

# *Growth of scientific production in Colombian universities: an intellectual capital-based approach*

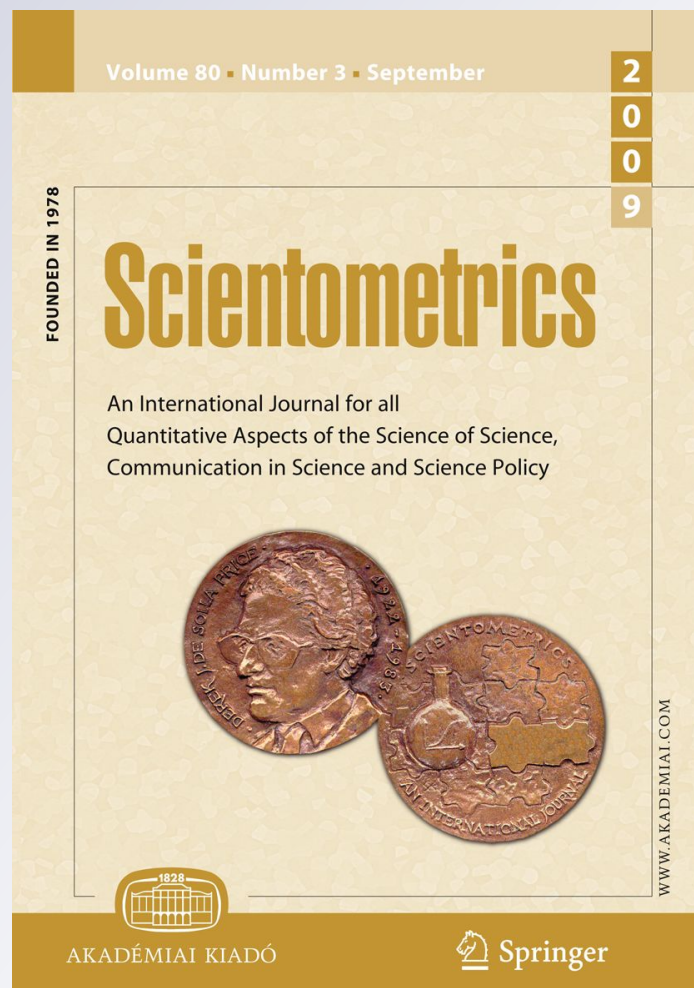
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## Growth of scientific production in Colombian universities: an intellectual capital-based approach

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**Abstract** The aim of this paper is to study the knowledge production of Colombian universities in terms of their accumulation of intellectual capital (IC). We observe Colombian universities' publications between 1958 and 2008, categorizing each university according to growth trends in its scientific publications: early exponential growth, late exponential growth, and linear and irregular growth. This work describes the relationships between these growth trends and IC accumulation. It presents an historical description of some institutional changes in Colombian universities that improved the research activity. In addition, we present an empirical study of IC accumulation in universities from the three growth trend categories between 2003 and 2009. We suggest that the adapting capacity, the accumulation time, and the strategies of IC accumulation related to feedback structures are key factors in explaining the differences in knowledge production between growth categories of Colombian universities. The results show critical differences—on orders of magnitude—in IC accumulation across the three categories. Therefore, it would be possible to define a roadmap to improve the knowledge production in Colombian universities.

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**Keywords** Colombian universities · Production of knowledge · Growth trends of scientific publication · Intellectual capital accumulation

## Introduction

The aim of this paper is to study the underlying relationships in universities' knowledge production systems in order to understand the trends in scientific production in universities so as to be able to support their decisions regarding research activity. Scientometric studies sometimes observe knowledge production of universities as a black box, considering just input–output indicators (Bonaccorsi et al. 2006; Janger 2005; Bonaccorsi and Daraio 2007).

According to Jin and Rousseau (2005), “scientists and decision makers have understood that, at least at the macro level, analyses based on scientometric and bibliometric indicators may provide a benchmark. [...] At the micro level, in particular in performance evaluations of scientists, scientometric and bibliometric indicators have severe limitations. For really ground breaking research the required activities are complex phenomena performed by human beings”. We propose that the input–output are related through feedback structures. Consequently, we observe a system of knowledge production—the university—that depends on internal feedback structures that reinforce or regulate intellectual capital (IC) accumulation over time. In this work, we will concentrate our study on the Colombian university system.

Research activity in Colombian universities was institutionalized approximately 50 years ago as a consequence of different reforms and institutional changes. It is important to emphasize the creation of the Colombian Administrative Department of Science, Technology and Innovation (Colciencias) and the Colombian Institute for Educational Evaluation (ICFES) in 1968, the two Inter-American Development Bank (IDB) credits for the ICFES and the three IDB credits for Colciencias, and also the creation of the national systems of science and technology—CSS&T— in 1991 (Villaveces and Forero 2007). Hence, in recent years, scientific research has begun to gain relevance in Colombia, and in particular within Colombian universities, which have played a key role in the country's research activity.

These institutions concentrate the financial resources, qualified personnel and motivation to carry out research (Aldana 2010; Villaveces and Forero 2007). Most of Colombia's knowledge production capacities are concentrated in its universities (Aldana 2010). For instance, in 2009, 90% of all researchers in Colombia worked at higher education institutions (HEIs) (Acosta et al. 2010), and more than half of the country's research and development expenditures were spent at universities (Aldana 2010).

We study Colombian universities' publications indexed in the ISI Web of Knowledge (WoS) between 1958 and 2008, and we categorize universities according to the growth trends in these publications: early exponential growth (EEG), late exponential growth (LEG) and linear and irregular growth (LIG). We observe different universities from each category and the relationship between these categories and their IC characterization.

This paper is an extended version of the paper presented at the 13th International Conference on Scientometrics and Informetrics (ISSI 2011) (Bucheli et al. 2011). It is organized in three sections, as follows. The first section presents a brief conceptual review and a description of the methodology to classify Colombian universities according to their growth in publications, and to study the relationship between these behaviors and their IC

accumulation. The second section shows the IC accumulation of universities in each category. The last section presents a discussion of the factors related to IC accumulation in Colombian universities, and future work.

### Knowledge production trends in Colombian universities

In the following section, we present a brief description of the studied universities, the method used to classify the universities into the growth categories, and the IC indicators used to observe the universities, in terms of the relationship between the growth curve and its IC accumulation.

#### Classified Colombian universities and IC studied

In previous lines, we explained that research activity in Colombia is relatively recent, has been gaining relevance over the last 50 years, and has occurred primarily at universities. The Colombian university system is quite heterogeneous: universities have been founded since the seventeenth century, in main cities with different populations and different economic development levels.

We consider 77 universities, which we classify into the three growth categories (See Table 1). Fourteen percent of these universities did not publish anything from 1958 to 2008, meaning that 67 universities had at least one publication in the 50 years of the study. For each category of universities, we observed the IC indicators (the IC description is presented in Appendix). All universities from the EEG category were taken into account in our work, whereas we studied 50% of universities from the LEG group and 35% from the LIG group (See Table 1).

In this work, we selected universities according to the availability of the data from the National Information System of Higher Education (SNIES), as well as from universities' reports on their official web pages. This information comprises the number of professors and their educational level, doctoral programs and enrolled students, and research groups. The financial information used is related to projects promoted by Colciencias—the agency that manages the resources supporting research activity in Colombia—which has awarded grants for science and technology research since 1968. Additional information about institutional accreditations was acquired from the National Accreditation Council (NAC), and other data on research activity in Colombian universities was retrieved from “The role of Universities in Science and Technology Development, Report 2010” (Santelices 2010).

**Table 1** Classification of the Colombian universities studied

	Universities	Studied universities (%)
Early exponential growth (EEG)	6	100
Late exponential growth (LEG)	32	50
Linear and irregular growth (LIG)	29	35
No publications	11	0
Total	77	61.7

Figure 1 shows the universities included in this study, classified by growth categories and their numbers of full-time-equivalent professors (FTE) and students (2009).

Trends in scientific publication data

One of the indicators used to represent scientific activity is the number of scientific publications, which has been employed since the first studies were carried out in the field of scientometrics. This indicator is currently used for several rankings that evaluate universities' performances in terms of their scientific activity. One way to represent the dynamics of a university's knowledge production is the increase in its number of publications.

Price (1986) studied the growth of science and noticed that it follows the logistic growth curve: the initial stage of growth is exponential, then saturation begins, growth slows down and growth finally stops. This behavior was associated with the cumulative advantage processes (Price 1976). The aim of this work is to study the different trends in the growth of Colombian universities' scientific publications in order to understand their dynamics related to IC accumulation.

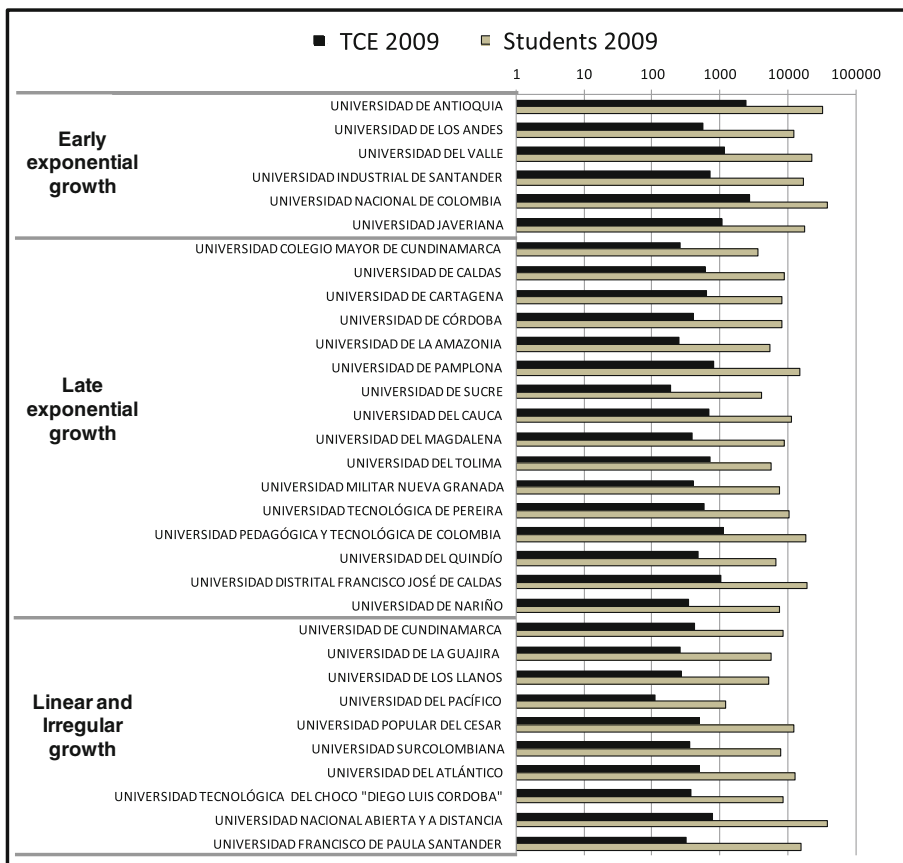


Fig. 1 Sizes of universities included in the study (log-normal plot)

Information about Colombian institutions' scientific publications was retrieved from WoS.<sup>1</sup> We retrieved 19,928 records from 1958 to 2008. The year of publication and information regarding institutional affiliation were extracted from each document. We categorized the universities according to the publication growth, identifying universities from the institutional affiliations of the publications' authors.

Colombian universities are classified according to the growth acceleration in their time series data of publications. For each case, series data were fitted to an exponential function and a linear function, and the comparison between the two adjusted  $R^2$  values was used to classify the universities into either the linear or the exponential categories. In some cases, universities with strong fluctuations in the number of publications did not fit any of the listed categories; these universities were classified into the linear and irregular category.

The universities were classified as follows:

- EEG: the curve of publications fits an exponential function. Furthermore, the universities have been publishing research for at least 25 years and have published more than 100 documents a year over the last 2 years.
- LEG: the curve of publications fits an exponential function. Furthermore, the universities have been publishing for less than 25 years and have published fewer than 100 documents per year in the last 2 years.
- LIG: the curve of publications fits a linear function or the curve of publications shows strong fluctuation in the number of publications, sometimes related to years without publications.

We suggest that the observed growth in the number of publications is a result of successive processes of IC accumulation. This means that universities with increasing resources and intangible assets dedicated to research activities—such as the human capital effort dedicated to research, doctoral programs, research expenditure and participation in research networks—will experience accelerated growth in their knowledge production. Research capacities in one period may be capitalized on, and these will increase their capacities to produce knowledge in the following period. In this way, universities show research systems with feedback structures.

### Intellectual capital

“Intellectual capital is intellectual material—knowledge, information, intellectual property, experience—that can be put to use to create wealth” (Stewart 1999, pp. XX). In the case of universities, IC can be understood as the capacity to produce knowledge. Knowledge production is a process in which some resources are leaked out of the system while others are capitalized on in order to be used in the next time period. In addition, the capacities accumulated over a period of time form the potential capital to produce knowledge in the next period (Bucheli et al. 2008). Hence, the IC characteristics accumulated over time can be observed as competitive advantages. IC is usually composed of human capital, structural capital and relational capital (Bernardez 2008; Bontis 1998; Meritum 2011; Marr and Moustaghfir 2005). In the context of this work, we also consider financial capital.

Appendix presents the indicators that were defined to study Colombian universities' IC. These indicators have been classified into four types, human capital, structural capital, relational capital and financial capital.

<sup>1</sup> The data was retrieved on April 2010. The search strategy used was “cu = (Colombia)”.

## Colombian universities' IC accumulation

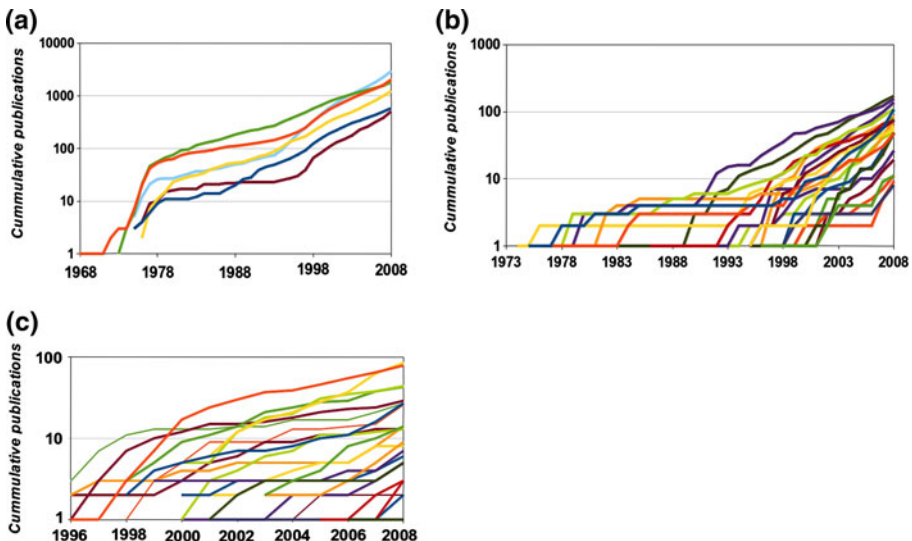
Fifty-six percent of Colombian universities are experiencing exponential growth in their publications, and the remaining 44% show LIG. Figure 2 shows the time series data of universities classified into the three categories, as explained in the previous section.

Nine percent of the universities are classified into the EEG category. These universities have published at least one piece of work over the last 25 years. Consequently, this category has the longest period of capital accumulation (42 years). Currently, universities in this category publish more than  $10^2$  papers per year.

The LEG category is characterized by a shorter period of accumulation than the EEG category, and each university's publications are on the order of  $10^1$  per year over the last 5 years. The linear and irregular category contains 44% of the universities. These universities began to publish recently, meaning that their rate of publication has not experienced accelerated growth. In addition, in some cases the number of publications of universities in the LIG category fluctuates greatly over time.

The behavior presented in Fig. 2 is associated with the accumulation of IC and means that the EEG category has been accumulating more IC than the other categories. We suggest that the exponential growth in research activity in Colombian universities is related to their adapting capacity; that is, changes to their internal structure in order to produce knowledge. We propose that internal structures of universities that have created feedback cycles within their system of knowledge production have accelerated growth in their numbers of publications.

These internal changes began with reforms at some universities, such as those at the Universidad del Valle (1962), the Universidad de Antioquia, and "Reforma Patiño" of the Universidad Nacional (1964) (Villaveces and Forero 2007). These reforms and institutional changes represent the first adaptations of Colombian universities to accumulate IC and to



**Fig. 2** Time series of Colombian universities' scientific publications (log-normal plots). **a** Trend of accumulated publications for each university in the EEG category. **b** Trend of accumulated publications for each university in the LEG category. **c** Trend of accumulated publications for each university in the LIG category

develop research activities. Eventually, other universities adopted some of these changes. Their late starts could be the cause of their delay in starting to publish.

Universities from the EEG category are characterized by early changes in the statute of professors, faculty career professors and programs of professor mobility for master's degrees and doctoral studies. A crucial adjustment in the organizational structure of these universities was the change of lecture professors to full-time professors. These changes could explain why the universities in the EEG category began to publish by 1970, and the accelerated growth of their publications began between 1970 and 1978. The universities from the LEG category began to publish by the end of the 1970s and show accelerated growth after 1990, which could be related to the creation of the CSS&T in 1991. Doctoral programs in Colombia began in 1986; this constituted a self-reproducing mechanism of human capital for research activities in Colombia.

Organizational changes have structured Colombian universities with the ability to produce and reproduce knowledge, which was observed by Colciencias's increasing financial resources for research activities, as well as the rising number of active FTE PhD professors and doctoral programs, changes in the structure of the co-authorship network, and other changes. The following section presents an empirical study of IC accumulation between 2003 and 2009.

### Financial capital

In its first 2 years (1969–1971), Colciencias awarded grants to eight universities for research activity. Ninety-four percent of these were universities from the EEG category (Table 2 shows that percentages have been similar over time). Universities from the EEG category have been awarded grants every year since 1969. Universities from the LEG category have received fewer grants—the number changes significantly and fluctuates over time—and universities from the LIG category show similarly small percentages of grants received.

We reviewed the research expenditures reported by universities to SNIES. Universities from the exponential groups had the highest growth rates. The average growth rate of research expenditure is 200% in universities from the EEG group, 150% in universities from the LEG group, and 50% in universities from the LIG group. This shows that universities with greater capacities receive more financial resources from Colciencias over time and that these universities allocate higher percentages of their internal resources to research than other universities.

### Human capital

Figure 3 shows that universities from the exponential categories revealed the greatest human capital accumulation, and that these had the largest changes in the active FTE faculty with

**Table 2** Percentage of grants awarded to universities in each group by Colciencias for research activities

	1969–1971 (%)	1972–1978 (%)	1979–1990 (%)	1991–2001 (%)
Early exponential group	94	89	80	77
Late exponential group	6	6	9	10
Linear and irregular group		1	3	4
Other universities <sup>a</sup>		4	8	9

<sup>a</sup> Other universities are presented in this table, but they are not included in this study

PhDs. Figure 3a shows critical differences, in order of magnitude, between Colombian universities. Universities from the EEG group have between  $10^2$  and  $10^3$  active professors with PhDs, and universities from the LEG group have between  $10^1$  and  $10^2$  active professors with PhDs. In the LIG group this relationship changes: there are more professors with PhDs than active professors, and the number of faculty with PhDs is closed to  $10^0$ .

Figure 3b presents the change ( $\Delta$ ) in both indicators. It shows that universities from the EEG category have the largest changes. In addition, it shows that the increase in number of professors with PhDs is associated with the increase in active professors. This is related to the universities' strategy of increasing active professors with PhDs to improve knowledge production.

### Structural capital

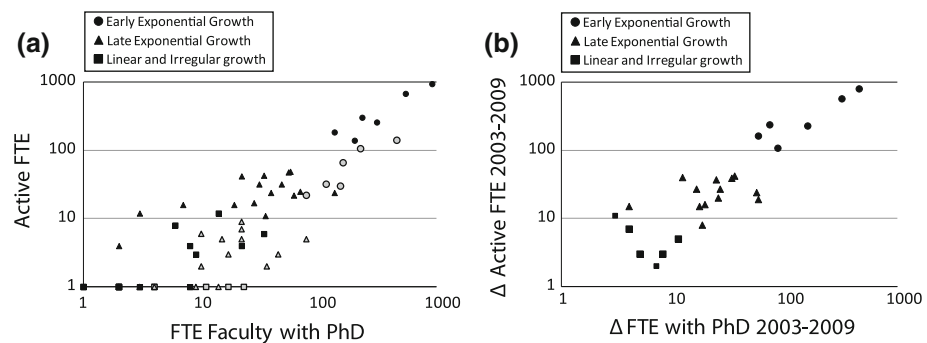
In the case of structural capital, doctoral programs (1986), institutional accreditations (2003), and taking part in research centers (2007) are distinguishing features of Colombian universities from the exponential groups. All universities from the EEG group had institutional accreditation, having 95% of doctoral programs in 2003 and 80% in 2009. In addition, all of them participate in at least one research center. Ten percent of universities from the LEG group had an institutional accreditation in 2009, and these universities had 5% of doctoral programs in 2003 and 20% in 2009. Universities from the other groups do not have doctoral programs. Consequently, these universities do not have the capacity to reproduce human capital through PhD programs. As mentioned above, universities with accelerated publication growth also have increased accumulated structural capital.

### Relational capital

The accumulation of relational capital was studied through research groups and co-authorship networks. In each case we observed the accumulation of relational capital.

### Research groups

Colciencias categorizes Colombian research groups into the categories A1, A–D, according to their academic production (results in science, teaching, technologies and innovation, etc.),



**Fig. 3** Human capital accumulation in Colombian universities (2003–2009), log plot. **a** Relationship between the FTE faculty with PhDs and active FTE. **b** Relationship between the change (*upward triangles*) in FTE faculty with PhDs and change (*upward triangles*) in active FTE. In **a**, the *gray data markers* 2003 and the *black data markers* 2009

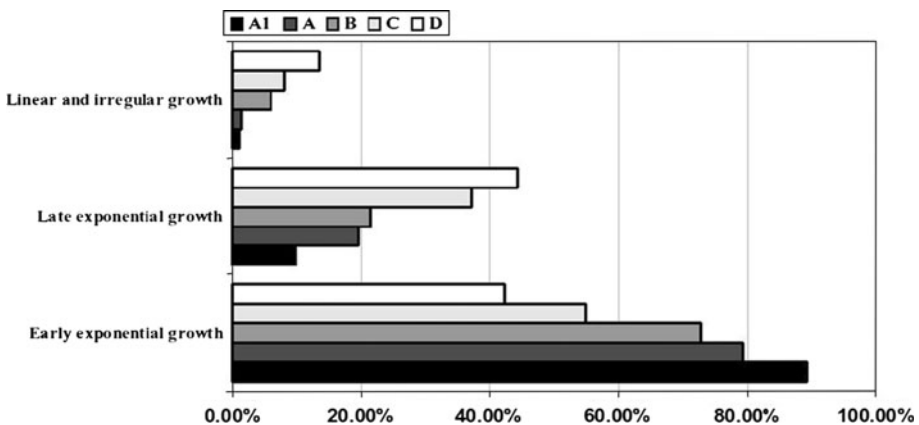
and uses these categories as the main criterion to allocate financial resources to develop research activities. A1 represents the highest performance, and D represents the lowest performance. Figure 4 shows that the large majority of research groups belong to universities from the EEG and LEG groups: universities from the EEG and LEG groups had 99% of the A1 and A research groups in 2008.

*Co-authorship networks*

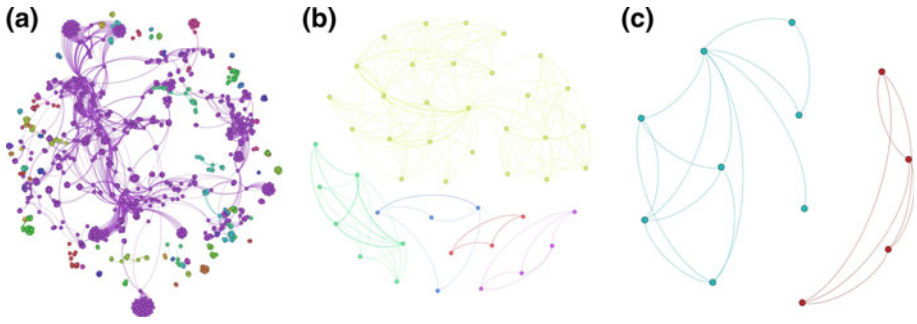
Relational capital is associated with the capacity to produce knowledge based on networks or social relationships. Newman (2002) and Catanzaro et al. (2004) report that co-authorship networks show structures similar to those of connected communities. We evaluate the sizes, cohesion and connectivity of university co-authorship networks and their relationships with the growth of knowledge production in Colombian universities. We found differences in these network characteristics between groups. Figures 5, 6 show the co-authorship networks of a university from each growth group; these illustrate the different characteristics announced and the network changes over 6 years (2003–2009).

Figure 7 shows that universities from the exponential categories have accumulated more FTE with PhDs and more external co-authorships over the 6 years. The accumulation of external co-authorship relationships is an important factor for producing knowledge, considering the efficiency of networks, information and resource sharing, and the availability of resources from the external network.

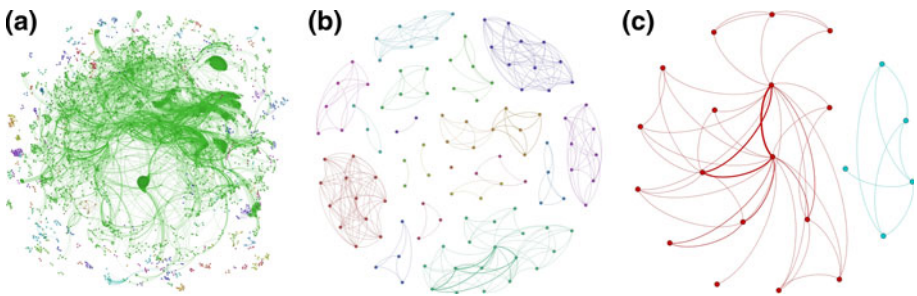
Figure 7a shows that critical differences in relational capital between categories are similar to those of human capital. Thus, universities from the EEG group show between  $10^2$  and  $10^3$  external co-authorship relationships, close to one co-author for each professor with a PhD. Meanwhile, universities from the LEG group have between  $10^1$  and  $10^2$  external co-authorship relationships. The LIG group have lower number of FTE with PhDs and external co-authorships than the other groups; relatedly, these present the smallest accumulation of relational capital. Figure 7b illustrates a direct relationship between change in FTE with PhDs and change in external co-authorship across all universities except those from the LIG group. This direct relationship shows that an increase in the number of professors with PhDs has enlarged co-authorship networks.



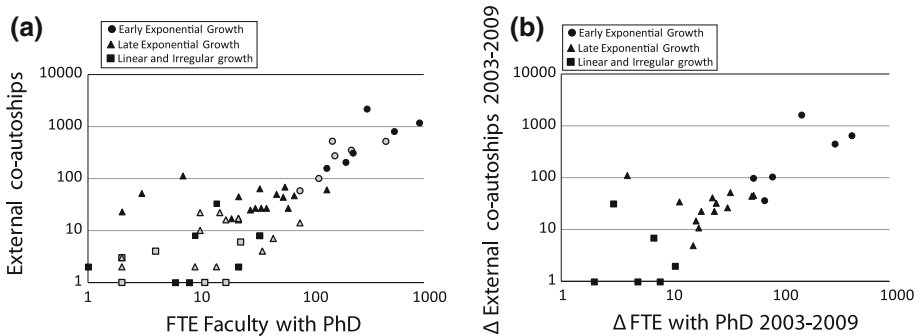
**Fig. 4** Research groups for each growth group (2008)



**Fig. 5** Co-authorship networks for each growth group (2003). **a** EEG. **b** LEG. **c** LIG



**Fig. 6** Co-authorship networks for each growth group (2009). **a** EEG. **b** LEG. **c** LIG



**Fig. 7** Relational capital of Colombian universities (2003–2009), log plot. **a** Relationship between external co-authorships and FTE faculty with PhDs. **b** Change (*upward triangles*) in the relationship between external co-authorships and FTE faculty with PhDs. In **a** the *gray data markers* 2003, and the *black data markers* 2009

Figure 8 shows behavior similar to that of the previous figures with regard to the differences in the order of magnitude between groups, and the greatest capital accumulation of universities from the exponential growth categories. It seems that there is a relationship between co-authorships and clusters, and this illustrates that universities from the EEG category have the largest co-authorship networks.

### Discussion and future work

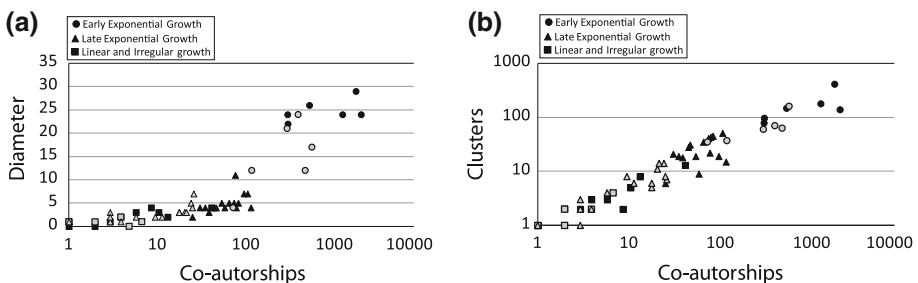
We identify three growth trends in the number of scientific publications by Colombian universities: EEG, LEG and LIG. These can be observed in Fig. 2. They may be part of the same pattern, yet, at different stages in the evolution of university's IC accumulation. We propose that this pattern is related to IC accumulation: universities with greater accumulations of IC have greater capacities to produce knowledge than others, constituting a mechanism for accelerated accumulation of research capacities.

We propose that universities from the EEG group first began to show exponential growth in their publications because they had the capacity to adapt (change internal structure) to the external pressures (public politics) that sought to improve research activity in Colombia. Some of these changes were: research activity as part of the vision of universities, statute of professors, programs of professor mobility for master's degree and PhD studies, more full-time professors, and a greater number of professors with PhDs. These gave rise to the initial human, structural and relational capital, thus generating feedback structures that allowed these universities to begin accumulating IC earlier than others.

We observed differences in the growth of universities' publications across the three categories: universities in the EEG group grew their annual publications by three orders of magnitude, those in the LEG group grew by two orders of magnitude, and those in the LIG group grew their publications by just one order of magnitude. The differences in order of magnitude are also observed in accumulation of human, structural, relational and financial capital.

We propose that this is related to the time of accumulation, independently of the foundation date; it could be related to internal policies, strategies, or organizations of the research systems. The IC characteristics observed are active FTE faculty with PhDs, external and internal funding allocated to research, doctoral programs, research groups, and external co-authorship networks.

The disparities in universities' accumulated capacities also generate differences in the dynamics of this accumulation. Universities with greater IC accumulate more capacities than others to carry out further research activity. These universities get to be recognized for their research, which supports their achievement of IC. The accumulation of IC translates into ever greater capacities for carrying out research activity. The universities in the EEG group have the highest number of publications, and in the last 5 years of the study published more than 80% of all Colombian publications.



**Fig. 8** Clustering and diameter of the co-authorship networks for each growth group (2003–2009). **a** Relationship between co-authorships and clustering. **b** Relationship between co-authorships and diameter, log plot. The gray data markers 2003, and the black data markers 2009

Our work suggests that we need to promote research in Colombia, especially within universities. Toward this end—and to support policy making in universities—it seems important to study in depth the relationships between the different types of IC and the feedback structures produced. This approach toward systemically observing research activity could be used to forecast and evaluate research policies at universities. Research toward understanding these feedback structures is proposed as future work.

Publications' growth patterns can be observed at different scales: academic unit, university, country, or region. This means that we can observe IC accumulation at several scales. As future work we propose studying IC accumulation and scientific production with scales other than at the university level. In similar way, we will study the growth patterns in different scientific fields and at different aggregation levels (e.g. university level, country level, regional level).

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## Appendix

See Table 3.

**Table 3** Intellectual capital indicators

Category of capital	Indicator	Description
Human capital	Full-time equivalent (FTE) faculty	A university's workforce (the number of professors) and its activities can be added up and expressed as the number of full-time equivalents
	Full-time equivalent (FTE) faculty with PhDs	Number of full-time faculty with PhDs
	Growth rate of FTE faculty	Quantifies the change in the number of professors over 7 years (2003–2009)
	Percentage of FTE faculty with PhDs	Percentage of full-time equivalent faculty with PhDs
	Ratio of FTE faculty active in publications	Percentage of full-time equivalent faculty with publications
	Ratio of FTE faculty with PhDs active in publications	Percentage of full-time equivalent faculty with publications and PhDs
Structural capital	Institutional accreditation	High-Quality Institutional Accreditation granted by the National Accreditation Council (NAC)
	Research excellence center	A research excellence center is a national network of research groups. This indicator identifies whether the university participates in at least one research excellence center
	PhD programs	This indicator identifies whether the university has at least one PhD program
	Students in PhD programs	This indicates whether students are enrolled in the PhD programs

**Table 3** continued

Category of capital	Indicator	Description
Relational capital	Research groups	The number of research groups weighted by category in 2008 (Colciencias categorizes Colombian research groups into A1, A–D)
	Research financial leverage ratio	The ratio between research expenditures from external sources and the total research expenditures (2008)
	Social network measurements of relationships in co-authorship networks	The size, number of cliques, and the lengths of the geodesic paths are evaluated (2003–2009)
	Growth rate of social network measurements in co-authorship networks	The increase in the social network measurements listed above (2003–2009)
Financial capital	Research and development expenditure	The money spent on creative work undertaken on a systematic basis to increase the stock of knowledge and the use of this knowledge to devise new applications (Organization for economic co-operation and development, 2005)
	Research income	Income received exclusively for research activities
	Growth rate income	The increase in income over 7 years (2003–2009)
	Growth rate research expenditure	The increase in research expenditure over 7 years (2003–2009)
	Percentage research income	The percentage of total income assigned to research

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