The Role of Information and Communications Technology, Economy and Patents in Productivity of South-American Countries

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***Abstract*—The relationships between patents and Information and Communications Technology (ICT), and labor productivity were proposed by Skorupinska & Torrent-Sellens [13]. This paper represents an exploration of research and development expenditure, patents and general ICT in South-America (SA) to support domestic innovation and productivity. However, no significant relations were found from year to year, possibly due to a number of different trends in patents. Further, we have found that the South American countries cataloged by the International Telecommunication Union have mostly dropped in their rankings, although they have made efforts in recent years. This has framed our discussion about productivity based on the countries explored and the conflicting policies towards innovation and industrial property ICT. The discussion was centered the Venn diagram generated as a result of a series of linear regressions, where each SA country was located in a different region of the diagram. On the other hand, in the group given, Paraguay Bolivia and Ecuador were outside the diagram, suggesting a different scenario to the multilinear regression proposed.**

I. INTRODUCTION

South America (SA) is a heterogeneous region, with one of the widest gaps between the rich and poor. However, greater economic stability in the region in the 21st century has put SA in a good position and specifically Brazil, Chile and Peru have grown at rates of over 3% [1], even today. Over the last 20 years several large foreign ICT companies have helped establish a favorable market in the region.

ICTs are raising the development of the different disciplines not only in science but also in the humanities. It has been suggested ICT, joined cognitive science, will generate by 2040 around 65 % of existing jobs [2]. While the primary reference charts of the United Nations specialized agency for ICT (IUT) refer to European, American, African, Arabic and Asiatic countries, except with regards to the gap of offer/supply of ICT professionals [14], there have not been many ICT reports bearing in mind the SA countries.

In the literature to date, the typical point of view focuses on from industrial competitiveness, and then uses patents as an index of competitiveness. For example, the patent system in USA also allows patents for software to be granted, which is helpful for the growth of ICT in a country. Retrieving patent analytical data via DataMarket [3] for ICT patents in USA (Figure 1) the high growth of ICT is observed in the corresponding decade to 1994 - 2004 among other things coinciding with the advent of Windows 95 in 1994 and the emergence of Google and the strength of the Asian market in 2004. Even several years after the first email sent by Tomlinson in ARPANET [24], in 1979, the figure was less than 20k and in 1984 around 20k. After the first computer virus sent by Morris, it was higher than 30k in 1989. Later at the time of Berners-Lee the World Wide Wed was introduced and the introduction of the MRI [23], in 1994 the figure came close to 50k. It was higher than 90k in 1999, and in 2004 around 110k. It was not analyzed after 2004 because there are patents that are granted after several years, other forms of ICT (see green line) are those that are growing to the point of possibly reaching or even exceeding those related to computer and office equipment. This short account demonstrates how ICT has progressed mainly in the Northern Hemisphere.

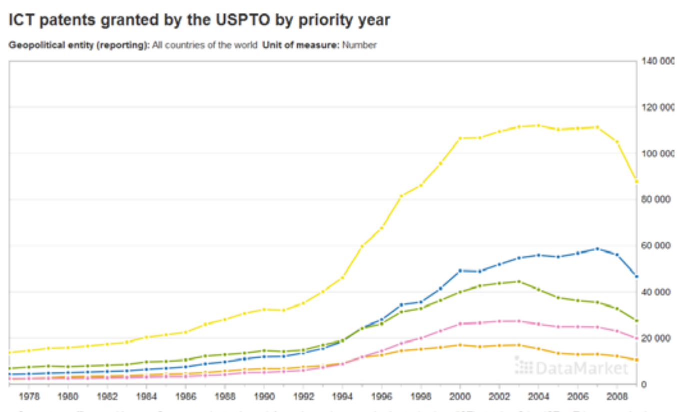

Figure 1. ICT patents granted in USA by priority year. See other ICT increase between 1996 and 2004 (plotted using Datamarket [3]).

But not all technological development is seen using patents; there are several other factors to bear in mind. Skorupinska and Torrent-Sellens have conducted a data analysis panel for the European Union member countries during the time period of 1993-2011 [13]. This panel considered nine variables: Labor productivity per hour worked (LP), Gross fixed capital formation as a percentage of GDP (GFCF), Total ICT spending (computer hardware, software and services, and communications) as a percentage of GDP (ICTS), Total public expenditure on education per total annual hours worked (EduS), Research and development expenditure as a percentage of GDP (RDS), Sum of exports and imports as a percentage of GDP (Trade. Openness), Gross enrollment ratio (Edu), and Human Resources in science and technology as a percentage of active population from 15-74 years old (HRST).

Therefore, including the previous variables and indicators in the well-established growth and productivity measurement model based on the growth model proposed by Solow [4], extended later by Jorgenson and Griliches [5], the aggregate production function after logarithm transformation of the variables of the final model in [6] takes form given in (1).

$$ln(LP) = \beta_1.ln(GFCF) + \beta_2.ln(EduS) + \beta_3.ln(RDS) + \beta_4.ln(ICTS) + \beta_5.ln(Trade.Openness) + \beta_6.(Edu) + \beta_7.INTuse + \beta_8.ln(Patents) + \beta_9.HRST \quad (1)$$

In this way, after identifying the accessible measures, first the univariate linear analysis is sought, and second, in order to examine the further multilinear regressors, linear variables were used to understand the dynamic in SA countries.

II. METHODS

A. Selecting variables for the analysis.

The model in (1) has been tailored for European outputs. Here, bearing in mind the main issues in ICT in South-American countries, we have analyzed the relationship between Patents, ICT spending (ICTS) and research expenditure (RDS) with the labor productivity according to (2).

$$ln(LP)= \beta_3.ln(RDS) + \beta_4.ln(ICTS) + \beta_8.ln(Patents) \quad (2)$$

In this way, the simplified model analyzed here considers the typical labor ecosystem, where R&D feeds the industries employing foreign capital, as well for National Patents that provide equipment and services for society. Therefore, ICT markers are expected to act with R&D, the patent system and society and consequently act as an influence on labor productivity, as shown in Figure 2.

B. Data collection for the analysis.

All tables and plots were obtained by the selection of different sources, and figures and relevant data plotted were shown in order to explain better the results. Plots and linear regressions were done in most cases according to the data available in specific sources, while companies are not consistently reported except for the countries that attract them to invest. Patents were only considered in terms of the invention modality.

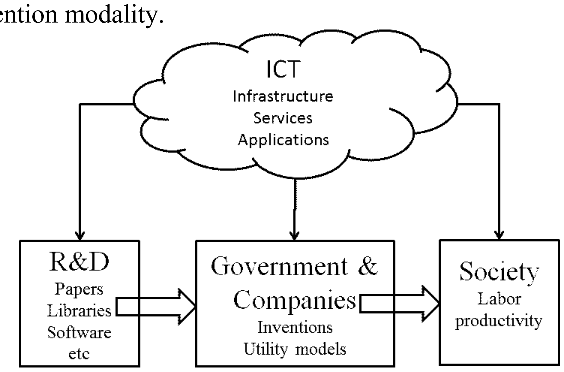

Figure 2 Simplified ecosystem considered in the model for productivity with the variables modelled in (2).

As further explained in the discussion, a Venn diagram was created bearing in mind the results for each SA nation with regard to the three different variables explored. With this diagram and based on other previous works, the discussion was elaborated.

III. RESULTS

A. Research and development expenditure as a percentage of GDP (RDS).

The average RDS for Organization for Economic Co-operation and Development (OECD) countries is around 2.28% [6]. The following figure considers the RDS in each SA country, with data coming from UNESCO [7]. Figure 3 displays the data available with regards to the investment in each country from 1996 up to 2012. The horizontal green line indicates that RDS is greater than 1/5 of OECD average only in Brazil and Argentina, greater than 1/10 also includes Chile and Uruguay (see horizontal yellow line).

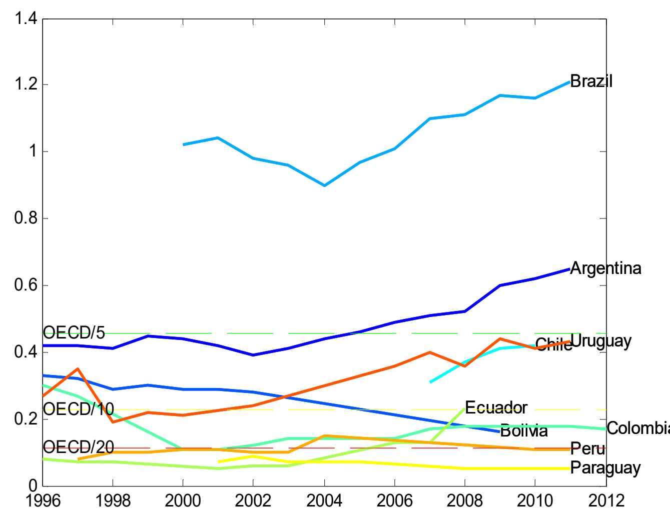

Figure 3 Research and development expenditure as a %GDP in SA countries.

A positive trend was seen in Ecuador and Uruguay under exponential regression (see the highest exponential constants in Table II). Unfortunately however, no significant regression was found for patents in SA (see R2 values at Table I). Also Bolivia possesses a good fit (R2 = 0.9037) but with a decrease in the expenditure for research and development. In the same way, Colombia and Paraguay have an exponential decrease in the regression.

Chile is an OECD country that was still below 20% percent of the OECD average for RDS in 2012. According to the trend, in the next few years Chile will join Brazil and Argentina in being above 20% of the average OECD countries for RDS. An account of the prediction in the regression was not made because of the small R2 value.

TABLE I. LINEAR REGRESSION RESULTS FOR RDS IN SA COUNTRIES

SA Country	Exponential equation	R-square value
Argentina	$y = 0.3702e^{0.0286x}$	$R^2 = 0.7321$
Bolivia	$y = 0.3667e^{-0.053x}$	$R^2 = 0.9037$
Brazil	$y = 0.8577e^{0.0191x}$	$R^2 = 0.5671$
Chile	$y = 0.0954e^{0.1014x}$	$R^2 = 0.8979$
Colombia	$y = 0.1746e^{-0.008x}$	$R^2 = 0.0175$
Ecuador	$y = 0.0503e^{0.0775x}$	$R^2 = 0.48$
Paraguay	$y = 0.1093e^{-0.051x}$	$R^2 = 0.7466$
Peru	$y = 0.0947e^{0.0147x}$	$R^2 = 0.2003$
Uruguay	$y = 0.2139e^{0.0434x}$	$R^2 = 0.6079$
Venezuela	N.A.	

N.A. = Not applicable

Other indicators may include the R&D performed abroad by majority-owned foreign affiliates of U.S. parent companies [8], by selected industry of affiliate in South-American countries. Table I shows data selected from [8] concerning the R&D expenditure by those companies in 2010. For each South-American country, we have selected and added the percentage related to investment in the different industries. The amount invested in Brazil was less than the half of ICT in Europe and less than 1/20 of electrical R&D, and also less than the Middle East, Asian and Pacific countries. No clear or significant investment in other SA countries was reported. This result indicated that R&D in SA countries should be driven more by both the SA private sector and the government. An example of effective support of this would be the facilitation laws that have been in place since 1967 in Brazil [20] up to the best known "Lei do Bem" in 2005 [21] which is a model that was taken into account by other countries such as Colombia.

In this study, few companies were found in countries with ICT rankings below Argentina and Brazil. For example, in Peru, Owens Illinois is an American company that mainly provided control adaptations of machines and design specifications to solve local problems, but it does not have clear research investments (personal communication).

TABLE II. LARGE US COMPANY R&D SPENDING FOR ICT ANALYSIS, IN MILLIONS OF DOLLARS

Country	All Indus-tries	Compu-ter, elec-tronic products	% Compu-ter, elec-tronic products	Electri-cal equip-ment, a-ppliances, Compo-nents	% Electrical equip-ment, a-ppliances, Compo-nents
Asia and Pacific	8,313	2011	24.19	275	3.31
Middle East	1,965	640	32.57	1	0.05
Europe	24,406	2,997	12.28	376	1.54
Argentina	115	N.A.	N.A.	< 1	<0.07
Brazil	1372	77	5.61	1	0.07

B. Total ICT spending as a percentage of GDP.

We consider this in terms of the Development Index (IDI) of the International Telecommunications Union in 2010 and 2011 [9] and 2012 and 2013 [10]. Because the ITU is around 150 years old, it provides a good framework to perform this analysis. The IDI is a combination of eleven indicators measuring access, use, and skills to use ICT. In this indicator, for example in 2011 Peru had dropped four positions to 86th (3.57 IDI) and by 2013 the Peru down to 105 (IDI 4.00), having South Korea first (IDI 8.56) in 2011 and being relegated to second place in 2013, and Chile in 55th (5.01 IDI) in 2011 and 56th in 2013. Between the 2012 and 2014 reports, 11 countries were introduced, which partially explains the fall in the rankings of several South American countries such as Bolivia and Paraguay (see Figure 4). However Peru fell 18 places, therefore the larger than expected fall requires explanation.

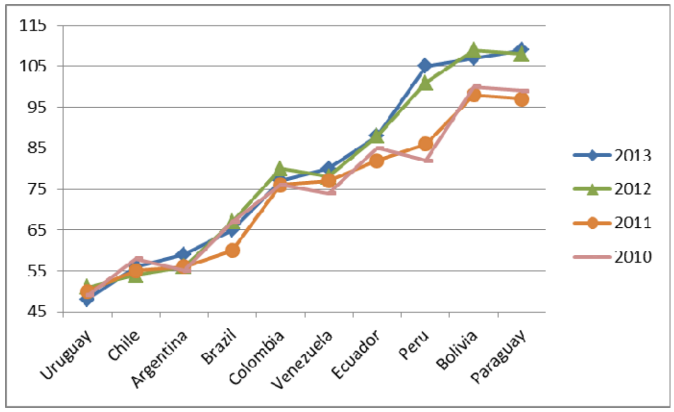

Figure 4 Global ICT for South-American countries ranked by ITU by year.

This further drop of Peru in 7 places can be approached by analysis of the skills measurements of the countries. Consistently, Bolivia and Paraguay had dropped around 10 places during the period of analysis (see Figure 5), while they have dropped in the overall rank (Figure 4). On the other hand, Venezuela and Peru remained relatively constant above these markers while they have dropped in the overall ranking 6 places and 18 places respectively. However, Chile and Argentina have improved significantly in this ranking within the top 30 positions.

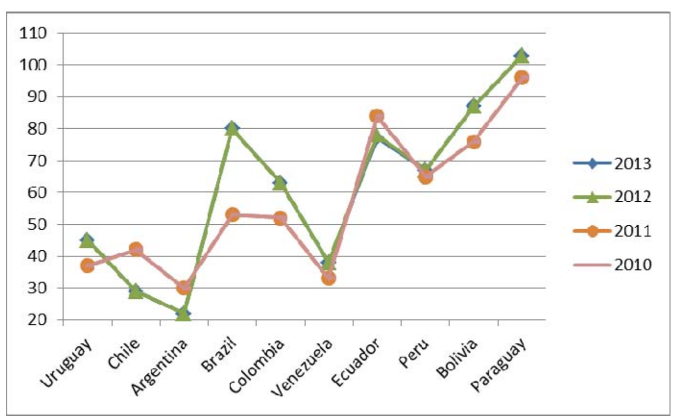

Figure 5 Skill in ICT for South-American countries ranked by ITU by year.

Clearly, the relative drop in ICT infrastructure explains the difference between Peru and the other countries of SouthAmerican countries. On the other hand, Chile and Argentina have relatively improved based on ICT Skills, and Venezuela has dropped 6 places instead of 11, based on a smaller (5 place) drop on ICT skills.

Another relevant finding is that to preserve the ICT ranking position, the IDI score should increase between 0.24 and 0.40 per year, looking at individual increases in the region 2010-2011 [9] and 2012-2013 [10]. The Peruvian National Competitiveness Advisor planned for a score of 5.0 [11], but this comparative analysis will lead to a reassessment from an IDI score of 4.00 [10] in 2013 to 5.2 or even 6.0 in 2018.

C. Patents per country.

The third marker is the number of patents granted. In developed countries, there is a trend of an apparently declining percentage of independent inventors, while in South American countries, the figure is still high. For example, in the USA over the last 20 years, the number of granted patents has dropped from around 17% to less than 6% (see Figure 6).

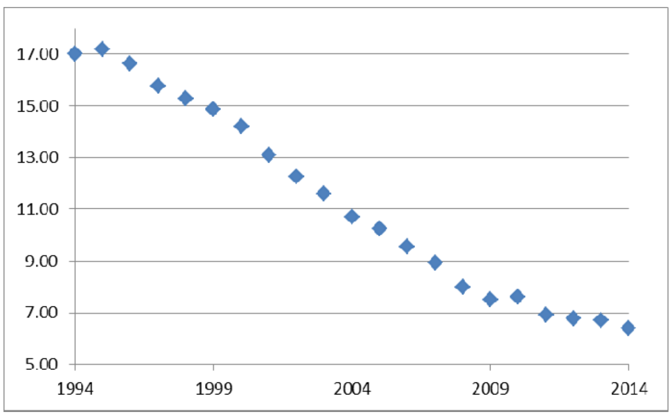

Figure 6 Companies/independent inventors of patents granted in USA by priority year.

For example in Brazil the number of resident applicants has grown from around 3000 in 2001 to around 4500 applicants in 2011, but granted patents have dropped from around 600 to around 300 [12]. Contrastingly, Peru has granted most of their national patents to natural persons (individuals) rather than companies. Moreover, in Figure 7 we a period of 15 years of patents granted to resident inventors in each SA country. It is notable that Brazil, Argentina and Chile each show more than 100 patents granted per year over the last 7 years. Colombia has joined this group with a clear increase in the period 2004-2013 and it is interesting to see what the trend might be in Colombia in the next 5 years. This pattern shows the impact of the beginning of the nation's Ministry of ICT.

At the other end of the spectrum, since 2010 Uruguay and Peru have less than 10 patents with a small drop in 2013, which is the last year available. Here, only inventions in each country were considered, the number of utility models was not considered and they have increased over recent years. Also, because Venezuela and Ecuador have effectively left the patent system in recent years (beginning from 2000 and 2007 respectively), these countries have not shown exponential regression and significant R2 values (Table II).

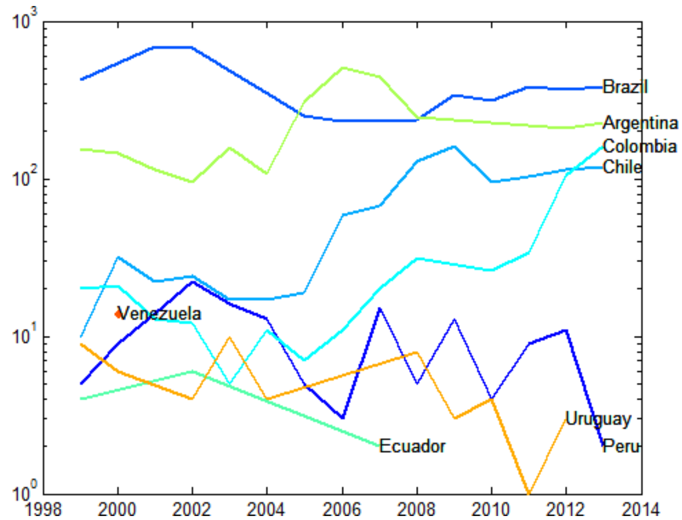

Figure 7 Number of Patents Granted to Resident Inventors in SA countries between 1999 and 2013.

The trend of Argentina and Colombia was found to be positive in the exponential coefficient in the linear regression, i.e. see 0.0602 for Argentina and 0.1463 for Colombia in Table II. Considering the R2 < 0.50 for SA countries, unfortunately, no quality regression was found for patents in SA (see R2 values at Table II). Overall, results consisted of a positive exponential regression and R2 close to 0.50 only for Colombia. On the other hand results for Uruguay show a negative exponential regression with a R2 close to 0.42.

TABLE III. LINEAR REGRESSION RESULTS FOR PATENTS GRANTED IN SA COUNTRIES

SA Country	Exponential equation	R-square value
Argentina	$y = 7E\text{-}51e^{0.0602x}$	$R^2 = 0.2459$
Bolivia	N.A.	
Brazil	$y = 5E\text{+}31e^{-0.033x}$	$R^2 = 0.1797$
Chile	N.A.	
Colombia	$y = 8E\text{-}127e^{0.1463x}$	$R^2 = 0.4894$
Ecuador	N.A.	
Paraguay	N.A.	
Peru	N.A.	$R^2 = 0.1123$
Uruguay	$y = 1E\text{+}81e^{-0.092x}$	$R^2 = 0.4187$
Venezuela	N.A.	

N.A. = Not applicable

D. Multilinear regression results.

Results did not fit significantly for the range of years under study in the SA countries explored. This confirmed the lack of consistency in the individual linear regressions.

IV. DISCUSSION

Overall, this paper has shown that ICT development is a key factor along with Patents and R&D expenditure for Labor Productivity which in turn influences economic development. This was evident in each separate analysis, although the multi-linear analysis did not fit. This may be due to the small number of patents in most of the SA countries, as well as their variable ICT indicators.

There are existing studies about ICT skills: Adduci's work focused on networking skills in Latin-American countries, oriented toward a study of the gap between demand and supply. Results pointed to an increasing gap in the required skills needed in all countries surveyed, save Colombia and Argentina, which are on the way to reduce gap for essential skills while Venezuela will maintain the same gap [14]. This ICT skill matches the Colombian result in terms of the granted patents increase in Figure 7. This suggested an interaction between both variables in SA countries that is not considered in the linear model in (1).

When the SA countries were considered in terms of a good value of the 3 variables analyzed in the Venn diagram, 6 countries were placed in different groups. Only one country was represented in all areas of overlap. This classification showed the variability of the outputs in each South-American nation, and it explained the non-significant multilinear regression.

On the other hand Paraguay, Bolivia and Ecuador have not shown numbers to follow these variables as possible regressors to predict Labor Productivity (see Figure 8). This analysis suggests that this paper constitutes a first step in order to explain labor productivity in South American countries. A catching-up model or North/South model with spillovers seems to be more appropriate, but different variables should be analyzed.

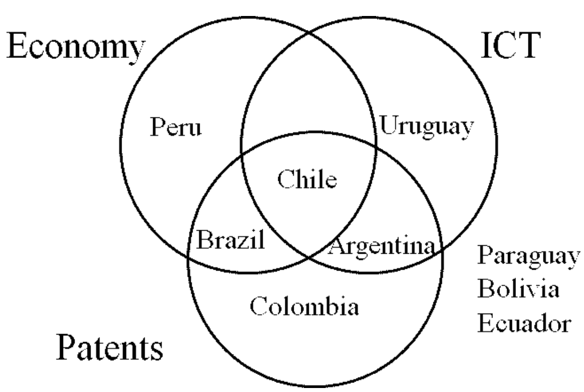

Figure 8 SA countries classified in a Venn diagram using the variables of analysis, i.e. ICT, number of Patents and GDP as Economy index greater than 3%.

Moreover, further research should consider different groups of countries and ranges of years considering the different economic and/or governmental changes in SA countries. This account may decrease the different levels of the regressors observed in Figure 8. The first issue to bear in mind here is the rationale to consider the groups by RDS, ICT, Patents or an interaction as a mixture of these groups. Adding to these interactions, feedback may be studied by employing a filtering analysis for the study of labor productivity, e.g. AutoRegressive, AutoRegressive with using the mean, or others). This kind of filtering approach may help us to consider the variable patterns of the number of patents described (see Figure 7). We did not consider patents abroad as well, since they do not contribute clearly to productivity in our simplified model.

Additional analysis may be done considering the effects of additional variables such as national transparency, management of consumer inflation and human capital effects on national development such as recent studies suggested [15]. For example Suri Electronics G8000 presented Sunlight, the first smartphone assembled in Bolivia. Suri is a company created by young visionaries who want to provide quality service to users [22] and contrasting with the decrease reported in Table I for RDS in Bolivia, Bolivia is part of technological innovation in SA. Therefore this analysis agrees with the suggestion to focus on ICT in development planning as a catalyst for economic development, bearing in mind that of course socio-economic factors and implementation of policies were not considered here.

In addition to national transparency and related factors, the culture behind ICT and patents has not been well-developed in growing economies. For example, as shown in Figure 8, Peru was found with a growing economy but with lack of ICT and patent development. An example maybe found in the few number of research and development and the great effort done by some researchers to contribute to the ICT research field [25].

Our conclusions were limited to the implications of R&D expenditure, ITU database and patent information and other local analysis of our results. We have combined patents and scientific article bibliometrics for this study. Although patents are a free and public source of current technological data, there are a few other sources of intellectual property protection such as industrial secrecy that may gain importance, given the small number of patents in SA countries. Patents have been widely used as a measure of innovation performance and life cycle for technology (e.g. [16]) but we have considered other factors for this ecosystem. Moreover, the number of patents in several countries was less than 10 in several years.

Building upon this paper, we identified some questions for future investigation. For example, what are the specificities of the South-American countries that may lead them to use their natural resources to create new industries? Why are foreign companies not seeking new markets in these countries? Are there peculiar political or cultural issues to be considered in the perspective for these countries?

Potentially the lack of a well-developed ICT system may be some address to an atypical explanation. Therefore a further research is needed that analyses which sector of ICT are performing well and which are not. An example is in the Brazilian skin care industries where the number of patents has reached equilibrium between independent inventors and companies. One possible explanation is the influence of other factors as R&D expenditure and ICT investment in those industries.

Other new ICT applications include "Smart Cities" employing Big Data and cognitive science on a practical level [17]. Along with the upcoming use of neuroinformatics and Virtual Reality, it is expected for 2040 ICT related positions will constitute 35% of available jobs [2]. Over the last 50 years the routine manual and cognitive skills have decreased in demand in favor of non-routine analytic and non-routine interactive ones [18] [19]. In this way the job tasks involved in many of current occupations, by their nature, are susceptible to be at least disrupted partially by new technologies [19]. Therefore, these facts reinforce the necessity to improve ICT skills in SA countries to have human resources for future labor productivity. While Peru and Brazil have good economic prospects, they lack significant ICT development. On the other hand, Chile has a relatively well developed economic environment, patents and ICT, showing a possible way forward.

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