Human capital as a conditioning factor to the convergence process among the Brazilian States.

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Abstract

This paper examines the convergence process among the Brazilian states using different concepts of convergence and giving special attention to the role of human capital as the conditioning factor to convergence. Different measures of human capital are used in the estimation of the convergence equations and the results show that they play a significant role in explaining the improvement of the standards of living of the Brazilian population. An interesting finding is that different levels of human capital have different impacts on the growth of per capita income depending on the level of development of the Brazilian states. Lower levels of human capital explain better the convergence process among the less developed states and higher levels of human capital are more adequate for controlling differences in the "steady-states" of the more developed Brazilian regions. The impact of the intermediate levels of human capital on growth is stronger in all samples.

JEL classification: O, O1, O15

Keywords: absolute and conditional convergence, club-convergence, σ- convergence, human capital, panel data.

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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 income or productivity (output per worker) were developed to explain economic growth, especially regional growth. Most empirical studies have shown that convergence is conditional rather than absolute. The former is the argument of the endogenous growth theory with increasing returns to scale properties (mostly in human capital and technology), the latter is the argument of the neoclassical approach to growth with constant returns to scale properties (or diminishing returns to capital) and exogenous technical progress. Therefore, the fundamental problem in growth theory consists in finding the conditioning factors that better explain the convergence process among different economies (states or regions). Among a variety of studies, the endogenous growth approach advocates that human capital is the engine of growth and that convergence is higher when this factor is introduced into the convergence equation. Convergence has been found to run at 2% annual rate, and this is a stylized fact either in samples with countries or in samples with different regions.

The aim of this study is to test the importance of human capital in the convergence process across the Brazilian states over the period 1980-2000, by using a panel data approach. Different measures of human capital are used in the estimation process, such as, basic schooling expressed by the illiteracy rate, secondary school enrolment rate, and total years of school attainment, as well as, a variable which measures the efficiency of scientific work, expressed by the publication rates of articles in international journals. The purpose of the study is to measure the different impacts of the different levels of human capital on the growth of per capita income among the Brazilian states, how do they affect the convergence rate and if different education levels affect differently the samples of regions with dissimilar levels of development. To our knowledge this gradual testing of different levels of human capital on growth and convergence has not been considered systematically, especially for the Brazilian economy.

To study the convergence process across the Brazilian states giving special attention to human capital, we structure the paper as follows: Section 2 explains the various concepts of convergence that are normally used in the growth literature. Section 3 describes the convergence model derived from the Solow´s growth theory. Section 4 discusses the importance of human capital on economic growth. Section 5 explains the data and the samples considered in the empirical analysis. Section 6 explains the disparities among the Brazilian states in terms of wealth and education standards and gives evidence on σ-convergence. Section 7 tests the hypothesis of absolute convergence. Section 8 tests the hypothesis of conditional convergence assuming that growth is conditioned to different levels of human capital. The final section concludes the main findings,

2. Concepts of convergence

Many concepts of convergence have been used to explain whether different economies tend to equalise their levels of economic development. Following Galor (1996), the controversy across different concepts has been largely empirical, focusing on the validity of the following hypotheses:

(i)The absolute convergence hypothesis: per capita income of countries converge to one another in the long run independently of their initial conditions. In other words, all economies converge to the same steady-state. This hypothesis is derived from the Solow`s growth model and can be tested empirically by the following regression

$$\frac{\ln y_{i,t_0+T} - \ln y_{i,t_0}}{T} = a + b \ln y_{i,t_0} + \varepsilon_{i,t_0+T} \qquad (1)$$

where y is per capita income, i the individual economy, b = (1-$e^{-\beta T}$) the convergence coefficient, β=-ln(1-b)/T the convergence rate, t_0 the initial period and T the time length that the per capita income growth rate is measured. If b occurs with a negative sign (b<0) in the estimation process then it can be said that the data produces absolute convergence.

(ii) *The conditional convergence hypothesis*: per capita incomes of countries that are identical in their structural characteristics (preferences, technologies, human capital, government policies, etc) converge to one another in the long run independently of their initial conditions. On the contrary to the absolute convergence, this hypothesis states that economies have different structures and therefore they converge to different steady-states. Or alternatively, economies will converge to the same steady-state only if they are similar to their structural characteristics. As Barro (1991) and Sala-i-Martin (1996) suggested, the hypothesis of conditional convergence can be tested by estimating the following equation

$$\frac{\ln y_{i,t_0+T} - \ln y_{i,t_0}}{T} = a + b\ln y_{i,t_0} + \psi \ln X_{i,t_0} + \varepsilon_{i,t_0+T} \qquad (2)$$

where X is a vector of factors that allow to control differences across economies. If $b<0$ and $\psi \neq 0$ we can say that the data exhibits conditional convergence. On the other hand, $b<0$ and $\psi = 0$ imply that convergence is absolute.

(iii)*The convergence- club hypothesis*: per capita income of countries that are identical in their structural characteristics converge to one another in the long-run provided that their initial conditions (starting levels of per capita income) are similar as well. This hypothesis is consistent with the phenomena of polarization, clustering or persistent poverty situation.

(iv) Beyond all these hypotheses, listed by Galor, the *σ-convergence* concept is also used to measure the dispersion of per capita income over time, among different economies. A group of economies is converging in this sense if the dispersion of their per capita income tends to decrease over time. The coefficient of variation is normally used to test the hypothesis of σ-convergence, given by the ratio of the standard deviation to the sample mean. This concept was first introduced by Barro (1991), to distinguish it from β-convergence associated to conditional convergence. As Barro argues, σ-convergence is a necessary but not a sufficient condition for β-convergence to occur. Both concepts are useful, giving different information about the convergence phenomenon.

All these alternative concepts will be used to test the hypothesis of convergence between the Brazilian states.

3. Description of the convergence model[1]

The concept of β convergence is derived from the Solow (1956) neoclassical growth model based on the Cobb-Douglas production function with labour-augmenting technical progress given by:

$$Y(t) = K(t)^{\alpha} \left[A(t)\, L(t)\right]^{1-\alpha}, \; with \; 0 < \alpha < 1 \tag{3}$$

where Y is output, K and L are the factor inputs, capital and labour, respectively, A measures the cumulative effect of technical progress through time, α is the capital elasticity 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. On the other hand, saving is a constant fraction of output s, ($S = sY, 0 < s < 1$) and K depreciates at a constant exogenous rate δ, therefore, $\dot{K} = \frac{dK}{dt} = I - \delta K$. Accordingly, a constant amount of capital δK, in each period t, is not used.

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

$$\bar{y} = \bar{k}^{\alpha}, \; with \; \bar{y} = \frac{Y}{AL} \quad \text{and} \quad \bar{k} = \frac{K}{AL} \tag{4}$$

The dynamic specification of the model with technical progress takes the following form:

$$\dot{\bar{k}}(t) = s\, \bar{k}(t)^{\alpha} - (n + g + \delta)\, \bar{k}(t) \tag{5}$$

Since in the steady-state the rate of growth of capital stock is zero ($\dot{\bar{k}} = 0$), $\bar{k}^*$ satisfies the following condition:

[1] The description of the convergence model follows closely Islam (1995).

$$s\bar{k}^*(t)^{\alpha} = (n+g+\delta)\bar{k}^*(t) \Leftrightarrow \bar{k}^* = \left(\frac{s}{n+g+\delta}\right)^{\frac{1}{1-\alpha}} \quad (6)$$

Substituting the expression found for $\bar{k}^*$ into the production function (4) we derive, analogously, the steady-state value of output

$$\bar{y}^* = \left(\frac{s}{n+g+\delta}\right)^{\frac{\alpha}{1-\alpha}} \quad (7)$$

From the definition of output in terms of efficient units of labour, $\bar{y} = \frac{Y}{AL}$, and the expression found for the level of output in the steady-state, equation (7), it is possible to derive an expression for the steady-state per capita income:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \ln A(0) + gt + \left(\frac{\alpha}{1-\alpha}\right)\ln(s) - \left(\frac{\alpha}{1-\alpha}\right)\ln(n+g+\delta) \quad (8)$$

In this equation gt is a constant, since the exogenous rate of technical progress is assumed to be equal in all economies and t is fixed in cross-section regressions. On the other hand, $A(0)$ may differ across economies, since it reflects not only the level of technology but also resource endowments, institutions, economic conditions, among others (Mankiw *et al.,* 1992). Accordingly, the term $\ln A(0)$ can be decomposed into two parts: the first is a constant (γ) and the other is stochastic (ε), representing a country (or region) specific shock:

$$\ln A(0) = \gamma + \varepsilon \quad (9)$$

Substituting $\ln A(0)$ into equation (8) and inserting gt into the constant term γ, we obtain the following expression:

$$\ln\left[\frac{Y(t)}{L(t)}\right] = \gamma + \left(\frac{\alpha}{1-\alpha}\right)\ln(s) - \left(\frac{\alpha}{1-\alpha}\right)\ln(n+g+\delta) + \varepsilon \quad (10)$$

A cross-section estimation of equation (10) is heavily dependent on the assumption that s and n are not correlated with the error term (ε). In general, this is not a convincing argument that saving and population (labour) growth rates will not be influenced by the factors included in $A(0)$. This problem is solved when panel regression (instead of cross-section) is used, allowing for country (or region) specific effects (fixed or random) providing, therefore, a better control for the technology shift term (ε).

Having this in mind, we consider the equation describing the out of steady-state behaviour of per capita income:

$$\frac{d\ln\bar{y}(t)}{dt} = \beta\left[\ln\left(\bar{y}^{*}\right) - \ln\left(\bar{y}(t)\right)\right] \tag{11}$$

where β = $(n+g+\delta)(1-\alpha)$ is the rate of convergence dependent on the rate of growth of population, technology, capital depreciation and the output elasticity with respect to capital. This equation implies that:

$$\ln\bar{y}(t_2) = \left(1-e^{-\beta T}\right)\ln\bar{y}^{*} + e^{-\beta T}\ln\bar{y}(t_1) \tag{12}$$

where $\bar{y}(t_1)$ is income per effective worker at some initial point of time and $T = t_2 - t_1$ the considered period.

Subtracting $\ln\bar{y}(t_1)$ from both sides of equation (12) we obtain a specification that represents a partial adjustment process:

$$\ln\bar{y}(t_2) - \ln\bar{y}(t_1) = \left(1-e^{-\beta T}\right)\left[\ln\bar{y}^{*} - \ln\bar{y}(t_1)\right] \tag{13}$$

In this model the growth of income per effective worker between the period t_2 and t_1 is determined by the distance of its initial level and the steady-state value.

Substituting for $\bar{y}^{*}$ we obtain the following expression:

$$\ln\bar{y}(t_2) - \ln\bar{y}(t_1) = \left(1-e^{-\beta T}\right)\left[\left(\frac{\alpha}{1-\alpha}\right)\ln(s) - \left(\frac{\alpha}{1-\alpha}\right)\ln(n+g+\delta) - \ln\bar{y}(t_1)\right] \tag{14}$$

In this equation the growth of income per effective worker is explained solely by its initial value (the unique factor of convergence), assuming ($g+\delta$) to be the same for all economies and saving and population growth rates are taken to be equal to the respective averages over the considered period. This is known as the neoclassical hypothesis of absolute or unconditional convergence.

The neoclassical convergence equation (14) defined in terms of income per effective worker does not show the correlation between the unobservable $A(0)$ and the observed included variables. This problem is more apparent when the equation is expressed in terms of per capita income.

Starting from the definition of income per worker $\bar{y}(t)=\dfrac{Y(t)}{A(t)L(t)}=\dfrac{Y(t)}{L(t)A(0)\,e^{gt}}$,

and getting logs we obtain:

$$\ln\bar{y}(t)=\ln\left[\frac{Y(t)}{L(t)}\right]-\ln A(t)\Leftrightarrow \ln\bar{y}(t)=\ln y(t)-\ln A(0)-gt \qquad (15)$$

where $y(t)$ is per capita income. Substituting for $\bar{y}(t)$ into equation (15) we obtain the usual convergence equation in per capita income terms:

$$\begin{aligned}\ln y(t_2)-\ln y(t_1)=\left(1-e^{-\beta T}\right)\frac{\alpha}{1-\alpha}\ln(s)-\left(1-e^{-\beta T}\right)\frac{\alpha}{1-\alpha}\ln(n+g+\delta)-\\ -\left(1-e^{-\beta T}\right)\ln y(t_1)+\left(1-e^{-\beta T}\right)\ln A(0)+g\left(t_2-e^{-\beta T}t_1\right)+v_{i,t}\end{aligned} \qquad (16)$$

where $\left(1-e^{-\beta T}\right)\ln A(0)$ is the time-invariant individual country-effect term and $v_{i,t}$ is the error term that varies across countries (regions) and over time.

A simplified conventional presentation of equation (16) with panel data is the following:

$$\Delta\ln y_{i,t}=\gamma+b\ln y_{i,t-1}+u_{i,t} \qquad (17)$$

where the rate of growth of per capita income of each economy is related to its initial level, the only factor of convergence. The higher the distance of the initial level of per capita income from its steady-state value, the higher will be the convergence rate. The constant term (γ) represents the common steady-state value of the per capita income dependent on factors, such as, s, n, g, δ and $A(0)$. The parameter $b=\left(1-e^{-\beta T}\right)$ is known as the coefficient of convergence, while β expresses the rate or speed of convergence given by $\beta=-\dfrac{\ln(1-b)}{T}$. Finally, T is the time length that the per capita income growth rate is measured.

If equation (17) is extended to include other structural factors (human capital, investment, I&D, trade, etc,) to control the steady-steady value, then we have the case of conditional convergence given by:

$$\Delta\ln y_{i,t}=\gamma_i+b\ln y_{i,t-1}+c_j\ln X_{i,t}^{j}+u_{i,t} \qquad (18)$$

Two main differences distinguish the conditional from the absolute convergence. The first is that economies converge to different steady-states, represented by γ_i. The second is that there are some activities, that in the long run, exhibit increasing returns to scale characteristics, such as, human capital, technology, innovation, among others **(**Barro and Sala-i-Martin, 1992, 1995). These activities with increasing returns characteristics counterbalance the diminishing returns to scale property of capital stock in the production function. The increasing returns to scale activities are included in the vector $X^j_{i,t}$. The hypothesis of absolute convergence is accepted when $\gamma_i = \gamma$ and $c_j = 0$, otherwise, convergence is conditional.

4. The role of human capital

Economists have been stressing the importance of human capital in the process of economic growth. In this paper we argue that human capital is a suitable factor to differentiate economies and to test the hypothesis of conditional convergence.

Mankiw et al (1992) were the pioneers in introducing human capital into the economic growth models. Barro (2001), also 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, so 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.

Sachs and Warner (1997) argue that human capital accumulation is a non linear function of the human capital level. When initial human capital is low, 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 accumulation of human capital is slow. This means that growth tends to be higher in countries with an intermediate level of human capital.

In the endogenous growth theory, human capital (and its result) is frequently the starting point to increasing returns to scale characteristics. Romer (1986,1990) 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 this author, new ideas have special characteristics, they are non-rival commodities generating, therefore, positive externalities and increasing returns to scale properties[2]. Many other authors used human capital (or its outcome) to formulate endogenous growth models and allow for increasing returns to scale. Lucas (1988) and Barro and Sala-i-Martin (1997) are some examples among them.

There is some kind of warning concerning the type of human capital to use in the growth equations. Mankiw et al (1992), Islam (1995), Sachs and Warner (1997), Temple (1999) and Barro (2001), among others, have pointed out some problems with the human capital measures. Barro suggests that the quality of schooling is much more important than the quantity, so measures of the efficiency of human capital must be considered to explain growth.

This study uses traditional measures of human capital, such as, illiteracy rate, secondary school enrolment and total years of schooling. Additionally, we propose a new measure of human capital reflecting the production capacity of scientific work, given by the number of scientific articles (per million of inhabitants) published in international journals, ART[3].

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

More explicitly, to study the convergence process across the Brazilian states we use different measures that represent different levels of human capital. The illiteracy rate (IR) expresses the lowest level of human capital, the rate of enrolment in the secondary

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

[3] Patel and Pavitt (1995) discuss the utility and the problems arising when this variable is used as a proxy for the scientific production. On the other hand, Bernardes and Albuquerque (2003) suggest that the number of published papers may be taken as an indicator of the general level of the educational system.

school (SEC) represents the basic level and total years of schooling (SCHOOL) embraces the intermediate (or superior) level of human capital. Finally, the amount of publications (per million of inhabitants) ART represents higher levels of human capital.

5. The Data, Samples and Methods of Estimation

To estimate the conditional convergence equation data were collected for the Brazilian states over the period 1980-2000 and were mainly taken from IPEA[4]. These data correspond to per capita income (y), illiteracy rate (IR), enrolment rates at the secondary level (SEC) and average years of school attainment[5] (SCHOOL). The source of the data for the variable representing higher levels of human capital, namely, the number of published articles per million of inhabitants (ART), was the Institute for Scientific Information (ISI)[6].

To analyze the convergence process across Brazil, three main samples are considered. The first sample is Brazil and includes 25 Brazilian States available for the period of analysis[7]. The second sample, South/ Southeast, comprises seven states from the south and southeast regions, the most developed area across Brazil. The last sample is constituted by nine Northeast states, the less developed area of Brazil. The division of Brazil in this way will allow to detect different processes of convergence and understand better the impact of human capital according to the level of development of the states.

A panel data approach is used to estimate the convergence equations (1) and (2) presented in section 2. The data are organized in five years intervals to avoid business cycle influences. The usual methods of estimations with panel data are employed based on Pooled regressions estimated by OLS, assuming fixed effects expressed in the individual dummy variables estimated by LSDV and assuming random effects estimated by GLS. Alternatively the GMM method suggested by Arellano-Bond (1991) is also used

[4] Instituto de pesquisa económica aplicada (Institute of applied economic research).
[5] Of the adult population aged over 25.
[6] We have used the "Science Citation Index", which excludes papers from arts and humanities. Patel and Pavitt (1995) consider ISI as the major source of systematic statistical information on the world's scientific publications and citation.
[7] 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. Because of this change we exclude these two states from the sample to avoid data inconsistency.

to take into account the endogeneity bias of the regressors and to proceed with dynamic panel estimation.

6. Disparities across the Brazilian States

Economic activity in Brazil is concentrated mainly in the Southeast area as Table 1 shows. In 2000, the Southeast area accounted for about 57% of the Brazilian GDP and its per capita income was almost three times higher than that of the Northeast.

Table 1. Brazil – Regional indicators of GDP and education

Regions	GDP per capita	%GDP	IR(2003)	Human(2003)
Centre west	6.50	6.95	9.50	6.50
North	3.87	4.60	10.60	6.20
North east	3.00	13.09	23.20	4.70
South	7.65	17.57	6.40	6.70
South east	8.71	57.79	6.80	7.00
Total	—	100.00	—	--

Source: IPEA((Institute of applied economic research)

Regional differences also apply when we focus on educational indicators. The illiteracy rate (IR) in the Northeast shows that almost 23% of its population was not able to read (or write) in 2003, while in the South and Southeast this rate was about 6%. The Northeast area also records the lowest rate of school attainment across all Brazil. People from the Northeast spend on average 4.7 years at school while in the South and Southeast spend about 7 years at school.

However, the state differences are even deeper. Table 2 shows the GDP growth rates among the 25 states[8], the relative per capita income in 1980 and 2000 respectively, and illustrates different levels of human capital.

Table 2. The evolution of GDP across the Brazilian states, and human capital indicators, 1980-2000

States	GDP (1980)[a]	GDP (2000)[a]	y_i/y_{DF} (1980)[b]	y_i/y_{DF} (2000)[b]	Annual Growth rate[c] %	IR (2003)[d]	Human (2002)[e]
Distrito Federal	11.61	14.64	1.00	1.00	1.16	4.45	8.54
São Paulo	10.33	10.14	0.89	0.69	-0.09	5.41	7.15
Rio de Janeiro	8.34	9.99	0.72	0.68	0.90	4.61	7.36
Rio Grande do Sul	6.99	8.45	0.60	0.58	0.95	5.77	6.50
Santa Catarina	6.21	8.06	0.53	0.55	1.30	5.00	6.56
Mato Grosso do Sul	5.46	5.68	0.47	0.39	0.20	9.60	6.16
Amazonas	5.33	7.09	0.46	0.48	1.43	6.61	6.84
Paraná	5.17	6.95	0.45	0.47	1.47	7.81	6.33
Espírito Santo	4.97	7.00	0.43	0.48	1.71	10.26	6.03
Minas Gerais	4.83	6.01	0.42	0.41	1.09	11.04	5.80
Rondônia	3.76	4.11	0.32	0.28	0.43	8.55	5.83
Mato Grosso	3.64	5.39	0.31	0.37	1.96	10.70	5.96
Roraima	3.58	4.00	0.31	0.27	0.56	9.67	5.54
Amapá	3.18	4.25	0.27	0.29	1.44	9.21	6.68
Bahia	3.14	3.68	0.27	0.25	0.79	21.36	4.53
Pará	3.12	3.08	0.27	0.21	-0.07	10.65	6.02
Pernambuco	2.82	3.75	0.24	0.26	1.42	21.76	5.14
Acre	2.64	3.10	0.23	0.21	0.79	16.86	6.19
Sergipe	2.34	3.37	0.20	0.23	1.83	19.15	5.25
Alagoas	2.29	2.44	0.20	0.17	0.31	30.41	3.98
Rio Grande do Norte	2.29	3.37	0.20	0.23	1.93	23.40	5.20
Ceará	2.00	2.82	0.17	0.19	1.73	22.76	4.62
Paraíba	1.62	2.60	0.14	0.18	2.38	25.21	4.44
Maranhão	1.45	1.66	0.12	0.11	0.68	23.78	4.14
Piauí	1.20	1.87	0.10	0.13	2.21	28.40	4.04

Source: IPEA (Institute of Applied Economic Research)
Notes: a) GDP per capita at constant prices (national currency)
b) Relative GDP per capita, y_i/y_{DF}, y_i being the GDP of the state i and y_{DF} the GDP of the "Distrito Federal" the richest Federal Unit
c) Average annual growth rate between 1980-2000
d) IR is the rate of illiteracy
e) Human is the average number of years spend at school

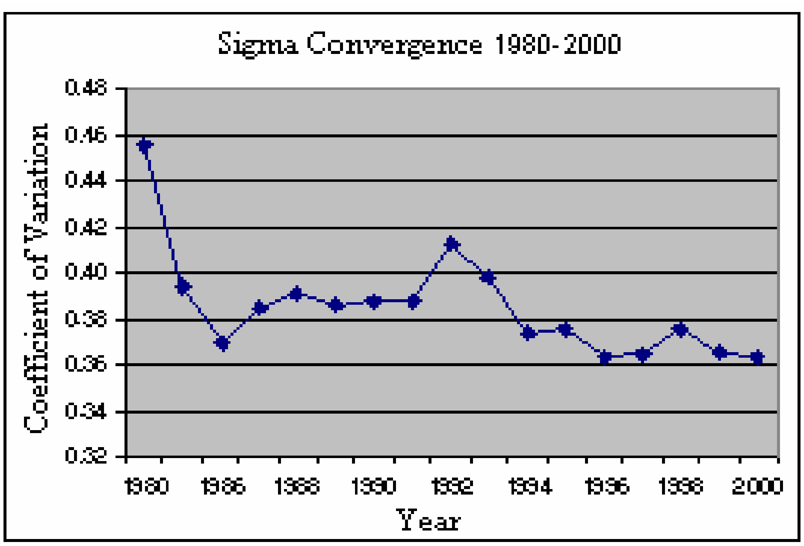
[8] More precisely the "Distrito Federal" is one Federal Unit and not a state. For simplification reasons, this differentiation is not made along the paper.

The data from Table 2 shows, for example, that in 2000 the GDP of the state of "Maranhão" was only 11% of that of the "Distrito Federal" and that only five states have achieved half of the GDP of the "Distrito Federal". Human capital, expressed by IR and Human, also displays huge disparities across states. In 2003, the rate of illiteracy was 28.40% in the state of "Piauí" while in "São Paulo" was only 5%. In the state of "Ceará" people spend about 4.62 years of their lives studying at school, versus 7.36 years in the state of "Rio de Janeiro".

After highlighting the differences among the Brazilian states, we shall try to identify any tendency towards converge. From column 4, of Table 2, comparatively to column 3 we can observe that some rich states (on the top of the table) reduced their relative position in terms of per capita income and some poor states (on the bottom of the table) improved their relative position. On the other hand, column 5 shows that some poor regions (Piauí, Paraíba, Ceará) grew faster relatively to some rich states (São Paulo, Rio de Janeiro, Rio Grande do Sul) over the period 1980-2000. This preliminary observation can be taken as evidence of catching up and absolute convergence.

In a more formal way, the coefficient of variation can be used to measure σ-convergence, indicating if asymmetries across economies are declining over time. Figure 1 plots the evolution of the coefficient of variation referred to GDP per capita of the Brazilian states over the period 1980-2000.

Figure 1. σ-convergence among the states of Brazil 1980-2000



As it can be seen the dispersion of per capita income has been reduced over the whole period, the reduction being more intensive in the beginning of the period. We can also observe a period of divergence between 1986 and 1992 which coincides with the period of hyper-inflation and general macroeconomic instability in Brazil. Ferreira (2000) has also found σ-convergence among the Brazilian states over the period 1975-1995.

7. Absolute convergence

As we explained in section 4, the hypothesis of absolute convergence can be tested by estimating equation (17)[9] which relates the growth of per capita income to the log of the initial level of the respective economy. Average annual growth rates in per capita income, calculated every five years, are used to measure convergence among the states of Brazil, over the period 1980-2000. Brazil (25 states) is also divided into two sub-samples, the South/Southeast area with the 7 more developed states and the Northeast area with the 9 less developed states. The scope of this division is to detect different convergence processes across Brazil confirming, therefore, the convergence-club hypothesis. The convergence equation has been estimated by the usual panel estimation methods and the results are reported in Table 3.

As we can see, the pooled regressions give evidence of absolute convergence which runs at very slow rates, 0.26% for Brazil, 0,56% for the South/Southeast and 0.72% for the Northeast areas. This result is consistent with the hypothesis that absolute convergence occurs between economies with similar characteristics in terms of institutions, policies, same language, free factor mobility, among others. We also note that convergence is more robust when specific effects are introduced to control differences in economic structures between the states. When state dummies are used convergence is higher in all samples, 3.78% for Brazil, 1.39% for the South/Southeast and 4.32% for the Northeast areas. The degree of explanation has increased significantly except for the South/Southeast area. When specific effects are assumed to be random

[9] This equation is the same as equation (1) of section 2.

Table 3- Absolute Convergence (1980-2000)

Estimated equation: $$\frac{\ln y_{i,t_0+T} - \ln y_{i,t_0}}{T} = a + b \ln y_{i,t_0} + \varepsilon_{i,t_0+T}$$

		Brazil (25)	South/Southeast (7)	Northeast (9)
Pooled (OLS)	a	0.0295*	0.0635**	0.0450*
		(3.2013)	(2.4910)	(2.7313)
	lny $_{i, t-1}$	-0.0131**	-0.0276**	-0.0356***
		(-2.1115)	(-2.0945)	(-1.9898)
	R^2 adjusted	0.0337	0.1114	0.0779
	β	0.0026	0.0056	0.0072
	d.f.	98	26	34
Fixed Effects (LSDV)	"dummies"	(a)	(b)	(c)
	lny $_{i, t-1}$	-0.1724*	-0.0671[n]	-0.1944*
		(-7.6749)	(-1.7171)	(-5.6598)
	R^2 adjusted	0.2840	-0.0506	0.4152
	β	0.0378	0.0139	0.0432
	d.f.	74	20	26
Random Effects (GLS)	a	0.1807*	0.0698**	0.1477*
		(5.6982)	(2.0808)	(4.3706)
	lny $_{i, t-1}$	-0.1227*	-0.0309***	-0.1567*
		(-6.5468)	(-1.7820)	(-0.1567)
	R^2 adjusted	0.4214	0.1401	0.5278
	β	0.0262	0.0063	0.0341
	d.f.	98	26	34

	Brazil	South/Southeast	Northeast
F test [d]	F(24,98)= 3.2145 Significance Level 0.000024	F(6,26)=0,4310 Significance Level 0,85143	F(8,34)= 4.51378 Significance Level 0.000829
Hausman Test [e]	Chi-Sq(1)= 16.11 Significance Level 0.0000597	Chi-Sq(1) = 1.06 Significance Level 0.30126	Chi-Sq(1)= 5,31 Significance Level 0.0211694

Notes: (a) All "dummies" are positive and significant at 1% level
(b) Six "dummies" are positive and significant at 10% level
(c) All "dummies" are positive and significant at 1% level
(d) Tests the hypothesis between pooled versus fixed effects
(e) Testes the hypothesis between random versus fixed effects
Numbers in brackets are t-ratio
*Coefficient significant at 1% level
**Coefficient significant at 5% level
***Coefficient significant at 10% level
n – Coefficient not significant

(GLS regressions) the results are also satisfactory and closer to the LSDV estimations. The Hausman test suggests that the model with fixed effects is preferable to the model with random effects but not in the sample of the South/Southeast area. In all methods of estimation the statistical significance of the convergence factor and the degree of explanation of the regressors in the South/Southeast area, are weak. These results are in line with Ferreira (2000) and Barossi and Azonni (2003) who also found absolute convergence for the Brazilian states.

The weak absolute convergence found in this section induces us to search for conditional convergence, as the fixed effects estimations suggest. Human capital is assumed to be the conditional factor to control properly structural differences between the states of Brazil.

8. Convergence conditional to human capital

The previous section argues that the convergence process among the Brazilian states can be better described when different equilibrium points are assumed for each state. In other words, each state converges to his own steady-state and this is the essence of conditional convergence. To control the different equilibrium points we use different proxies for human capital, such as, the illiteracy rate (IR), the enrolment rate at the secondary school (SEC) and average years of school attainment (SCHOOL) to express the basic and intermediate levels of human capital qualifications. Additionally, the rate of scientific publications (nº of articles per million of inhabitants, ART or nº of articles per thousand of graduates, ARG[10]) is used to express differences in scientific production reflecting higher levels of human capital, All these proxies are introduced separately into the convergence equation, to avoid colinearity problems 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 shown in Table 4[11].

As it can be seen, when the illiteracy rate is introduced into the convergence equation its impact is negative as expected, revealing that the higher the rate of illiteracy the lower is the growth of per capita income. Convergence among the Brazilian states

[10] The number of graduate students (in the last semester of attainment of the graduate course) is provided by INEP (www.inep.gov.br).

[11] Ferreira (2000) and Azzoni *et al* (2000) have introduced other variables in the convergence regression and found conditional convergence to human capital for the Brazilian states. However, their results are not directly comparable to ours since we have included different levels of human capital separately and the methodology used is also different.

Table 4- Conditional Convergence (1980-2000) - Fixed effects

Estimated equation: $$\frac{\ln y_{i,t_0+T} - \ln y_{i,t_0}}{T} = a + b \ln y_{i,t_0} + \psi_j X^j_{i,t_0} + \varepsilon_{i,t_0+T}$$

		Brazil	South/Southeast	Northeast
	"dummies"	*	*	
	lny $_{i,\,t-1}$	-0.2218*	-0.2174*	-0.2209*
		(-10.6307)	(-6.1292)	(-6.2916)
IR	IR	-0.0739*	-0.0724*	-0.0520**
Illiteracy rate		(-5.6037)	(-5.7824)	(-2.0021)
	R^2 adjusted	0.4925	0.5992	0.4759
	β	0.0502	0.0490	0.0499
	d.f.	73	19	25
	Test F[(a)]	F(24,97)=5.7404	F(6,25)=5.4429	F(6,25)=5.6320
	Signif. Level	0.0000	0.0010	0.0001
	Hausman Test[(b)]	Chi-Sq(2)=15.7325	Chi-Sq(2)=2.9983	Chi-Sq(2)=4.4364
	Signif. Level	0.0003	0.2233	0.1088
	"dummies"		*	
	lny $_{i,\,t-1}$	-0.2123*	-0.2359*	-0.2339*
		(-9.9175)	(-5.0165)	(-7.0516)
SEC	SEC	0.0323*	0.0432*	0.0325*
Enrolment		(4.7944)	(4.4678)	(2.9118)
Rate at	R^2 adjusted	0.4480	0.4607	0.5458
secondary	β	0.0477	0.0538	0.0532
school	d.f.	73	19	25
	Test F[(a)]	F(24,97)=5.0658	F(6,25)=4.1953	F(6,25)=7.1419
	Signif. Level	0.0000	0.0047	0.000018
	Hausman Test[(b)]	Chi-Sq(2)=16.660	Chi-Sq(2)=3.1529	Chi-Sq(2)=4.2841
	Signif. Level	0.0002	0.2067	0.11741
	"dummies"		*	
	lny $_{i,\,t-1}$	-0.2144*	-0.2185*	-0.2233*
		(-9.1098)	(-4.5832)	(-6.0977)
SCHOOL	SCHOOL	0.0769*	0.1341*	0.0480***
Average years		(3.7537)	(4.0357)	(1.8070)
Of schooling	R^2 adjusted	0.3916	0.4045	0.4621
	β	0.0483	0.0493	0.0505
	d.f.	73	19	25
	Test F[(a)]	F(24,97)=4.4324	F(6,25)=3.2490	F(6,25)=5.3813
	Signif. Level	0.0000	0.0168	0.00022
	Hausman Test [(b)]	Chi-Sq(2)=16.2973	Chi-Sq(2)=3.1130	Chi-Sq(2)=4.4613 /
	Signif. Level	0.0003	0.2108	0.10745
	"dummies"	*	*	*
	lny $_{i,\,t-1}$	-0.1914*	-0.2512*	-0.2058*
		(-8.1127)	(-6.4581)	(-4.7684)
ART	ART	0.0067**	0.0283*	0.0026^n
scientific		(2.1751)	(5.9630)	(0.4499)
production	R^2 adjusted	0.3183	0.6148	0.3967
	β	0.0425	0.0578	0.0461
	d.f.	73	19	25
	Test F[(a)]	F(24,97)=3.6079	F(6,25)=7.2723	F(6,25)=4.3730
	Signif. Level	0.0000	0.00014	0.00111
	Hausman Test[(b)]	Chi-Sq(2)=15.8478	Chi-Sq(2)=2.9441	Chi-Sq(2)=4.4676
	Signif. Level	0.0004	0.22944	0.10711

Table 4 (continued)	"dummies"	*	*	*
	$lny_{i,\ t-1}$	-0.1878*	-0.2184*	-0.1918*
		(-6.4574)	(-6.3880)	(-4.2422)
ARG Scientific Production	ARG	0.0070[n]	0.0292*	-0.0006[n]
		(1.5313)	(6.0675)	(-0.0897)
	R^2 adjusted	0.2517	0.6235	0.3920
	β	0.0416	0.0492	0.0426
	d.f.	64	19	25
	Test F[(a)]	F(21,85)=2.9329	F(6,25)=6.7471	F(6,25)=3.7424
	Signif. Level	0.0003	0.0002	0.00324
	Hausman Test[(b)]	Chi-Sq(2)=12.9444	Chi-Sq(2)=2.9777	Chi-Sq(2)=4.3911
	Signif. Level	0.0015	0.2256	0.11129

Notes:
IR is the illiteracy rate of the population with age over 15
SEC is the percentage of young people with age between 15 and 17 that attended the secondary school or they had completed 8 years of schooling
SCHOOL is the average number of school attainment of the population with age over 25
ART is the number of published papers in international journals per million of inhabitants
ARG is the number of published papers in international journals per thousand of graduates
(a) Tests the hypothesis between pooled versus fixed effects
(b) Testes the hypothesis between random versus fixed effects
Numbers in brackets are t-ratio
*Coefficient significant at 1% level
** Coefficient significant at 5% level
*** Coefficient significant at 10% level
n – Coefficient not significant,

now runs at a higher annual rate, around 5% in all samples. The estimated equations are more robust (comparing to the absolute convergence) in terms of the statistical significance of the coefficients and the degree of explanation of the regressors. Therefore, human capital in its lowest level controls satisfactorily the differences between the Brazilian states. The convergence process is similar in all samples, not being able to distinguish any differences between the most developed (South/Southeast) and the less developed (Northeast) states.

The results are also satisfactory when the enrolment rate at the secondary school is used to express basic levels of human capital. All coefficients have the predicted signs and are highly significant, indicating that human capital stock at the secondary level is relevant in explaining the convergence process among the Brazilian states. This variable contributes positively to the increase in wealth in this country and this is shown in all samples. Convergence runs at a similar annual rate of around 5.3% in the South/Southeast and Northeast areas and it is somehow higher than the convergence found by using the illiteracy rate. Once again, the convergence process is not differentiated between these two subsets.

Convergence has been found to be similar in the three samples when the average years of school attainment is used as proxy for intermediate levels of human capital, running at 5% per year. The effect of this type of human capital stock on growth is positive and higher than in the previous proxies of literacy levels, in all samples. An interesting thing to note is that the marginal effect of this type of human capital is higher in the sample of the more developed (South/Southeast) area. Every additional year in education induces 0.13% increase in wealth in the South/Southeast area against only 0.05% in the Northeast. This level of Human capital is more efficient in the South/Southeast area inducing higher growth. The same Human capital has a smaller impact on growth in the Northeast area and its statistical significance is weak. It seems that this intermediate level of human capital differentiates now the convergence process between the South/Southeast and the Northeast areas. The Northeast area constituted by less developed states has to improve farther the intermediate educational levels to achieve higher growth.

The last proxy we use for human capital is the rate of scientific publications per million of inhabitants (ART) or alternatively per thousand of graduates (ARG). These variables attempt to capture higher levels of human capital related to scientific production ability. Now the impact of this type of human capital differentiates clearly the convergence process between the South/Southeast and Northeast areas. ART is highly significant in the sample of the South/Southeast that comprises the more developed states and it doesn't have any significance in the Northeast sample, constituted by the less developed states of Brazil. Convergence also runs at a higher rate in the South/Southeast area, 5.7% against 4.6% in the Northeast area and the degree of explanation of the regressors is much higher in the South/Southeast sample than in the others. The alternative variable ARG has a similar behaviour not altering the conclusions derived from ART. The rate of convergence, the marginal impact of human capital and the robustness of the estimation are weak for the sample of Brazil relatively to the previous estimations where intermediate levels of human capital were used.

The Arellano-Bond (1991) dynamic panel data estimation technique has also been used to estimate the convergence equations taking care of the endogeneity problem of the regressors, The obtained results were similar to Table 4, not contradicting the main findings. For comparison, these results are reported in the Appendix.

Our evidence at this stage seems to suggest that intermediate levels of human capital expressed mostly by SCHOOL explain better the convergence process in all samples. Convergence is higher and the impact of this level of human capital stock on growth stronger, especially in the South/Southeast zone. This is consistent with the Sachs and Warner (1997) argument that growth tends to be higher in countries with an intermediate level of human capital. On the other hand the differentiation in the convergence process between the South/Southeast and Northeast areas lays on the use of higher levels of human capital that have stronger effects in the former than in the latter. Higher levels of human capital expressed by ART or ARG control better the differences between the more developed states than the less developed states of Brazil. Higher levels of human capital do not make a significant contribution to growth in the Northeast area. This shows that the Northeast area has to improve primarily the basic and intermediate levels of human capital before going to develop higher levels of education.

9. Main conclusions

In this paper we have analysed the convergence process across the Brazilian states over the period 1980-2000. Our analysis has been focused on the issue of conditional convergence considering various levels of human capital to control differences in structures between the states of Brazil.

Initially we observed that the dispersion of per capita income among the Brazilian states has been declining over time and this is evidence of σ-convergence. Absolute convergence also found, but the estimations are not robust. On the other hand conditional convergence on human capital boosts the results, reinforcing the convergence rate and increasing the degree of explanation. In general, it can be assumed that convergence in per capita income among the Brazilian states runs at approximately 5% per year when differences in human capital are controlled for. This is higher than the standard 2% rate stylized by Barro, A farther finding in this study is that the intermediate levels of human capital explain better the convergence process among the Brazilian states. When this type of human capital is used convergence is higher and the marginal impact on growth significantly stronger, improving the standards of living of the populations to a greater extent. This is consistent with the idea that growth tends to be higher in countries (or states) with an intermediate level of human capital.

The conditional convergence estimation approach on the other hand shows that different levels of human capital have different responses to growth depending on the sample used. Variables that represent higher levels of human capital affect more efficiently the more developed than the less developed states in Brazil.

Generally our results suggest that the proposed human capital variables properly control the differences in the steady-states across the Brazilian states and their influence to growth is depending on the level of human capital they intent to represent. Therefore, to optimally exploit resources, human capital improvements have to be progressive.

Appendix

Dynamic panel estimation (GMM:Arellano-Bond)

One criticism that is often made to the estimation of the convergence equations is that, the conventional estimation methods used fail to account for the endogeneity of the regressors. When explanatory variables are endogenous the regression estimates are biased and inconsistent,

To account for endogeneity we estimate the convergence equation by using the GMM estimation approach proposed by Arellano-Bond (1991) and first employed by Caselli et al (1996). The growth equation is first differenced to eliminate the specific effects and then all lags of the explanatory variables are used as instruments. The dynamic estimated equation is, therefore

$$\Delta((\ln y_{i,t_0+T} - \ln y_{i,t_0})/5) = b\Delta \ln y_{i,t_0} + \psi\Delta \ln X_{i,t_0} + \Delta\varepsilon_{i,t_0+T}$$

The results of the estimation of this equation are shown in Table 5. The J-specification statistic confirms in most cases the validity of the instruments used in the estimation. The degree of explanation and the statistical significance of the regressors are more robust (smaller standard errors). Generally, these new results validate the previous findings of Table 4.The introduction of human capital reinforces the convergence process showing the potential role of human capital to growth. The basic and intermediate levels of human capital are those that better explain the convergence process across Brazil. The higher levels of human capital have a stronger growth impact in the South/Southeast area. All human capital levels are significant in the Northeast area but the growth impact of the intermediate levels (SEC) is stronger.

Table 5 - Conditional Convergence - GMM estimation (Arellano-Bond)

Estimated equation: $\Delta((\ln y_{i,t_0+T} - \ln y_{i,t_0})/5) = b\Delta \ln y_{i,t_0} + \psi\Delta \ln X_{i,t_0} + \Delta\varepsilon_{i,t_0+T}$

		Brazil(25)	**South/Southeast(7)**	**Northeast(9)**
IR Illiteracy rate	*lny* $_{i,\ t-1}$	-0.1821*	-0.2673*	-0.2610*
		(-15.8792)	(-40.7825)	(-14.6160)
	IR	-0.0602*	-0.0876*	-0.0776*
		(-6.5447)	(-15.0644)	(-8.4786)
	Adjusted R^2	0.7034	0.7143	0.8523
	Β	0.0402	0.0622	0.0604
	d.f.	73	19	25
	J-Specification(a)	J-Stat. = 20.0640	J-Stat. = 4.7736	J-Stat. = 6.9056
		Signif. = 0.0444	Signif. = 0.9416	Signif. = 0.8066
SEC Enrolment rate at Secondary School	*lny* $_{i,\ t-1}$	-0.1765*	-0.2631*	-0.2638*
		(-10.4754)	(-6.0803)	(-130.61)
	SEC	0.0216*	0.0430*	0.0362*
		(7.5936)	(5.8196)	(26.0607)
	Adjusted R^2	0.7008	0.6743	0.8706
	Β	0.0388	0.0610	0.0612
	d.f.	73	19	25
	J-Specification(a)	J-Stat. = 18.4139	J-Stat. = 6.8587	J-Stat. = 8.0610
		Signif. = 0.0724	Signif. = 0.8104	Signif. = 0.7078
SCHOOL Average years of schooling	*lny* $_{i,\ t-1}$	-0.1608*	0.2907*	-0.2480*
		(-8.0379)	(-7.1888)	(-19.4299)
	SCHOOL	0.0408*	0.1581*	0.0621*
		(3.6414)	(5.2435)	(3.2855)
	Adjusted R^2	0.6470	0.5798	0.8376
	β	0.0350	0.0686	0.0570
	d.f.	73	19	25
	J-Specification(a)	J-Stat. = 14.2921	J-Stat. = 5.7894	J-Stat. = 8.2714
		Signif. = 0.2172	Signif. = 0.8870	Signif. = 0.6887
ART Scientific Production	*lny* $_{i,\ t-1}$	-0,1789*	-0.2562*	-0.2237*
		(-9.6188)	(-19.9787)	(-10.7739)
	ART	0.0085*	0.0274*	0.0090*
		(5.0481)	(11.9714)	(14.9671)
	Adjusted R^2	0.6371	0.7379	0.7689
	β	0.0394	0.0591	0.0506
	d.f.	73	19	25
	J-Specification(a)	J-Stat. = 14.5046	J-Stat. = 6.7732	J-Stat. = 8.0653
		Signif. = 0.2063	Signif. = 0.8171	Signif. = 0.7074
ARG Scientific Production	*lny* $_{i,\ t-1}$	-0.1900*	-0.2240*	-0,2166*
		(-13.7364)	(-29.7220)	(-11,6315)
	ARG	0.0124*	0.0330*	0,0100*
		(4.7007)	(27.8955)	(18,1759)
	Adjusted R^2	0.6344	0.7408	0,7373
	β	0.0421	0.0507	0,0488
	d.f.	64	19	25
	J-Specification (a)	J-Stat. = 15.3581	J-Stat. = 105348	J-Stat. = 6.0325
		Signif. = 0.1666	Signif. = 0.0000	Signif. = 0.8711

Notes:

Numbers in brackets are t-ratio

(a) tests the validity of the instruments used in the estimation

*Coefficient significant at 1% level

** Coefficient significant at 5% level

*** Coefficient significant at 10% level

n – Coefficient not significant,

The basic code for GMM estimation based on Arellano-Bond (1991) using RATS (6.0) is provided in “The RatsLetter” (2002). We appreciate the suggestions given by Tom Doan from the Estima office responsible for the Rats package.

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