HUMAN CAPITAL THRESHOLDS AND ECONOMIC GROWTH IN BRAZIL

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Abstract

This paper examines the convergence process in Brazil over the period 1985-2004, giving a special attention to the role of human capital in this process. Different measures of human capital are used in the growth regressions and the results show that they play a significant role in explaining the economic growth process. The evidence indicates that different levels of human capital have different impacts on per capita GDP growth, depending on the level of development of the regions. Lower levels of human capital explain better the convergence among the less developed states and higher levels of human capital are more adequate among the more developed states.

JEL: O1, O15, R11

Keywords: Regional growth; Human capital, Panel data.

Resumo

Este artigo analisa o processo de convergência condicional no Brasil no período 1985-2004, com atenção especial ao papel do capital humano neste processo. Diferentes medidas de capital humano são utilizadas nas regressões de crescimento e os resultados mostram que estas medidas tem um papel significante na explicação do processo de crescimento econômico. Os resultados empíricos indicam que diferentes níveis de capital humano têm differentes impactos no crescimento da renda per capita, dependendo do nível de desenvolviemto das regiões. Niveis mais baixos de capital humano explicam melhor a convergência entre os estados menos desenvolvidos e níveis mais altos de de capital humano são mais adequados entre estados mais desenvolvidos.

JEL: O1, O15, R11

Palavras Chave: Desenvolvimento regional; Desenvolvimento humano. Panel data.

1 Introduction

Since the 1980s, the convergence phenomenon has been widely discussed in the growth literature and many concepts related to convergence in per capita GDP or productivity (output per worker) were developed to explain regional economic growth. Empirical studies following Barro (1991), Barro and Sala-i-Martin (1992) and Mankiw *et al.* (1992) have confirmed that convergence is conditional rather than absolute. Therefore, the fundamental problem in growth theory consists in finding the conditioning factors that better explain the convergence process among different economies (Sala-i-Martin, 1996). The endogenous growth approach stresses the importance of human capital for growth and advocates that human capital is the engine of growth and the factor responsible for increasing returns to scale char-

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acteristics in the long term (e.g. Romer, 1986, 1990; Lucas, 1988). Later, with the development of the concept of conditional convergence, human capital became a key factor to growth process and the idea of local increasing returns to scale was accommodated in the neoclassical conditional convergence equation.

However, the empirical evidence suggests that the relation between most measures of human capital and growth is weak (Sala-i-Martin, 2002). Mankiw *et al.* (1992), Islam (1995), Sachs and Warner (1997), Temple (1999), Barro (2001), and Cohen and Soto (2007), among others, have pointed out problems with human capital proxies and suggest the use of a qualitative measure of human capital. Therefore, data quality could be the problem that overcast the relation between human capital and growth. Nevertheless, the weak effect of human capital on growth can also emerge when a wrong proxy for human capital is used given the level of development of an economy due to nonlinearity in human capital and threshold effect (e.g. Azariades and Drazen, 1990; Sachs and Warner, 1997; Kalaitzidakis *et al*., 2001).

The purpose of this study is to evaluate the importance of human capital for the convergence process across the Brazilian states over the period 1985-2004, considering different levels of human capital. Using a panel data approach, different measures that are related to human capital levels expressed by illiteracy rate, secondary school enrolment rate, average years of school attainment, and publication rate of articles in international journals are used in the estimation process to identify different patterns of human capital effects across different regions in Brazil. The paper analysis whether there are different impacts on growth stemming from different levels of human capital, how they affect the convergence rate, and whether different levels of human capital affect differently regions with dissimilar levels of development. This gradual testing of the importance of different levels of human capital for economic growth in regions with different level of development has not been explored yet.

Therefore, to study the importance of human capital for growth and the existence of educational thresholds in Brazil, this paper is structured as follows: Section 2 describes the growth framework and the specification used in the estimation process. Section 3 discusses the importance of human capital to economic growth. Section 4 explains the data, methods of estimation and the samples considered in the empirical analysis. Section 5 tests the hypothesis of conditional convergence assuming that growth is conditioned to different levels of human capital. Section 6 discusses the endogeneity problem of the regressors in the growth equation and the final section concludes.

2 The Empirical Model

The convergence specification is based on the Solow (1956) neoclassical model and was formally derived by Mankiw *et al*. (1992). They suggested an augmented Solow model based on the production function with labour-augmenting technical progress that includes human capital accumulation given by:

$$Y(t) = K(t)^{\alpha} H(t)^{\beta} [A(t)L(t)]^{1-\alpha-\beta}, \text{ with } 0<\alpha+\beta<1 \quad (1)$$

where Y is output, K, H and L are factor inputs, physical capital, human capital and labor, respectively. The term A is the level of technology, α and β are the physical and human capital elasticities with respect to output, and t is time.

The model assumes that L and A grow exogenously at constant rates n and g, given by $L(t)=L(0)e^{nt}$ and $A(t)=A(0)e^{gt}$, respectively. Therefore, the number of effective units of labor, that is, $A(t)L(t)$, grows at rate $n+g$.

On the other hand, savings, S, is a constant fraction of output ($S=sY$, $0<s<1$) and K depreciates at a constant exogenous rate d, therefore, $\dot{K} = \frac{dk}{dt} = I - \delta K$, where I is investment. Accordingly, a constant amount of capital, dK, in each period t, is not used. The same argument is also valid for human capital, which depreciates at the same rate as physical capital.

Under the standard neoclassical assumption of constant returns to scale, the production function in terms of effective units of labour is given by:

$$\bar{y} = \bar{k}^{\alpha} \bar{h}^{\beta}$$
$$\text{with } \bar{y} = \frac{Y}{AL},\ \bar{h} = \frac{H}{AL}, \text{ and } \bar{k} = \frac{K}{AL} \quad (2)$$

The capital accumulation equations that determine the path of human and physical capital accumulation are expressed by:

$$\dot{\bar{k}}(t) = s_k \bar{y}(t) - (n+g+\delta)\bar{k}(t) \quad (3)$$
$$\dot{\bar{h}}(t) = s_h \bar{y}(t) - (n+g+\delta)\bar{h}(t) \quad (4)$$

These equations together with the production function determine the GDP per capita steady-state given by:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \left(\frac{\alpha}{1-\alpha-\beta}\right)\ln(s_k) - \left(\frac{\alpha+\beta}{1-\alpha-\beta}\right)\ln(n+g+\delta) + \left(\frac{\beta}{1-\alpha-\beta}\right)\ln(s_h) \quad (5)$$

Mankiw *et al*. (1992) demonstrated that by approximating around the steady-state the growth model could be estimated by the following specification:

$$\ln y(t_2) - \ln y(t_1) = (1-e^{-\lambda T})\frac{\beta}{1-\alpha}\ln(h^*) + (1-e^{-\lambda T})\frac{\alpha}{1-\beta}\ln(s_k) - (1-e^{-\lambda T})\frac{\alpha}{1-\alpha} \ln(n+g+\delta) - (1\text{-}e^{-\lambda T})\ln y(t_1) + (1-e^{-\lambda T}) \ln A(0) + g(t_2 - e^{-\lambda T}t_1) + v_{it} \quad (6)$$

where $(1\text{-}e^{-ëT})$ ln$A$(0) is the time-invariant individual country-effect term and $v_{i,t}$ is the error term that varies across countries and over time. Estimating equation (6) using panel data (instead of cross-section) one takes into account for differences in production functions across countries by introducing specific regional effects using the Least Squares Dummy Variable (LSDV) approach as in Islam (1995).

According to Temple (1999), though the Mankiw *et al*. (1992) model provides a theoretical framework for growth regressions, the most common approach is the use of a more *ad hoc* regression that encompasses other factors that influence growth. These variables are chosen based on previous results in the literature rather than on an explicit theoretical model. Regressions of this type are known as "Barro Regressions", after Barro (1991) seminal work. Once these informal regressions include the investment ratio and initial GDP, they can be seen as an extension of Mankiw *et al.* (1992).

The hypothesis of convergence has been tested by estimating the following simple equation:

$$\Delta \ln y_{it} = a_i + b \ln y_{i,t-1} + \psi X_{it} + v_{it} \quad (7)$$

where $\Delta \ln y$ denotes the GDP per capita growth, $\ln y_{t-1}$ is the initial GDP per capita, i denotes each individual economy, b the convergence coefficient, t represents each period of time considered and X represents a vector that allows the growth framework to incorporate factors that control differences across economies. This vector encompasses the growth determinants suggested by the original Solow model (physical capital and population growth) as well as other growth determinants that came from outside the formal Solow's model (e.g. education, rule of law, institutions, trade). If the coefficient of the initial GDP per capita is negative ($b<0$) and $\psi = 0$ the data exhibits conditional convergence. If the coefficient of the initial per capita GDP is negative ($b<0$) and $\psi = 0$, absolute convergence holds.

3 The Role of Human Capital

Economists have been stressing the importance of human capital in the process of economic growth, although empirical evidence does not always provide conclusive results of this fact. This paper argues that human capital is always important for economic growth when an adequate proxy for the human capital level that is associated to the intermediate level of human capital of a given economy is considered.

Mankiw *et al.* (1992) were the pioneers in introducing human capital into the neoclassical growth model, recognizing the theoretical importance of this capital to growth, as demonstrated in the previous section. Barro (2001) suggests that a higher ratio of human capital to physical capital tends to generate higher growth through at least two channels. First, more human capital facilitates the absorption of higher technologies developed by leading countries. Second, human capital tends to be more difficult to adjust than physical capital, therefore a country that starts with a high ratio of human to physical capital tends to grow rapidly by adjusting upwards the quantity of physical capital.

The endogenous growth theory spotlighted the role of human capital for the growth process and provides many insights about the channels through which human capital affects growth. In this literature, human capital (and its result) is frequently the starting point to increasing returns to scale characteristics. Romer (1986, 1990), for example, formalized the relationship between economic growth and the stock of knowledge and technical progress. In others words, Romer has formalized the relationship between economic growth and the outcome of human capital. According to him, new ideas have special characteristics, they are non-rival commodities. This characteristic can generate positive externalities and increasing returns to scale properties[3]. Lucas (1988) emphasized that human capital accumulation can be considered as an alternative source of sustained growth. Growth is primarily driven by the accumulation of human capital, thus differences in growth rates across countries can be explained by differences in the rates of accumulation of human capital over time. Barro and Sala-i-Martin (1997) also used the outcome of human capital to formulate an endogenous growth model with increasing returns to scale characteristics that accommodates convergence across economies.

The more *ad hoc* framework represented in equation (7) is arguably more flexible and can implicitly be seen as a link between the neoclassical and endogenous growth models, once it encompasses the hypothesis of convergence and allow the use of variables that present local increasing returns to scale characteristics.

However, there has been some cautionary discussion concerning the type of human capital to use in the growth equations. Mankiw *et al*. (1992), Islam (1995), Sachs and Warner (1997), Temple (1999, 2001) and Barro (2001), among others, have pointed out some problems with the human capital measures. More recently, Cohen and Soto (2007), for example, argue that the inaccuracy of human capital proxies can be part of the problem that led many empirical works to find a negative impact of human capital on growth and the improvement in data quality could overcome this problem. Another important issue is related to the quality of human capital. Barro (2001), for instance, suggests that the quality of school-

[3] More precisely, Romer (1986) argues that the ideas and knowledge are non-rival goods but human capital itself is rival.

ing is much more important than the quantity; therefore measures of the efficiency of human capital must be considered to explain growth.

However, even if the data is well constructed, another reason that leads to negative impact of education on growth is the inadequacy of some proxies for human capital to a given set of economies due to threshold effects. Azariades and Drazen (1990) argue that threshold externalities may easily arise in the accumulation of human capital. They argue that there are two ways in which human capital accumulation can result in development take-offs; when an economy reaches a given level of knowledge, it makes it easier to acquire further knowledge or induces a sharp increase in production possibilities. Threshold externalities in the accumulation of human capital become particularly pronounced when economic state variables attain a threshold value.

This nonlinear human capital effect can be observed as the level of human capital reaches a certain level that starts influencing economic growth. For a cross-section of Brazilian states, for example, Lau *et al.* (1993) test the threshold effects of educational level beyond which human capital would have a significant effect on growth. Using the average number of years of formal education, they set up a hierarchical set of 5 human capital variables to test for the threshold effects. They observed a rise and fall of the estimated coefficients of human capital, suggesting the existence of thresholds at an intermediate level of human capital.

Sachs and Warner (1997) argue that human capital accumulation is a nonlinear function of the human capital level. When initial human capital level is low, the speed of human capital accumulation is low too. When human capital is at an intermediate level, then the increase in human capital is faster. When the level of human capital is already very high, then once again the human capital accumulation is slow.

Kalaitzidakis *et al.* (2001) also suggest the existence of a nonlinear relationship between growth and human capital (measured by average years of schooling). They argue that at low levels of human capital the effect on growth is negative and became positive at middle levels. This means that growth tends to be higher in regions with a relative intermediate level of human capital[4].

The objective of this study is in line with Lau *et al.* (1993) that constructed 5 variables from the original data of years of schooling to identify educational thresholds in Brazil. Nevertheless, one could also expect limited ability of this variable to proxy for high levels of human capital. Proxies that do not capture many levels of human capital will not be able to capture the educational effect on growth[5]. The difference in this paper is that, alternatively, it uses different variables to proxy for different levels of education to identify different thresholds. In addition to the traditional measures that are related to the human capital level, such as, illiteracy rate, secondary school enrolment and average years of schooling (that also captures tertiary education), a newly constructed measure reflecting the production capacity of scientific work is used. This new measure is given by the number of scientific articles (per million of inhabitants) published in international journals, *ART*. This proxy has already been discussed in different context in the economic literature. For instance, Patel and Pavitt (1995) discuss the utility and the problems arising when this variable is used as a proxy for scientific production. Bernardes and Albuquerque (2003) consider that the number of published papers may be taken as an index of the state of the educational system, reflecting the efficiency of the educational system. In the context of growth models, this proxy was used by Soukiazis and Cravo (2008) and performed well in explaining the growth process among developed nations.

This new proxy emerges as alternative to measure the quality of higher levels of human capital associated to highly skilled labour. For example, two economies that hold the same level of education in terms of years of schooling can be different in their levels of scientific work given by *ART*. The economy with higher *ART* presents a better quality of education or makes a better use of the acquired skills. Therefore, *ART* expresses higher levels of human capital associated to more skilled labour that cannot be captured by the usual schooling measures.

More explicitly, to study the convergence process across the Brazilian states, different measures that represent different levels of human capital are used, in the sense that those levels are related to different levels of skills requirements. Conceptually, there has not been a clear definition on how human capital should be represented and in this paper we assume that each measure is related to different levels of knowledge and skill requirements. For instance, a definition of human capital put forward by Becker *et al*. (1990) states that human capital is knowl-

[4] Note that the intermediate level of human capital differs across regions and is relative to the level of human capital in a given economy.

[5] For example, the illiteracy would not be a proper proxy for rich economies human capital level, where there is no illiteracy. In the same sense, when the population of an economy starts to reach the maximum number of years of the formal schooling, this proxy could be ineffective to measure the effect of human capital on growth.

edge embodied in people. This paper assumes that all variables related to the human capital level encompass this characteristic from the basic level of knowledge to scientific knowledge. The illiteracy rate (IL) expresses the lowest level of human capital and it is reasonable to assume that this proxy is associated to very basic levels of skills required to perform simple tasks. The rate of enrolment in the secondary school (*SEC*) represents the level of human capital related to skills necessary to perform activities that requires secondary schooling knowledge. In its turn, the average years of schooling (*SCHOOL*) also encompasses the years of tertiary education and embraces the level of human capital related to skills necessary to perform more specialized jobs. Finally, the amount of publications (per million of inhabitants) (*ART*) represents higher levels of human capital associated to research and development.

Figure 1 expresses the idea of human capital thresholds along the process of development following the idea of nonlinearities in human capital[6]. In this figure there are three critical points where the economy jumps towards the steady state of another level of technology. The point H_1^* can be seen as the threshold that ignites a higher growth towards another level of development when our economy reaches the first critical point in terms of level of education. Once this stage is reached, the economies should converge at least temporarily until another critical point of a higher level of education represented by H_2^*. The process is repeated again until the next jump when one economy reaches the next critical point H_3^*. The critical points have more human capital than necessary to the respective steady-state. However, this overqualification of the labour force is necessary to reach the point that will trigger higher growth towards another level of development.

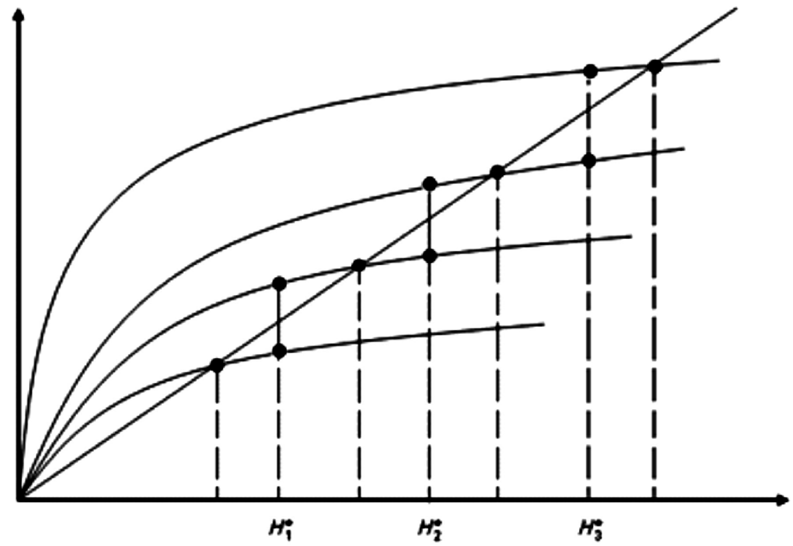

Figure 1 – Human Capital Thresholds

Therefore, to capture the effect of human capital on growth, it is necessary to use a proxy appropriated to each stage of development linked to a relative different intermediate level of human capital that can be associated with an interval that can present local convexity (increasing returns associated to human capital).

4 The Data, Methods of Estimations, and Regional Samples

4.1 Data and Methods of Estimations

The data set for Brazilian states for the period 1985-2004 includes real per capita output, capital stock, population and various proxies of human capital levels.[7] The data are organized in 5-years time span to avoid modelling business cycles and are taken from the following sources.

1. Real per capita output (*Y*) data was collected from IPEA (Institute of Applied Economic Research)[8].

2. The data for population (*n*), used to calculate the population growth were collected from IPEA (Institute of Applied Economic Research).

3. Capital stock (*K*) data are not available for Brazilian States. As a proxy, the average of industrial consumption of electricity for each 5-years period is used instead. This measure has been extensively used as a proxy to capital stock in Brazil (e.g. Lau *et al*., 1993; Ferreira, 2000; Nakabashi and Salvato, 2007; Cravo et al., 2010). Lau *et al*. (1993), for instance, argue that this measure has the advantage over the capital stock once it already embodies a rate of utilization adjustment. This data is also taken from IPEA.

4. The traditional proxies for human capital, illiteracy rate (IL) of the population aged 15 years and over, enrolment rates at the secondary school (*SEC*) and average years of school attainment (*SCHOOL*) of the population over 25 and over are taken from IPEA.

5. Publication ratio (*ART*) is a constructed variable that is defined as the number of articles published in scientific journals, per million of

[6] Similar figure is found in Azariades and Drazen (1990).
[7] The last year of the analysis is 2004 because the methodology to calculate the GDP was changed after that year.
[8] The value of 2004 for the GDP per capita of 2005 is used due to a change in the National Accounts methodology from 2005 onwards.

> "He observes that when there are two different growth regimes within a group of economies, the traditional convergence coefficient could be misleading because it represents the average and is not able to capture different dynamics across regions."

inhabitants. The source of the data is the Institute for Scientific Information (ISI), and the "Science Citation Index", which excludes papers from arts and humanities, was used to construct this data. Patel and Pavitt (1995) consider ISI as the major source of systematic statistical information on the world's scientific publications and citation, and this indicator has been discussed and used in different context in the literature[9].

A panel data approach is used to estimate the convergence equation (7) presented in section 2. The data are organized in five years intervals[10] to avoid business cycle influences. First, the model is estimated assuming fixed effects expressed in the individual dummy variables estimated by Least Squares Dummy Variables (LSDV) as in Islam (1995). Nevertheless, although LSDV explicitly incorporates the economy micro-regional specific effect, it does not consider the endogeneity problem. To take into account the endogeneity, the GMM in first difference (Arellano and Bond, 1991) and the system GMM (Blundell and Bond, 1998) are used to take into account the endogeneity problem that emerge in growth regressions.

4.2 Regional Samples

Brazil is a country with great regional asymmetries, where the wealth is concentrated in the southern part of the country (e.g. Ferreira, 2000; Azzoni, 2001; Laurine *et al*., 2005; Cravo, 2010a, Resende, 2011). Therefore, pooling all states in the same sample ignores the dynamics of the distribution of GDP per capita across regions and could create difficulties to draw useful inferences for public policy regarding growth and education in Brazil.

Quah (1996, 1997) argue that the traditional analysis based on the standard convergence equation says nothing about the distribution of GDP per capita and suggests the analysis of the distribution of the GDP per capita to identify different dynamics across economies. He observes that when there are two different growth regimes within a group of economies, the traditional convergence coefficient could be misleading because it represents the average and is not able to capture different dynamics across regions. Andrade *et al*. (2004), Laurini *et al*. (2005), and Cravo (2010a) follow Quah's analysis and provide evidence of two different growth regimes in Brazil stemming from the existence of two convergence clubs; a poorer club formed mainly by municipalities of the Northern regions, and a richer club formed mainly by the municipalities of the Southern regions. Alternatively, using a "regression tree" analysis, Coelho and Figueiredo (2007) also found similar pattern. Their results suggest the existence of club convergence and confirm the regional pattern that the northeast region belongs to the poorest club while the south and southeast states belong to the richest one. Silveira-Neto and Azzoni (2006), Cravo (2010b), Resende (2011) use a local indicator of spatial association and suggest the existence of two geographical income clusters in Brazil. In one cluster encompassing South and Southeast regions they observe the presence of high-high values for per capita income. The second cluster of low-low values dominates the spatial pattern in the Northern part of the territory.

Therefore, to control for different growth dynamics this study considers two alternative samples based on the evidence provided by the empirical studies for Brazil presented above. Besides the full sample that includes data on 25 Brazilian states available for the period of analysis[11], two regional samples were created. One sample comprises seven states from the South and Southeast (SSE) regions (the most developed area in Brazil), and the other regional sample, is constituted by nine Northeast (NE) states (the least developed area of the country). According to Sala-i-Martin (1996), one can explicitly control for different steady-states creating samples with regions that are more similar. The purpose of this division is twofold: first, to detect different convergence processes among the various groups that have different levels of development, the more advanced (SSE) and less advanced (NE); sec-

[9] Please refer to the appendix for more detail on the data collecting process to construct the variable publication ratio to the Brazilian States.

[10] The data for School, SEC and IL is not available for 2000 and we used the data for 2001 instead.

[11] Brazil is divided into 27 Federal Units including the Federal District of Brasília. The most recent State (Tocantins) was created in 1988 which constitutes the northern territory of the former state of Goiás. These two states were excluded from the sample.

ond, to find what level of human capital contributes more for the improvement of the standards of living among the groups of states with dissimilar levels of development.

5 Empirical Results

5.1 Convergence Conditional to Human Capital in Brazil

The existing literature provides evidence of convergence for Brazilian states and suggests that convergence is conditioned to structural factors such as population growth, share of small businesses, physical capital and human capital (e.g. Ferreira and Diniz, 1995; Ferreira, 1998, 2000; Azzoni, 1997, 2001; Cravo, 2010a; Resende, 2011). Although these studies used human capital as a conditioning convergence factor, they do not provide a detailed analysis of the role of human capital in this process.

Additionally, some studies focused specifically on the importance of human capital for Brazilian states. Lau *et al*. (1993) constructed a set of hierarchical human capital variables based on years of schooling to analyze whether there are threshold effects of human capital on growth in Brazil. They found that human capital has a positive and significant effect on growth and suggested the existence of educational threshold at intermediate levels of human capital. Recently, Nakabashi and Salvato (2007) analyze the importance of human capital quality for growth in Brazil. They constructed a human capital variable that considers the quality of education multiplying the number of years of schooling by an index of education quality that includes the percentage of teachers holding an undergraduate degree, student pass rate and number of student per classroom[12]. Their results suggest that quality of human capital is important for Brazilian growth.

This study is close to Lau *et al*. (1993) and Nakabashi and Salvato (2007) in the sense that it is concerned with threshold effects as in the former and with the quality of human capital as in the latter. However, this paper is different because it is concerned with threshold effects using different measures of human capital and not a set of constructed variables based on years of schooling as Lau *et al*. (1993). The proxies used in this study have advantages to analyze growth when higher levels of human capital that are not captured by the years of schooling are considered. Similarly, when the quality of human capital is considered, this paper does it using a different variable (*ART*) that intends to capture higher levels of human capital. For example, if two states hold the same human capital stock represented by *SCHOOL*, they can differ in their scientific publication rate. The economy with the higher levels of these qualitative measures of human capital shows higher standards of education, or at least that it makes better use of the acquired skills in education. A priori these new measures depict, gradually, higher levels of human capital and higher efficiency of education that cannot be obtained from the years of schooling conventional variable (Soukiazis and Cravo, 2008). Additionally, this paper analyses the existence of different responses to human capital coming from regions that presents different levels of development.

In order to analyse economic growth and human capital level, Equation (7) is estimated by introducing, along with the population growth and physical capital, human capital related variables presented in Section 4. These variables intend to capture different levels of human capital related to different skill requirements and allow us to observe whether there are threshold effects in education in Brazil.

Initially, from columns 1 to 4, all human capital proxies are introduced separately into the convergence equation, to avoid multicolinearity and to measure the individual impact of each level of human capital on growth. The results of the panel estimations of the conditional convergence equations using fixed effects are presented in Table 1 bellow.

The estimations confirm previous results in the literature that conditional convergence in Brazil is a robust result. The estimation for human capital that is associated to skills related to the lowest level of human capital represented by the illiteracy rate is negative as expected, revealing that the higher the rate of illiteracy, the lower the growth of per capita GDP. The null hypothesis on this coefficient is rejected at 1% level of confidence (column 2).

The results also suggest a positive impact of human capital on growth when higher levels of human capital are considered. The coefficient for the enrolment rate at the secondary school has the expected positive sign and is highly significant, indicating that human capital at the secondary level is relevant to explain the convergence process among the Brazilian states (column 3).

When the average years of schooling is considered (a measure that also captures the tertiary education) the effect of education on growth remains positive and significant (column 1). Each 1% increase in the average years of schooling induces 0.42% increase in the GDP per capita. This level of human capital also provides the highest explanatory power (adjusted-R^2 is 0.44) among the conditioned regressions that consider each level of human capital separately.

[12] However, the stock of human capital (average year of schooling) is the base of the corrected final variable, regardless of the quality of this stock. Therefore, their final proxy is likely to be heavily influenced by the stock of education.

Table 1- Conditional Convergence in Brazil (1985-2005) – LSDV

	(1)	(2)	(3)	(4)	(5)
Dependent Variable	**GDPgrowth**	**GDPgrowth**	**GDPgrowth**	**GDPgrowth**	**GDPgrowth**
ln($GDPpc_{t-1}$)	-0.855***	-0.897***	-0.863***	-0.752***	-0.882***
	(-9.02)	(-8.95)	(-8.78)	(-7.04)	(-8.90)
ln(*SCHOOL*)	0.422***				0.15
	(4.65)				(0.75)
ln(*IL*)		-0.257***			-0.102
		(-4.37)			(-1.01)
ln(*SEC*)			0.140***		0.110*
			(4.22)		(1.71)
ln(*ART*)				0.0174	-0.0339*
				(1.12)	(-1.89)
ln(*K*)	0.0899**	0.105**	0.0799*	0.0973*	0.101**
	(2.02)	(2.33)	(1.74)	(1.90)	(2.25)
ln(*n*+*g*+ä)	-0.0468	-0.0055	0.147	-0.2	0.0472
	(-0.27)	(-0.03)	(0.75)	(-0.96)	(0.24)
Observations	100	100	100	100	100
Adjusted-R^2.	0.441	0.425	0.417	0.283	0.46
AIC	-215.5	-212.7	-211.3	-190.7	-217.3

Notes: *t* statistics in parentheses. * p-value<0.10, ** p-value<0.05, *** p-value<0.01. *IL* is the illiteracy rate of the population aged over 15.*SEC* is the percentage of young people aged between 15 and 17 that attended the secondary school or had completed 8 years of schooling. *SCHOOL* is the average years of school attainment of the population aged over 25. *ART* is the number of published papers in international journals per million of inhabitants

“ This variable attempts to capture higher levels of human capital related to scientific production ability but fails to influence growth in Brazil. The results of these estimations for each level of human capital are... ”

On the other hand, the estimate for the rate of scientific publications per million of inhabitants (*ART*) suggests that there is no significant effect of the highest level of human capital on growth in Brazil, although having an expected positive sign (column 4). This variable attempts to capture higher levels of human capital related to scientific production ability but fails to influence growth in Brazil. The results of these estimations for each level of human capital are compatible with the existence of thresholds, and are in line with Lau *et al*. (1993) that suggests the existence of educational thresholds at an intermediate level of human capital. It is reasonable to assume that *ART* is not related to the intermediate level of human capital in Brazil and therefore does not affect growth. Column 5 summarizes the empirical evidence of Table 1. When all variables of human capital are included into the convergence equation, the results provide additional support for the existence of thresholds. In this specification, *SEC* dominates and is the only level of human capital that has positive effect on growth and is statistically significant, suggesting that schooling at the secondary level is the relative intermediate level of human capital that triggers economic growth in Brazil. Conversely, *ART* has a negative impact on growth, indicating that investments in higher levels of human capital do not favour economic growth.

The results for physical capital are in line with the theory and are significant and positively related to growth in the Brazilian states. On the other hand, the results for population growth are not significant and could be related to the fact that GDP per capita is the main determinant of migration in Brazil (Figueiredo and Garcia, 2003). Similar results were found by Nakabashi and Salvato (2007) and Cravo (2010a). Following Lau *et al*. (1993), the Wald test is used to test the hypothesis of specific human capital level effect. In the first part of Table 2, the restrictions imposed on coefficients to account for no educational effect in the regressions that consider each human capital proxy separately (specifications 1 to 4) suggests that the null hypothesis of no educational effect is not rejected only for *ART*; reinforcing the idea that this proxy is not suitable for explaining the growth process in Brazil. The hypothesis of no educational effect stemming from each level of human capital in the full specification (with all levels of human capital together) is also tested. The results are shown in the second part of Table 2, which rejects the idea of no human capital effect on growth, confirming the importance of this factor to the process of economic growth.

Table 2 – Test of Coefficient Constraints for Brazil

Hypothesis of Null Coefficient	Test-Statistic	Level of Significance
Part 1 - Individual Human Capital Proxy Regressions		
b[*IL*]= 0	F(1, 71) = 19.06	0.0000
b[*SEC*] = 0	F(1, 71) = 17.78	0.0001
b[*School*] = 0	F(1, 71) = 21.63	0.0000
b[*ART*] = 0	F(1, 71) = 1.25	0.2665
Part 2 - Joint Regressions for all Human Capital Proxies		
b[*IL*]=b[*SEC*]= b[*School*]=b[*ART*] = 0	F(4,68) = 6.97	0.0001
b[*IL*] = 0	F(1,68) = 1.02	0.3156
b[*SEC*] = 0	F(1,68) = 2.94	0.0911
b[*School*] = 0	F(1,68) = 0.56	0.4567
b[*ART*] = 0	F(1,68) = 3.57	0.0631

Note: b stands for the coefficient of the respective variable in brackets.

Finally, the restrictions of no educational effect coming from each human capital variable in the full specification are tested. The null of no educational effect for the two significant variables in column 5 of Table 1 is rejected; *SEC* and *ART*. As evidenced in Table 1, a positive educational effect from *SEC* and a negative one from *ART* is expected. Overall, these results support the view that Brazilian growth responds differently to different levels of human capital. The evidence support the idea of a threshold effect at the intermediate level of human capital represented by *SEC* and also suggests that the scientific production represented by *ART* did not reach its threshold value necessary to trigger its contribution to growth in Brazil. This interpretation is in line with Bernardes and Albuquerque (2003) who suggest that Brazil did not reach a threshold at which *ART* starts to influence growth and with Soukiazis and Cravo (2008) that found that *ART* is more important for growth in developed countries.

"The LSDV results for the two regional samples are shown in Table 3. The results for each proxy of human capital separately (columns 1 to 4) show the same pattern for the Northeast region when comparing to the country as a whole. Convergence is always observed and IL, SEC *and* SCHOOL..."

5.2 Regional Growth and Human Capital

The influence that human capital seems to have on growth when considering the results for all Brazilian states together might reveal different results after controlling for different regional dynamics. The LSDV results for the two regional samples are shown in Table 3. The results for each proxy of human capital separately (columns 1 to 4) show the same pattern for the Northeast region when comparing to the country as a whole. Convergence is always observed and *IL*, *SEC* and *SCHOOL* have a positive and significant educational effect. Conversely, higher levels of human capital expressed by *ART* have no effect on Northeast growth. Column 5, presents the results obtained by estimating the convergence equation where all human capital variables are used as conditioning factors to growth. In this case, results show a significant convergence but the coefficients for all levels of human capital are not significant.

Table 3 - Conditional Convergence (1985-2005)-LSDV Northeast and South/Southeast Regions

	NE					SSE				
	(1) GDP growth	(2) GDP growth	(3) GDP growth	(4) GDP growth	(5) GDP growth	(6) GDP growth	(7) GDP growth	(8) GDP growth	(9) GDP growth	(10) GDP growth
ln(*GDP*) $_{t-1}$	-0.828***	-0.815***	-0.906***	-0.901***	-0.849***	-0.904***	-0.966***	-0.851***	-1.020***	-0.694***
	(-8.01)	(-7.92)	(-8.31)	(-7.12)	(-6.49)	(-2.96)	(-4.34)	(-3.05)	(-4.27)	(-3.78)
ln(*SCHOOL*)	0.365**				0.0495	0.616*				-2.237***
	(2.46)				(0.13)	(1.87)				(-3.77)
ln(*IL*)		-0.322**			-0.154		-0.366***			-0.671***
		(-2.52)			(-0.56)		(-3.78)			(-3.74)
ln(*SEC*)			0.109**		0.0899			0.141*		0.094
			(2.49)		(0.97)			(2.02)		(0.84)
ln(*ART*)				0.0317	-0.0159				0.137***	0.138*
				(1.40)	(-0.40)				(3.55)	(1.82)
ln(*k*)	0.0297	0.028	0.0638	0.0912	0.0316	-0.137	-0.137	-0.0901	-0.205*	-0.00795
	(0.39)	(0.37)	(0.91)	(1.22)	(0.40)	(-1.09)	(-1.54)	(-0.83)	(-2.01)	(-0.09)
ln(*n+g+ä*)	-0.506	-0.474	-0.514	-0.798*	-0.397	-0.0571	0.314	-0.106	0.284	0.326
	(-1.26)	(-1.17)	(-1.30)	(-1.86)	(-0.84)	(-0.10)	(0.68)	(-0.20)	(0.59)	(0.97)
Observations	36	36	36	36	36	28	28	28	28	28
Adjusted-R^2	0.763	0.765	0.764	0.724	0.748	-0.016	0.335	0.012	0.297	0.665

Notes: *t* statistics in parentheses. * p-value < 0.10, ** p-value < 0.05, *** p-value < 0.01. *IL* is the illiteracy rate of the population aged over 15. *SEC* is the percentage of young people aged between 15 and 17 that attended the secondary school or had completed 8 years of schooling. *SCHOOL* is the average years of school attainment of the population aged over 25. *ART* is the number of published papers in international journals per million of inhabitants.

When all different levels of human capital are put together in the convergence equation, different levels of human capital are correlated to each other progressively (Knowles *et al*., 2002) and can generate multicolinearity. This multicolinearity problem among the regressors makes it difficult to distinguish the individual effects of the different levels of human capital and affects the credibility of the statistical significance of the regressors (low t-ratios).

A very different scenario appears in the results for SSE in Table 3 (columns 6 to 10). In the regressions with only one type of human capital (columns 6 to 9), all levels of human capital are significant and are important for growth. The main difference is that *ART* is positive and significant for growth. This result might indicate that this region reached a level of human capital that ignited the effect of the upper layer of human capital on growth. The results for the regression for all human capital proxies show that *ART* is positive and significant (column 10). This reinforces the idea that higher levels of human capital are important for growth in the richer states.

Conversely to the results for the country as a whole (Table 2), overall, physical capital is not significant for regional growth. This different pattern could be explained by the fact that physical capital can be related to the regional level of technology. Splitting the sample for NE and SSE implicitly control for the regional level of technology, generating insignificant results for physical capital.

Complementary, as for the case of Brazil as a whole, the Wald test is used to test the hypothesis of specific educational effects. The first part of Table 4 reports results for the test of no specific human capital effect for NE and SSE when human capital variables are employed separately. Results support the idea that basic levels of human capital are important for the Northeast. The Wald test rejects the null of no educational effect from all basic levels of human capital (*IL*, *SEC* and *SCHOOL*) and does not reject the null of no educational effect coming from *ART*. For the SSE, results in the first part of Table 4 suggest the presence of educational effect and conversely to the NE strongly rejects the null of no educational effect stemming from *ART*. This result supports again the existence of thresholds in education, with the higher levels of human capital being able to trigger economic growth only in the richest area of Brazil. The second part of Table 4 presents results when constraints on the full specification that comprises all levels of human capital are imposed. For NE, the tests always do not reject the null of no educational effect; however, this result could have been induced by the lack of statistical significance caused by multicolinearity in the regression in column 5 from Table 3[13]. On the other hand, for SSE, results suggest the existence of a human capital effect on growth and again confirm the hypothesis that *ART* is important for growth. Overall, the results in Table 4 support the view that higher levels of human capital represented by *ART* are important for growth in the richest states in Brazil.

Table 4 - Test of Coefficient Constraints for SSE and NE

Hypothesis of null coefficient	Test Statistic(NE)	Level of Significance(NE)	Test Statistic(SE)	Level of Significance(SE)
Part 1 Individual Human Capital Proxy Regressions				
b[*IL*]= 0	F(1, 23) = 6.37	0.0190	F(1, 17) = 14.30	0.0015
b[*SEC*] = 0	F(1, 23) = 6.22	0.0203	F(1, 17) = 4.08	0.0593
b[*School*] = 0	F(1, 23) = 6.07	0.0216	F(1, 17) = 3.50	0.0786
b[*ART*] = 0	F(1, 23) = 1.95	0.1762	F(1, 17) = 12.62	0.0024
Part 2 Joint Regressions for all Human Capital Proxies				
b[*IL*]= b[*SEC*]= b[*School*]= b[*ART*] = 0	F(4, 20) = 1.83	0.1618	F(4, 14) = 12.03	0.0002
b[*IL*]= 0	F(1, 20) = 0.31	0.5834	F(1, 14) = 13.97	0.0022
b[*SEC*] = 0	F(1, 20) = 0.95	0.3424	F(1, 14) = 0.70	0.4160
b[*School*] = 0	F(1, 20) = 0.02	0.8994	F(1, 14) = 14.23	0.0021
b[*ART*] = 0	F(1, 20) = 0.16	0.6930	F(1, 14) = 3.33	0.0896

Note: b stands for the coefficient of the respective variable in brackets.

"However, Temple (1999) argues that this procedure is not quite watertight as researchers seem to think. Even if the endogeneity problem is solved..."

6 Endogeneity

However, although the fixed effect approach explicitly recognizes the economy specific effect, it fails to consider the endogeneity problem and the estimates of the growth equation can be biased and inconsistent due to the fact that the explanatory variables are correlated with past and current realizations of the error term. Researchers sometimes resort to the use of initial values of the conditioning variables to treat endogeneity. However, Temple (1999) argues that this procedure is not quite watertight as researchers seem to think. Even if the endogeneity problem is solved, perhaps some omitted variables, like the political regime, affect both growth and the initial level of variables like schooling. In this case, growth and schooling are affected simultaneously by one positive (omitted) policy action and remain endogenous. If the omitted factors influence the behaviour of the conditioning variables these effects are incorporated in their final values. This paper does not use the initial values of the conditioning variables to treat the endogeneity coming from omitted factors. Instead, to take into account the endogeneity, the differenced GMM Arellano and Bond (1991) estimator (GMM-DIFF), such as first applied to the convergence regression by Caselli *et al*. (1996) and the system GMM Blundell and Bond (1998) estimator (GMM-SYS) are the alternative estimates to tackle this problem. The results of these estimations for the full specification for all samples are shown bellow in Table 5.

[13] It could also be argued that, in fact, educational policy does not thrive in Northeast due to institutional failures that force qualified people to leave the region or to remain in the region but overqualified for the overall regional level of productivity.

Table 5 – Conditional Convergence (1985-2005) - GMM Estimates

	Brazil		NE		SSE	
	(1)	(2)	(3)	(4)	(5)	(6)
	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM	DIFF-GMM	SYS-GMM
Dep. Variable	GDPgrowth	GDPgrowth	GDPgrowth	GDPgrowth	GDPgrowth	GDPgrowth
ln(*GDP*pc) $_{t-1}$	-1.355***	-0.497***	-0.811***	-0.362**	-0.591***	-0.196**
	(-7.25)	(-3.67)	(-16.26)	(-2.49)	(-4.66)	(-2.23)
ln(*IL*)	0.458*	-0.303**	-0.234	-0.797***	-1.071***	-0.102
	(1.88)	(-2.41)	(-0.70)	(-3.45)	(-3.79)	(-0.92)
ln(*SCHOOL*)	0.293	-0.348*	-0.0249	0.122	-2.767***	-0.0632
	(0.67)	(-1.79)	(-0.06)	(0.29)	(-4.43)	(-0.43)
ln(*SEC*)	0.0678	0.452***	0.0767***	-0.0885	0.330**	0.0305
	(0.38)	(2.61)	(3.05)	(-1.03)	(2.19)	(0.35)
ln(*ART*)	-0.046	0.0183	-0.0107	0.0193	0.126***	0.00172
	(-1.46)	(0.58)	(-0.44)	(0.95)	(2.73)	(0.03)
ln(*k*)	0.062	0.0313	-0.00139	0.0242	0.000653	-0.0116
	(0.78)	(0.66)	(-0.03)	(0.79)	(0.01)	(-0.55)
ln(*n*+*g*+*d*)	0.962*	-0.175	-0.635	-1.062**	0.404	-0.304***
	(1.95)	(-0.42)	(-0.64)	(-2.49)	(1.27)	(-4.09)
dummy1995	0.199**	-0.129*	-0.00967	-0.115	-0.116*	0.0645
	(2.11)	(-1.71)	(-0.10)	(-1.37)	(-1.71)	(0.92)
dummy2000	0.358*	-0.380***	-0.0409	-0.279**	-0.286*	-0.0163
	(1.86)	(-3.33)	(-0.36)	(-2.04)	(-1.81)	(-0.14)
dummy2005	0.541**	-0.474***	-0.00941	-0.329*	-0.330*	-0.0496
	(2.18)	(-3.28)	(-0.06)	(-1.86)	(-1.80)	(-0.40)
Observations	75	100	27	36	21	28
Instruments	24	31	24	31	21	28
m1 p-value	0.111	0.171	0.0186	0.0585	0.144	0.116
m2 p-value	0.868	0.932	0.362	0.764	0.356	0.487
Sargan *p*-value	0.248	0.000672	0.131	0.00452	0.04	0.0544

Note: *t* statistics in parentheses. * p<0.10, ** p<0.05, *** p<0.01. The m_l statistic for the *l*-lag order correlation proposed by Arellano and Bond (1990) is given by the following expression: $m_l = \frac{\hat{v}'_{-l}\hat{v}}{\sqrt{\hat{v}}}$, where $\hat{v}$ represents the estimated residuals of GMM estimations. The m_l order statistic is standard normal distributed and test the null that differenced errors are not *l*-order serially autocorrelated. The reported results are p-values of the test. The Sargan statistic is given by: $J = \hat{v}'Z(\sum_{i=1}^{N} Z'_i\hat{v}_i\hat{v}'_iZ_i)^{-1}Z'\hat{v}$, where $\hat{v}$ represents the one-step residuals and Z the vector of instrumental variables. Sargan statistic is distributed as chi-squared with degrees of freedom equal to the number of over-identifying restrictions.The null hypothesis is $E[Z'v]=0$. Under the null that instruments are valid. The results are for the robust one-step GMM estimator, considering the lagged value of GDP per capita as predetermined and other conditioning variables as potentially endogenous. All regressions collapsed the instruments using the package Xtabond2 for Stata, see Roodman (2006).

> "The results indicate that there is educational effect but this effect varies according to the sample considered. An interesting finding in this study is that different levels..."

Overall, the alternative results presented do not invalidate the previous findings that higher levels of human capital are more important for the growth process in the most developed area in Brazil. The results for GMM-DIFF and GMM-SYS show that the higher level of human capital expressed by *ART* is not significant for growth and confirm previous results that Brazil did not reach the level that triggers the effect of this type of human capital on growth (columns 1 and 2). Conversely, the results for *IL*, *SEC* and *SCHOOL* are mixed but the GMM-SYS is in line with previous results and suggests that the human capital level represented by *SEC* is the most important for growth in Brazil. The GMM-SYS results confirm the importance of IL and *SEC* to growth and also suggest that higher levels of human capital expressed by *ART* are not important for Brazil as a whole. The GMM regressions for NE are in line with the results of Table 3 in the sense that only basic levels of human capital expressed by *IL* and *SEC* are important for growth. Furthermore, both results for NE suggest that *ART* does not affect growth in NE. Additionally; the results also suggest that there is no human capital effect from higher levels of human capital on growth in the NE region. Finally, for SSE, the GMM-DIFF estimates suggests a positive and significant effect of *ART* on growth, in line with the idea that higher levels of human capital are more important for growth in the richest regions in Brazil. Again, only for SSE the empirical results show a human capital effect stemming from upper layers of human capital.

However, GMM-DIFF and GMM-SYS estimators are ideal when N is large and T is small. Roodman (2006) also stresses this point and argues that when N=20, for instance, the results of the GMM estimators should be interpreted with caution. Therefore, the results of Table 5 must be interpreted with caution due to the limited finite properties of these estimators.

7 Conclusions

This paper used the convergence approach to analyze the relationship between growth and human capital in Brazil, using a panel data for the period 1985-2004. Our analysis focused on the issue of conditional convergence considering various levels of human capital to control for structural differences in Brazil, NE and SSE regions and test for the existence of educational thresholds.

The results indicate that there is educational effect but this effect varies according to the sample considered. An interesting finding in this study is that different levels of human capital have different responses to growth depending on the level of regional development, reflecting the existence of different threshold effects that might be associated with the relative intermediate level of education in each sample. Variables that represent higher levels of human capital affect more efficiently the more developed states in Brazil.

Overall, the empirical findings suggest that the proposed human capital variables properly control the differences in the steady-states across the Brazilian states and their influence to growth depend on the level of human capital they intent to represent. The presence of threshold effects suggests that overqualification would be required before an economy reaches the threshold level. This implies that investment in education must be required well before education starts influencing growth. Furthermore, this investment in education must be done at the right level of human capital. Therefore, to optimally exploit resources, human capital improvements must be planned and implemented progressively.

Appendix
Construction of the Publication Ratio

The data on scientific papers comes from the Institute of Scientific Information (ISI), and from the "Science Citation Index" database, which excludes papers from arts, humanities and social sciences. The data used in this study is based on the information collected from the ISI's website using the search field for address to retrieve information on scientific papers where at least one of the authors is affiliated with an institution or firm in a given state. For each state a specific search expression (reported Table 6) was set up to obtain the number of papers published in that given state. This process was repeated for all states and each year used in the panel data of this study. A paper can have multiple authors that belong to different states and in this case the paper counts once for all states involved in its production. A more detailed approach counting each paper with multiple authors would allow a more accurate analysis and would open up the possibility of applying a discount for multiple addresses. However, this would only be possible if one collects all the information in each paper published in Brazil individually. This requires much more human resources than the available for this project. Although the data processing described above may create some measurement error, the information on papers reported bellow and used in this study might still contribute to the analysis of the growth process in Brazil incorporating new aspects related to human capital.

Table 6. Number of Papers Published by States

State	1985	1990	1995	2000	2005
Acre	0	4	2	5	7
Alagoas	7	6	16	31	80
Amazonas	31	33	31	104	175
Amapá	0	0	1	2	5
Bahia	42	67	74	178	444
Ceará	21	38	56	227	429
Distrito Federal	71	93	146	327	592
Espírito Santo	11	14	38	94	151
Goiás	16	35	34	99	249
Maranhão	3	2	9	20	50
Minas Gerais	128	173	388	1056	1791
Mato Grosso do Sul	7	9	19	65	87
Mato Grosso	3	4	9	19	51
Pará	18	41	61	153	234
Paraíba	20	36	62	147	281
Pernambuco	73	89	135	296	539
Piauí	1	0	5	12	50
Paraná	53	91	225	544	1069
Rio de Janeiro	448	671	1128	2079	2965
Rio Grande do Norte	28	16	24	111	220
Rondônia	1	1	0	7	14
Roraima	2	0	4	17	19
Rio Grande do Sul	121	174	361	772	1650
Santa Catarina	31	75	133	346	646
Sergipe	0	5	5	39	61
São Paulo	1017	1489	2237	4852	8276
Tocantins	0	1	0	3	14

Notes: The data were retrieved in April 2008. The general search expression used to retrieve the number of papers published in each state is: Brazil same "name of respective state" or Brazil same "abbreviation of the respective state name" or Brasil same "name of respective state" or Brasil same "abbreviation of the respective state name". The exception is the case of Mato Grosso and Mato Grosso do Sul. These states were part of the former Mato Grosso that was divided in two in 1978. However, for many years papers produced in Mato Grosso do Sul were still missing the word "Sul". For that reason, the information for these states was retrieved individually checking the municipality of the affiliation and then assigning the paper to the right state. The value of 0.10 was assigned to the zeros to allow for logarithm transformations.

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