006), Italy (Leten et al., 2014), and the U.K. (Jong & Slavova, 2014).

In parallel, another branch of the literature on economic development emphasises the contribution that the manufacturing sector can make to sustained economic growth and export upgrading (Cooke, 1992; Rehner et al., 2014). Manufacturing activities tend to have higher productivity than agriculture and most services (McMillan, Rodrik, & Verduzco-Gallo, 2014; Rehner et al., 2014) and can generate more linkages and knowledge spillovers (Burger et al., 2015; Cooke, 1992; Ocampo, Rada, & Taylor, 2009). The expansion of manufacturing activities also goes together with the diversification and upgrading of the export basket (Felipe, Kumar, & Abdon, 2014).

At the empirical level, Ocampo (2006) finds a positive correlation between the expansion of manufacturing output and economic growth. Industrialisation was behind the East Asian Miracle, allowing countries like South Korea to expand well-paying jobs and enhance international competitiveness (Lin & Chang, 2009; Wade, 2004). More generally, the rise of developing countries during the 1960s and 1970s (Amsden, 1989, 2004) and almost all other development successes–including those of Northern Europe (Fosu, 2013)–went hand-in-hand with the stretching of manufacturing capacities.

Yet, what is the relationship between scientific production and manufacturing development? There are reasons to believe scientific capabilities and manufacturing expansion can reinforce each other. The effective incorporation of new technical knowledge may be more accessible in the manufacturing sector than in others, and productivity growth in that sector can then trigger positive effects in other parts of the economy (Moaniba et al., 2018). Knowledge transfer can also contribute to the creation of new products and processes in manufacturing (Jong & Slavova, 2014; Leten et al., 2014). Paus (2014), for example, emphasises the positive interaction between the creation of what she calls social capabilities–including scientific knowledge, human capital, and better infrastructure–and the promotion of structural change. In contrast, in her view, the lack of those interactions can lead to a middle-income trap, which is particularly evident in Latin America (see also Caldentey, 2012; Martínez Franzoni & Sánchez-Ancochea, 2014; Paus, 2012).

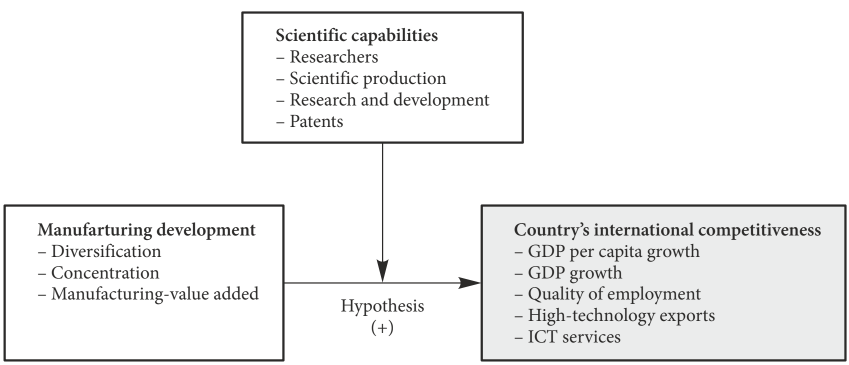

Figure 1. The relationship between scientific capabilities, manufacturing development, and international competitiveness

Yet, few people have empirically explored the extent to which scientific capabilities and manufacturing development reinforce each other in practice, particularly in the Latin American (LA) context. In this paper, we study this interaction and also evaluate the independent contribution that scientific capabilities–measured by a combination of indicators (see Figure 1 and Table 1)–and manufacturing development can make to international competitiveness (see Figure 1).

2. Defining the variables

To explore the relationship between scientific capabilities, manufacturing development, and international competitiveness, we constructed an eleven-year panel data for the period 2003–2013[1]. We incorporate data from different sources for the main ten South American countries (see list in Table 1). Before moving to a more detailed description of the indicators and data sources, in this section, we explain how we measure international competitiveness, scientific capabilities, and manufacturing development.

2.1. Measuring a country's international competitiveness

Increasing a country's international competitiveness requires higher rates of economic growth as well as export upgrading (Choo & Moon, 2000; Choo, Moon, & Kim, 2008). Thus, building on our previous work, we measure LA's international competitiveness through the integration of economic and innovation indicators (Castro-Gonzáles et al., 2014, 2016; Peña-Vinces, 2009). We include three indicators of economic development (Guerrero et al., 2015; Siddiqui & Rehman, 2017): (1) annual growth of GDP; (2) annual growth of GDP per capita; and (3) the annual change in the employment rate[2]. We include both GDP and GDP per capita to simultaneously evaluate a country's ability to expand economic activity and benefit the whole population (Choo & Moon, 2000). The inclusion of employment signals that the process of competitiveness must have a positive effect on workers; job-less growth will not be politically or socially sustainable over the long run (Castro-Gonzáles et al., 2016).

Likewise, to account for the dimension of innovation in our construct of international competitiveness, we use two indicators (1) high-tech exports (i.e., % of total exports of goods); and (2) information and communication technology (ICT) exports (i.e., % of total service exports), which include computer and communications services as well as computer data and news-related service transactions. A large share of high-tech exports is one of the best indicators of a country's capacity to innovate and undertake complex processes (Barge-Gil & Modrego, 2009; Héraud & Lévy, 2005; Mok & Kan, 2013; Teixeira & Queirós, 2016). According to Dunning & Lundan (1998, p. 119), high- tech industries will use their domestic bases as platforms for generating their key resources (e.g., innovatory potential). ICT services capture how companies' domestic suppliers create advantages in downstream

[1] Please see, the section four, where we explain the reseasons why have chosen this period.

[2] The employment rate is calculated as 100 minus the unemployment rate in percentage terms for the period 2003–2013.

industries (Barba-Sánchez & Calderón-Milán, 2018; Choo & Moon, 2000). In a hyper-competitive environment, ITCs have become a critical piece for steady growth (Barba-Sánchez & Calderón-Milán, 2018), providing other sectors with efficiency and cost gains (Peña-Vinces, Cepeda-Carrión, & Wynee, 2012). Services companies have also become a crucial actor in international trade (ECLAC, 2016).

2.2. Measuring manufacturing performance

To measure manufacturing performance, three indicators were used. Our first indicator is the share of manufacturing sector in GDP. The other two indicators evaluate the structure and composition of a country's exports–that is a good reflex of the global power of domestic industries.

Drawing on the UNCTAD database (UNCTAD, 2017), we include the inverse of the concentration and diversification indexes.[3] The first index measures the number of products a nation exports (see UNCTAD, 2017). Values closer to 1 indicate that exports are concentrated on a few products, which are likely to be primary goods with limited links to manufacturing. In contrast, values closer to zero reflect a large export basket with many products and thus a more significant presence of the manufacturing sector.

The diversification index considers how close a nation's export basket (NEB) is to the global structure. Like the concentration index, its value goes from zero to one. The closer the index is to zero, the smaller the difference between the composition of the NEB and the global structure. For most developing countries, including those in South America, the process of industrial development has entailed a transition from traditional to non-traditional exports (Rehner et al., 2014), thus moving the NEB closer to the global average.

2.3. Measuring a country's scientific capabilities

As discussed above, the scientific capabilities refer to the country's ability to generate scientific knowledge and research and development. To measure it, we consider four different indicators. Based on Furukawa et al. (2013) and Jong and Slavova's (2014) recommendations, we use the number of articles published by each of the countries in our sample. To reflect the role of human capital (Siddiqui & Rehman, 2017) in generating scientific outputs (Burger et al., 2015; Cooke, 1992), we consider the number of home researchers working in R&D (Castro-Gonzáles et al., 2016; Dufour & Gingras, 1988; Kafouros et al., 2015). We also include R&D expenditure as a share of GDP (Cooke, 1992; Moaniba et al., 2018) and the number of patent applications from residents (Jong & Slavova, 2014; Leten et al., 2014; Moaniba et al., 2018). The World Bank (2018) and the National Science Foundation (2016) constitute the sources for these two indicators. Table 1 summarises the indicators employed in the study as well as the sources.

[3] For a more exhaustive explanation of each of the two indicators, we suggest visiting the statistics section of the UNCTAD webpage, which presents the formulas to calculate them. In each case we use the inverse of the UNCTAD indicators because we want to be consistent with the rest of the analysis: a higher value should represent more manufacturing development.

Table 1. Research variables and measurement

Variables/Measurement	Code	Source	Countries
Scientific Capabilities			Argentina Bolivia Brazil Chile Colombia Ecuador Paraguay Peru Uruguay Venezuela
Researchers working in R&D (by MM individuals)	X1	NSF	
Scientific and technical journal articles	X2	NSF	
Research & Development expenditure (% of GDP)	X3	WB	
Number of Patents	X4	WB	
Manufacturing Development			
Diversification index	X5	UNCTAD	
Concentration index	X6	UNCTAD	
Manufacturing, value added (% GDP)	X7	WB	
Country's international competitiveness			
GDP per capita growth (annual %)	X8	WB	
GDP growth (annual %)	X9	WB	
ICT exports (% GDP)	X10	WB	
High-technology exports (% of manufactured exports)	X11	WB	
National employment performance	X12	WB	

Notes: National Science Foundation (NSF), The World Bank (WB) and UNCTAD.

3. Analysis of the data: descriptive statistics

Our analysis focuses on a period of high growth in Latin America supported by the commodity boom. We stop in 2013 because this is the year when economic growth slowed down as a result of deteriorating international conditions, including the euro crisis, China's economic deacceleration and a sustained reduction in commodity prices. The recession led to a shift in science and education policies across the region, including a drastic reduction of public spending in these areas.

3.1. South America in the 2000s: poor average performance with significant diversity

This section reviews South America's performance in international competitiveness, scientific capabilities, and manufacturing development during the period 2003–2013. We show common weaknesses, as well as a significant diversity in both the dependent and independent variables. These similarities and differences make South America an ideal region to explore the interlinks between our variables of interest. Let's start our descriptive analysis with the various dimensions of international competitiveness. As reflected in Figure 2, economic growth has been high across the board, with Peru, Argentina, and Uruguay leading the pack during this period. Simultaneously, there is some variance between countries, both in the levels and in the relationship between GDP and GDP per capita.

There is even more regional diversity in the level of unemployment (see Figure 3). For example, the unemployment rate in Colombia is more than three times higher than in Peru.

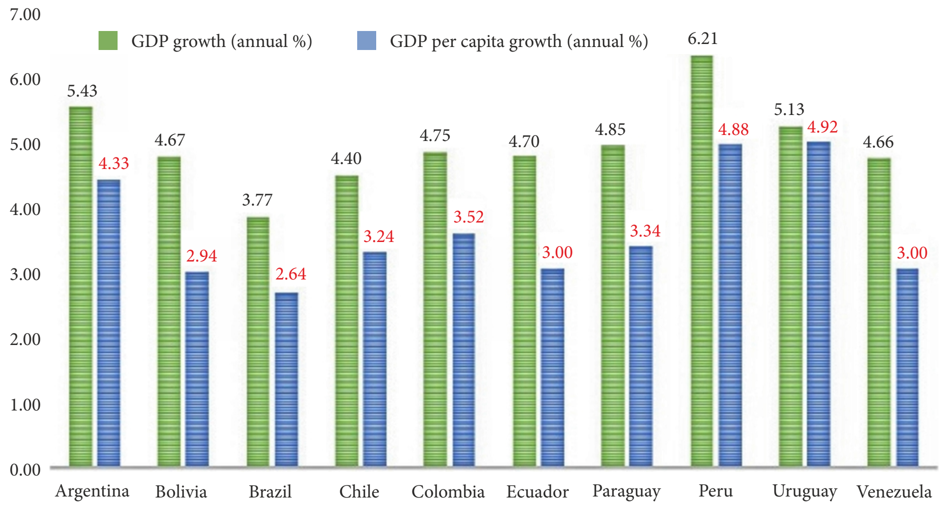

Figure 2. GDP vs GPD per capita, the average annual rate of growth (2003–2013)

At the same time, all countries share a similar downward trend, which was particularly intense in Argentina and Venezuela.

High economic growth and employment creation, during this period, were primarily due to the commodity boom, and were not accompanied by export upgrading. As Figure 4 shows, high-tech exports were below 12% of total exports in all countries during the whole period. This is in contrast with East Asia, where they accounted for more than 60% of total exports.

Let's now move to the analysis of manufacturing performance. Figure 5 reflects the share of the manufacturing sector in GDP in each of the ten countries, which was generally low: in six of the ten countries, it was below 15%, and only in one country (i.e., Argentina), it was above 20%. The case of Brazil is particularly surprising. After being a manufacturing powerhouse during the 1960s and 1970s, Brazil's manufacturing sector accounted for just 15.5% of GDP during this period, which was below Argentina, Peru and Uruguay.

Figure 6 depicts the export concentration index for all South American countries during the period 2003–2013. Remembering that values closer to one indicate that a nation's exports are dependent on a few products, we can see that Venezuela (HHI = 0.57) and Ecuador (HHI = 0.49) performed particularly poorly in this area. In contrast, Brazil (HHI = 0.15) present the highest level of diversification in Latin America, reflecting some remaining manufacturing capacity despite the recent process of deindustrialisation. The rest of the countries had a medium level of concentration (between 0.24 and 0.36). Latin America's poor performance in this arena is clear when comparing it to some of the leading emerging economies in the world (China and India).

Figure 7 reflects the level of export diversification in the region, which measures the difference between each country's NEB and the global average. It is thus a good reflection of the evolution from traditional to non-traditional exports. Again, with the notable exception of Brazil, diversification in South America is well below that in China and India. During the 2000s, the region deepened its specialisation in commodities, becoming more vulnerable

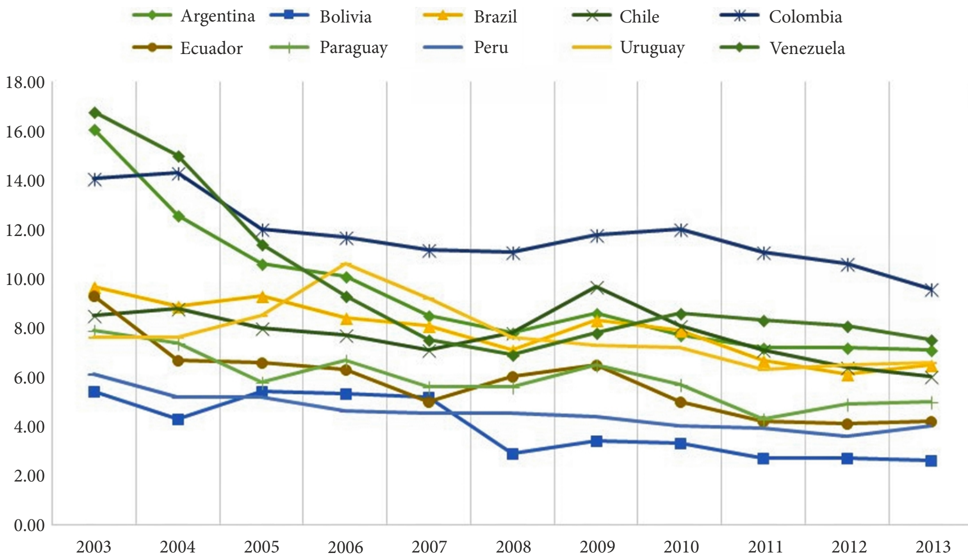

Figure 3. Unemployment rate (% of total labour force), 2003–2013

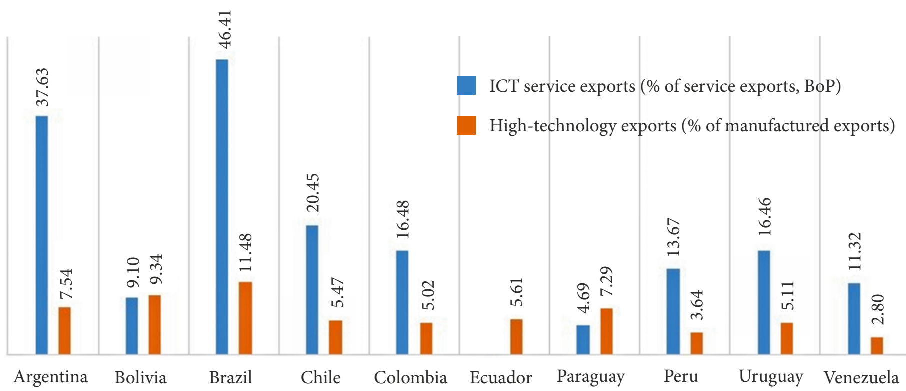

Figure 4. Latin America's ICT and high-tech exports (2003–2013)

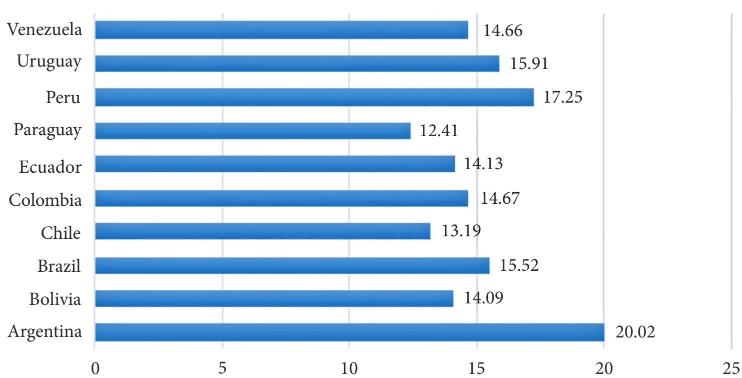

Figure 5. Manufacturing value added (2003–2013)

to changes in global conditions (Parteka & Tamberi, 2013; Rehner et al., 2014). Figure 7 is consistent with a 2016 study by ECLAC (2016) that highlights Latin America's concentration on commodities and natural resource-based manufactures and its difficulties to develop the type of manufacturing products that are characteristic of more developed parts of the world.

We finally consider our indicators of scientific capabilities in Figure 8. Several facts demonstrate both the region's common weaknesses and the differences between leading and backward countries. The disparity between countries is evident, for example, in the case of researchers in R&D, where Argentina occupies a leading position with 1,200 per million people. Three other countries are in a range between 400 and 600, and the others are below 200. The region's weakness is evident in the case of spending in R&D, where all countries but Brazil spend less than 0.6% of GDP in this item. The contrast with some of the most advanced economies, like Germany (which spends 2.9% of GDP) and the USA (2.7%), is striking.

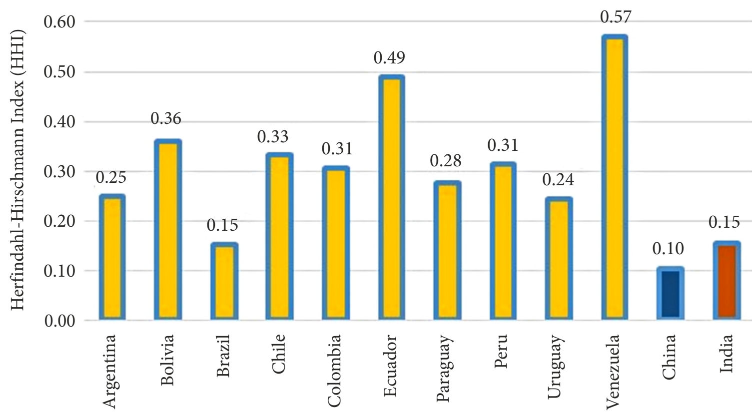

Figure 6. The export concentration index of South America, China and India, analysis for the period 2003–2013

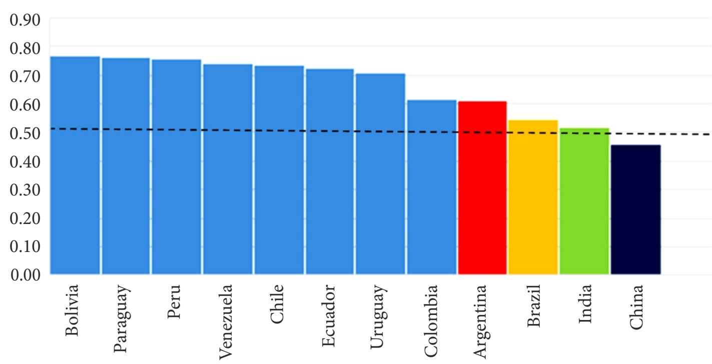

Figure 7. The export diversification index in South America, China and India analysis for the period 2003–2013

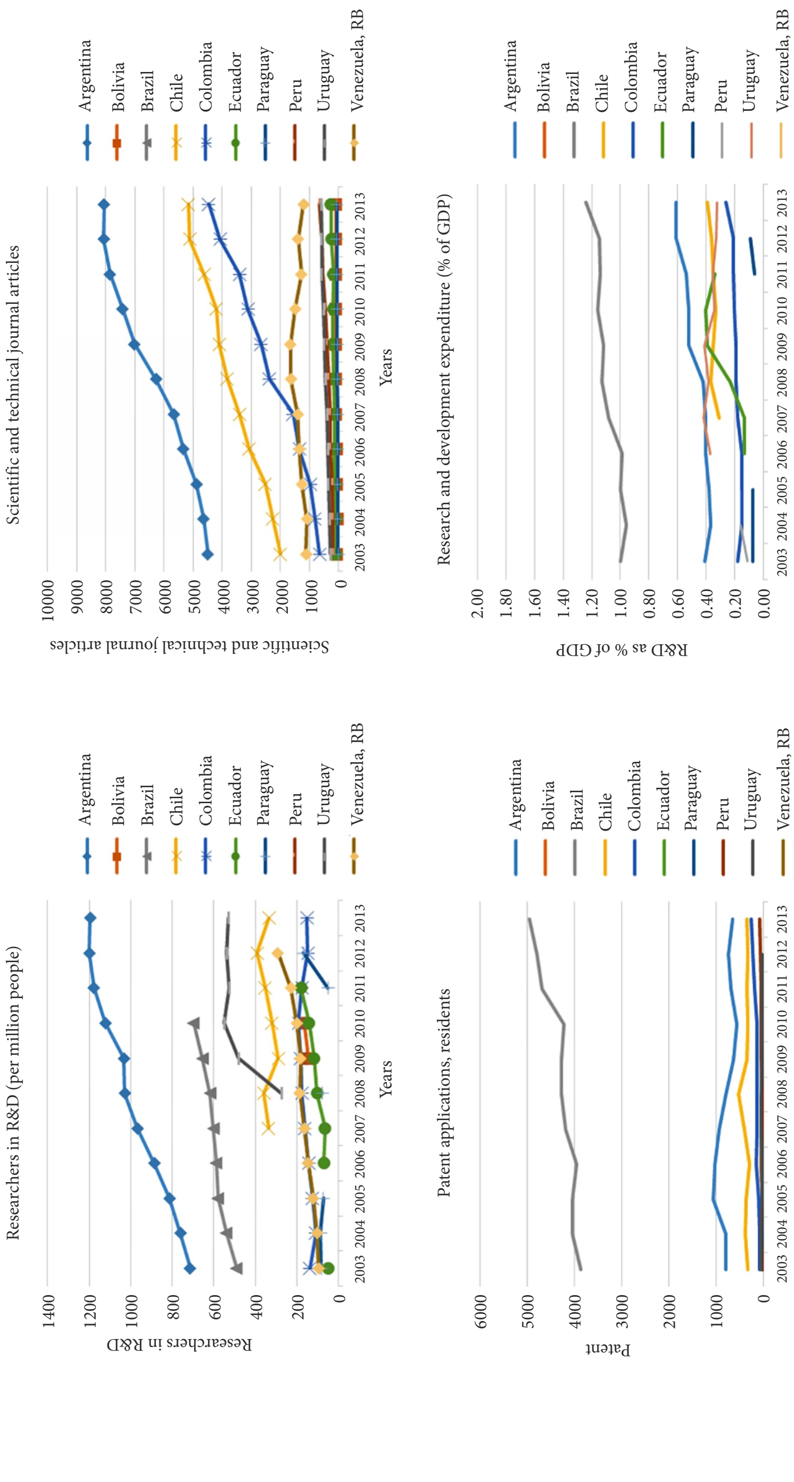

Figure 8. Development scientific indicators of South America (2003–2013)
(source: Own elaboration based on data from the World Bank, 2018 and NSF, 2017)

4. Exploring the relationship between international competitiveness, scientific capabilities, and manufacturing development

4.1. Hypothesis testing

Given the existence of latent variables (i.e., dimensions of both the dependent and independent variables that have not been made explicit), we had to carry out the reliability construct before performing the Hayes' Process Method OLS Regression (Hayes, 2013; Hayes & Rockwood, 2017).

To do so, we undertook a validity of construct analysis, which assesses the extent to which a variable has a proper sample of items-indicators to represent it–in other words, if the overall domain is adequately represented by their indicators (Castro-Gonzáles et al., 2016; Hair, Black, Babin, & Anderson, 2009). Meanwhile, individual item reliability evaluates the validity of the construct by analysing the standardised loadings (λ). According to Hair et al. (2009), for a construct principal exploratory components analysis to be accepted, loading factor (λ) must exceed the threshold of 0.20–which is the case for all our indicators (see Table 2).

We then run the reliability construct through principal exploratory[4] components analysis (e.g. Kaiser–Meyer–Olkin (KMO) and Bartlett's test of sphericity (χ^2)) with varimax rotation for the following variables: scientific capabilities and manufacturing development. The values

Table 2. Results of validity-reliability of constructs and PCA

Variables/Dimensions	Code	Ŋ	λ	KMO	χ2	CA	AVE
Scientific Capabilities (SC)	logX1	78	0.504	0.825	203.453***	0.916	0.753
	logX2	110	0.989				
	logX3	82	0.951				
	logX4	84	0.935				
Manufacturing Development (MD)	Code	Ŋ	λ	KMO	χ2	CA	AVE
	logX5	110	0.834	0.661	67.243***	0.884	0.646
	logX6	110	0.833				
	logX7	108	0.741				
Country's international competitiveness (CIC)	Code	Ŋ	λ	KMO	χ2	CA	PCA
	logX8	110	0.920	0.579	184.304***	N.A.	compo1
	logX9	110	0.919				compo1
	logX10	100	0.922				compo1
	logX11	110	0.928				compo2
	logX12	109	0.477				compo3

Note: All variables are included in natural logarithms. Cronbach alpha (CA); Loadings (λ); Number of observations (Ŋ) and Principal Component Analysis (PCA). ***Significant at 1% level.

[4] Both KMO and χ^2 demonstrated adequate values (see Table 2). Regarding construct reliability, the Cronbach alphas (see Table 2) for SC and MD construct have shown high values that go beyond the 0.70 thresholds. Posteriorly, the construct variance for first-order constructs (i.e., SC and MD)–using the average variance extracted (AVE)–were evaluated, which require that its index should be above 0.50 (Hair et al., 2009).

obtained suggested the absence of a single factor that registered for most of the covariances of our constructs.

However, principal components analysis (PCA) for the international competitiveness variable discovered that it was a second-order construct that was formed by three components (Table 2), in contrast to the scientific capabilities and manufacturing development construct composed of only one component. In line with previous research (Kull, Yan, Liu, & Wacker, 2014; Wagner, 2010) a second-order international competitiveness factor was calculated from the three first-order international competitiveness components (see Table 2). Thus, the three first-order factors are obtained by PCA with varimax rotation, utilising Kaiser Normalisation for IBM SPSS version 22.0. The elements are distinct and account for 78% of data variance. The PCA component matrix confirmed satisfactory item-to-factor correlations that are beyond the 0.5 thresholds (Hair et al., 2009). Finally, for this construct, KMO, χ^2 and Cronbach alphas (λ) analyses performed for each one of the three components which showed values above the limit.

After performing the reliability and validity construct, we undertook the Hayes' Process Method OLS Regression (HPM-OLS) using the Johnson-Neyman technique (Hayes, 2013; Hayes & Rockwood, 2017). All assessments were realised in the SPSS 22 software (see Table 4). Our panel model was assessed conforming with the following Equation:

$$CIC_{i.\,-2003-2013} = a_1 + \beta_1(\mathrm{MD}_{\,i.\,-2003-2013}) + \beta_2\,(\mathrm{SC}_{\,i.\,-2003-2013}) + \beta_3(\mathrm{MD} * \mathrm{SC}_{\,i.\,-2003-2013}) + \varepsilon_{\,i.-2003-2013},$$

where a_1 is the intercept; *i* are the Latin American economies analysed; 2003–2013 is a base period of the longitudinal study; and ε_i represents the residual term.

Although many OLS models utilise control variables, they are not required when using latent constructs as a dependent variable like it is the case here. Due to, some of the latent construct's indicators might play the role of control measures (Castro-Gonzáles et al., 2016). In fact, the international competitiveness construct is constituted of nine indicators instead of one as happens with models based on observable variables.

4.2. Results and discussion

Before undertaking the HPM-OLS, we explored the bivariate correlation coefficients (cc) between international competitiveness, scientific capabilities, and manufacturing development (see Table 3). International competitiveness is positively correlated with scientific capabilities (cc = 0.687***) and with manufacturing development (cc = 0.493***), which constitutes a preliminary confirmation of some of our initial hypotheses.

The normality of the error terms was evaluated through the normal probability plots and Shapiro–Wilk test (Dunning & Lundan, 1998; Hair et al., 2009). Both analyses suggested a normal distribution of our study's variables.

We then moved to the econometric analysis that considers the interactions between the two independent variables (i.e., X and M) more explicitly. Table 4 presents the results, corroborating the positive relationship between international competitiveness and both manufacturing development (β = 0.269***) and scientific capabilities (β = 0.320***). More remarkably, our results confirm the existence of a positive interaction effect. The effect of manufacturing development on international competitiveness is higher when better scientific capabilities mediate it (i.e., the interaction effect has a value of β = 0.173***).

Analysing the econometric model, we can note that scientific capabilities (b = 0.374) have more weight than the other, since this element has more explicative power in the OLS.

HPM-OLS were examined through the bootstrapping method with bias-corrected (Hayes & Rockwood, 2017). With 50,000 bootstraps resamples, the 95% confidence interval was attained. Results from the HPM-OLS interaction analysis corroborated the mediating character of scientific capabilities in the relation amongst manufacturing development and international competitiveness (β = 0.173**). Also, the direct effect of manufacturing (x) on international competitiveness (y) is significant (β = 0.269***) when it is conditioned for the science role play, thus suggesting full interaction. Figure 9 displays these results.

Table 3. Correlation analysis

Variables	(Y)	(X)	(M)
(Y) International competitiveness	1		
(X) Manufacturing development	0.493***	1	
(M) Scientific capabilities	0.687***	0.507***	1

Note: ***Significant at 1% level.

Table 4. Results of the HPM-OLS

Model summary	β	b	SE
(Y) constant	0.123	0.057	0.048 ***
(X) Manufacturing development	*0.269*	0.234	0.051 ***
(M) Scientific capabilities	*0.320*	0.374	0.055 ***
X·M	*0.173*	0.096	0.061 ***
R			0.734
R2			0.539
F			71.039***
Increasing due to interaction: (X·M)			
R2			5%
F			2.025***
50, 000 bootstraps resamples			
	Kurtosis		–0.237(0.599)
Test of normality	*Shapiro-Wilk*		0.910***
	Kolmogorov-Smirnov		0.17***
Degrees of freedom			62
Endogeneity test H0: Durbin Watsson			1.467
Std. Error of the Estimate			0.499

Notes: B = Coefficients standardised, b = regression coefficients (SPSS v. 22) (SE) = Standard errors. Significant at the *p < 0.10, **p < 0.05, and p < 0.01. Type of Hayes' Model = 1 PROCESS Procedure: Hayes (2013). *All variables are included in natural logarithms.*

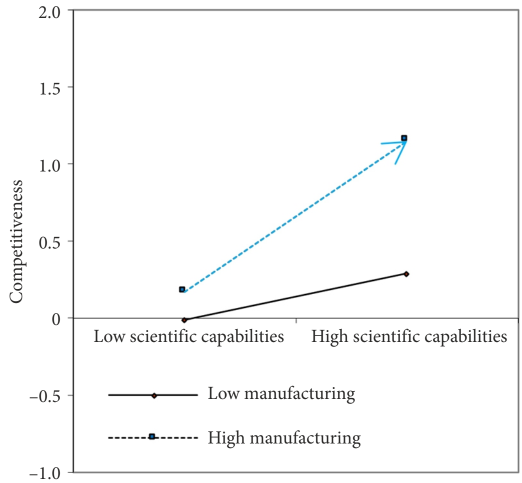

Figure 9. The interaction effect between science capabilities, manufacturing development, and international competitiveness

Figure 9, conveys how the impact of manufacturing development on international competitiveness varies depending on the level of scientific capabilities. When the scientific capabilities of a country are high, the influence of the manufacturing sector on international competitiveness is significantly larger. The graph thus constitutes a good reflection of the power of the interaction effect (i.e. the positive impact on international competitiveness is particularly large when manufacturing development, and scientific capabilities are both high).

In practical terms, the econometric model summarised in Table 4 indicates that international competitiveness increases by 27% ($\beta 1 = 0.269$) when manufacturing development increased by one unit and by 32% when scientific capabilities increase by one unit. Moreover, when considering the interaction effect, the impact of each of these two factors increases even more.

It may be useful to explore the relevance of these results when designing future policies, taking the country's investments as a point of departure. The results suggest that if a country invests in manufacturing development and scientific capabilities simultaneously, it will improve international competitiveness by 76%, including the interaction effect (X 0.27 + M0.32+ X.M0.17 = 0.76). In other words, per each unity invested to boost the Latin American international competitiveness, we might have a return on investment of 0.27 and 0.32 in industry and science, respectively. Of course, a country is not a company, but this is may still be a useful illustration, given that Latin American policies toward innovation and scientific capabilities are financed with international loans from international institutions such as the World Bank and the Inter-American Development Bank.

Regarding a country's scientific capabilities, we have found that it varies significantly among South American countries (see Figure 8). Combining the number of patents plus the number of journal articles published during the period of study (2003–2013), Uruguay, Peru, Ecuador, Bolivia, Paraguay, and Venezuela show a low level of scientific capabilities; Argentina, Chile, and Colombia have a moderated level of scientific capabilities; and Brazil has a high level of scientific capabilities. Some Latin American economies would need to double their scientific effort to reach the level of Brazil–the regional leader.

These results provide useful information of the design of economic policies, given that not all indicators or dimensions of the econometric model have the same impact on international competitiveness. Thus, one must be careful to choose the key areas that can have the largest impact on international competitiveness. For example, one analysis (see the values of λ on Table 2) shows that the effect of journal articles (λ = 0.989), R&D expenditures (λ = 0.951), and patents (λ = 0.935) on scientific capabilities is quite similar and larger than the potential investment in researchers (λ = 0.504). In the case of manufacturing development, the overall effect of concentration (λ = 0.833) and diversification (λ = 0.834) is larger than manufacturing value added (i.e., % GDP; λ = 0.741). This analysis suggests that the growth of the manufacturing sector is less important for international competitiveness than the diversification of production (i.e., a reduction in commodity exports and the expansion of innovative products), although they are both obviously related.

In terms of the debate on industrial policy, our results confirmed some of the insights from previous research in Latin America (Ocampo, 2006; Rehner et al., 2014; Sanchez-Ancochea, 2006). The data reveals that Latin American economic growth seldom translates into export upgrading or a steady improvement in manufacturing. Industrial policy should occupy a larger role in the region's agenda and should be more explicitly linked to the creation of more scientific knowledge and human capital (Siddiqui & Rehman, 2017; Teixeira & Queirós, 2016)

Our conclusions are consistent with a recent study conducted by Peña-Vinces, Casanova, Guillen & Urbano (2017), which shows that Peruvian exports are highly standardised (that is, with very few techs component). This problem results from a variety of shortcomings that have been discussed in previous literature. For example, Barge-Gil and Modrego (2009) showed that the low productive capabilities of the small and medium-sized enterprises (SMEs)–which are still the dominant actor in all South American countries–impedes an effective exploitation of the knowledge generated by scientific institutions (i.e., universities, institutes, academies). In fact, SMEs are often unaware of the knowledge created by their national research centres (Czinkota & Pinkwart, 2012) and consequently, cannot use them effectively to generate new competitive advantages (Teixeira & Queirós, 2016).

Another explanation may be related to the high level of isolation of Latin American manufacturing firms. As previous literature suggests, the best outcomes are generated when companies are integrated and work in clusters (Burger et al., 2015; Delgado, Porter, & Stern, 2014). Companies with close geographical proximity to universities and R&D centres tend to build more associations (Moaniba et al., 2018), while physically dispersed agents tend to struggle more (Cooke, 1992; Porter, 1998; Quintas, Wield, & Massey, 1992). In Latin America, of course, many economic agents (i.e., universities and institutes) exist, but the truth is that the vast majority of them are full of bureaucracy more than scientists and technicians (Peña-Vinces & Urbano, 2014).

The region's ultimate challenge is how to diversify exports and move into more high-tech activities. Promoting domestic firms has historically been difficult, due to a series of problems, including corruption and low productivity levels. Attracting foreign investment in high-tech activities will be hard as investment decisions will depend on the receiving-country's advantages, including its national innovation system (Santhapparaj, Sreenivasan, & Jude Chong Kuan, 2006; Teixeira & Queirós, 2016), technology-intensity and economic structure (Barba-Sánchez & Calderón-Milán, 2018; Belderbos & Sleuwaegen, 2005; Cooke, 1992; Moaniba et al., 2018). Unfortunately, as we have seen in this paper, South American countries lack effective national innovation systems or a sufficient level of high-tech manufacturing activities. Most of the largest multinational enterprises (MNE) that operate in Latin America are specialised in commodities and have a limited impact on upgrading.

Given the results of our analysis, we propose more attention to scientific institutions and their interactions with the manufacturing sector to meet these challenges. Latin American countries should pay more attention to how to improve their scientific capabilities while simultaneously supporting their use by domestic and international (manufacturing) firms. This strategy would bring benefits for the private sector, which could benefit from knowledge accumulation and more support in its economic application (Barba-Sánchez & Calderón-Milán, 2018; Guerrero et al., 2015; Jong & Slavova, 2014). In this way, the scientific community could become a crucial agent for economic development and the core of a country's competitive advantage (Castro-Gonzáles et al., 2016; Guerrero et al., 2015; Kafouros et al., 2015; Siddiqui & Rehman, 2017).

Conclusions and implications

This paper has considered the interrelations between scientific capabilities, manufacturing development, and international competitiveness in the Latin American context. Drawing on multi-dimensional definitions of each of the three concepts and using a cross-section database for the period 2003–2013, we found a positive correlation between scientific capabilities and manufacturing development and international competitiveness in South America. In doing so, we confirmed insights for numerous studies that highlight the role of science and industrialisation in the promotion of economic growth and export upgrading.

Yet, our contribution went further than that. We also found a positive interaction effect (i.e., the positive impact of scientific development on international competitiveness is significantly higher in countries that have also succeeded in securing manufacturing capacity). Moreover, our research also identified some dimensions that are particularly important for international competitiveness, including the amount of spending on R&D, patents and the exports' concentration and diversification levels.

Our results provide new insights and raise new questions in several areas. Let us here emphasise a few. First, we provide a different discussion of international competitiveness than much of the previous literature, based on a definition first proposed by Peña-Vinces (2009) and Castro-Gonzáles et al. (2016). Moving beyond traditional approaches that rely on Porter's diamond (Cho, Leem, & Shin, 2008; Choo & Moon, 2000; Porter, 1998), we link international competitiveness to standards of living. The use of an expansive understanding of competitiveness raises new questions for the future: should we consider additional dimensions? For example, should we expand our discussion of employment to consider the quality of jobs–as suggested by the International Labour Organization?

Second, our paper demonstrates the need to pay more attention to the way scientific capabilities interact with the economic structure (Moaniba et al., 2018). Most of the studies that highlight the role of R&D and call for more investment in scientists (i.e., human capital) and patents fail to consider which sectors are most likely to use the new knowledge. In our view, expanding the scientific capacity will be particularly effective when combined with more attention to manufacturing capacity– in terms of both the size of the manufacturing sector and the ability to diversify and modernise the export structure. A diversified economy with a large manufacturing sector is one with more opportunities to absorb scientific knowledge–at least in the South American context of the 2000s. Our research thus calls for more quantitative research and more case studies that explore the relationship between different sectors and R&D efforts. What are the reasons behind the positive role of the manufacturing sector? Will some manufacturing activities be more effective than others? Can some advanced services play a similar role in the promotion of competitiveness? Is the relationship between all these factors different in other parts of the developing (and developed) world?

Our research also provides new insights to account for Latin America's weaknesses–which have become particularly evident in recent years. The region has traditionally struggled to promote international competitiveness–for example, just 13% of its exports are high-tech, compared to 60% in more advanced economies–and it may continue doing so in the future. On the one hand, as Section 4 shows, most South American economies do not invest enough in R&D or scientists, and they performed quite poorly regarding patents and other knowledge indicators. On the other hand, its manufacturing development is insufficient when compared to other developing countries like China.

It is hard to identify who will be the actors for change in the future. The most dynamic domestic firms are generally concentrated in the primary sector (Schneider, 2013) while a majority of SMEs have limited capacity to innovate or invest in scientific personnel (Peña-Vinces & Urbano, 2014). Meanwhile, attracting more dynamic foreign firms is not easy. The region lacks the knowledge assets and the scientific parks that high tech foreign companies demand, and that are present in some Asian countries (Kafouros et al., 2015; Mok & Kan, 2013).

Latin American countries will also have to confront a series of socio-political obstacles, including the lack of involvement of experts (i.e., scientists) in scientific progress; the excessive politicisation of scientific and industrial policy; the insufficient mobility of high-skill workers within the region, as well as the brain drain; and the weakness of the country and its fiscal capacity. Overcoming all these problems will not be easy, but it may be more likely–we show–if it is part of a strategy that combines sectoral and knowledge promotion simultaneously.

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Author contributions

JPV demarcated the research problem, literature review and formulated hypothesis and made the statistical analysis with SPSS. He wrote the first draft of the article. DSA defined the study variables, wrote the qualitative analysis, and he has re-written the manuscript. JG has developed the panel data-set and statistical analysis and made the first critical revision of the paper. LFA definition of methodological procedures and second revision of the document and improvements of the literature review.

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