MULTIPLE DIMENSIONS OF REGIONAL ECONOMIC GROWTH IN BRAZIL, 1991-2000[1]

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Resumo

O presente artigo analisa o crescimento econômico brasileiro em múltiplas dimensões entre 1991 e 2000. Sugere-se uma metodologia que permite lidar simultaneamente com o "problema da unidade de área modificável" (*Modifiable Areal Unit Problem* **-** MAUP), auto-correlação espacial e incerteza de modelos (*model uncertainty*). Estes dois últimos problemas têm sido tratados pela literatura empírica de crescimento de maneira isolada focando apenas na questão da auto-correlação espacial ou na questão da incerteza de modelos, enquanto que o MAUP tem sido negligenciado nos estudos sobre crescimento econômico. Com a metodologia proposta, este artigo busca entender como e porque os determinantes do crescimento econômico (incluindo as externalidades espaciais) podem se manifestar de maneira distinta em diferentes escalas espaciais, abrangendo desde a escala municipal até a estadual. A análise empreendida revela que o MAUP distorce as estimações de crescimento econômico para o caso brasileiro. Se uma única regressão é estimada para cada escala espacial, os resultados mudam à medida que a escala é modificada. Entretanto, o teste de robustez executado foi capaz de identificar variáveis que são simultaneamente significantes em diferentes escalas espaciais: maior capital educacional e nível de saúde da população e melhor infra-estrutura local estão relacionados com taxas mais altas de crescimento econômico. Entre outros resultados, este estudo identificou que as externalidades espaciais estão operando predominantemente em escalas espaciais menores. O artigo termina com uma discussão das implicações dos resultados encontrados para políticas que buscam promover o crescimento econômico.

Abstract

The aim of this paper is to analyze Brazilian economic growth in multiple dimensions between 1991 and 2000. This paper suggests a general framework that allows dealing simultaneously with "Modifiable Areal Unit Problem" (MAUP), spatial autocorrelation and model uncertainty. Indeed, the latter two issues have been treated in relative isolation, by focusing only on spatial autocorrelation or on model uncertainty, while MAUP has been neglected by economic growth literature. With this framework, this paper seeks to understand how and why the determinants of economic growth (including spatial spillovers) may manifest themselves differently at different spatial scales, ranging from municipalities to state regions. The analysis reveals that MAUP jeopardizes Brazilian economic growth estimates. If single regression is estimated at the different scales levels, the results change as scale level changes. However, the robustness test was able to identify variables that are simultaneously significant at different spatial scales: higher education and health capital and better local infra-structure are related to higher economic growth rates. Among other results, this paper

[1] I want to thank my supervisors Frédéric Robert-Nicoud and Steve Gibbons that provided useful comments on earlier drafts and improved the paper, and Daniel da Mata that gave some inputs to the dataset. The paper has also benefited from discussions with Professors Ian Gordon and Andrés Rodríguez-Pose in an internal seminar at LSE. Remaining errors and misunderstandings are, of course, the responsibility of the author. Finally, I acknowledge financial support from IPEA and CAPES.

identified that spatial spillovers are operating especially at finer scales. The paper ends with a discussion of the implications of these results for policies to promote growth.

1. Introduction

This paper aims to analyze Brazilian economic growth in multiple dimensions. Usually, economic growth models (e.g. neoclassical and endogenous models) assume that similar rules apply at all spatial scales[2] and empirical studies only test theoretical models using a single scale level. However, it is important to note that "what is true at a given spatial scale might not be true at another" (Overman, 2004, p.513). Indeed, recent geographic studies view that economic processes are not independent of scales at which subjects are observed and analyzed (Sheppard & McMaster, 2004). For understanding the multiple dimensions of economic growth in Brazil between 1991 and 2000, I prepared datasets to examine the economic growth determinants and β-convergence process at five spatial scales (states, municipalities, micro-regions, spatial clusters and urban agglomerations). In addition, recent empirical studies [for example, Magalhãe et al. (2000), Silvera Neto (2001), Lall & Shalizi, (2003) and Silveira Neto & Azzoni (2006)] recognize the importance of spatial spillovers that ultimately affect economic growth. However, such spatial autocorrelation of economic growth could manifest itself with different intensities at the various scale levels. Thus, multiple dimensions of spatial spillover effects need to be analyzed.

While it is expected that this article is informed by the discussion of spatial externalities and economic growth determinants (including rates of convergence) it has a distinct objective of these two issues. The main question of this paper is: What is the role of spatial unit definition in internal income dynamics of Brazil? Or in other words, do the determinants of economic growth in Brazil vary with different levels of spatial aggregation of the observational units? According to Rey & Janikas (2005), while a number of studies have examined the robustness of growth regression to various aspects of research design (Levine and Renelt, 1992; Sala-i-Martin, 1997; Sala-i-Martin et al., 2004), changes in spatial scale have yet to be incorporated in this important line of research. An important issue is how and why the determinants of economic growth (including spatial spillovers) may manifest themselves differently at different spatial scales.

The role of spatial aggregation of the observational units has received very little attention in the mainstream economic growth literature. The choice of regional units and posterior empirical analysis is guided by availability of data. Thus, we do not know if the result holds if the degree of regional aggregation changes. This issue can be analyzed using the concept of "Modifiable Areal Unit Problem" (MAUP) that is the variability in statistical results endemic to the selection of different area units (Openshaw & Taylor 1979, 1981). Basically, MAUP is a statistical issue. Besides this issue, this paper seeks to understand why the exploratory variables of economic growth and respective spillovers in Brazil have different impacts at each one of the spatial scales. Thus, this paper aims therefore investigating more rigorously the space-economic growth dynamics in Brazil over the 1991-2000 period in order to show that levels of spatial aggregation of the observational units are unavoidable features. The choice of this time period allows me collecting information of five spatial scales from the last two Brazilian Population Census (1991 and 2000).

The rest of the paper is organized as follows. The next section reviews the literature. I discuss some economic growth models and the determinants of economic growth in Brazil at various scales: states, micro-regions, municipalities and urban agglomerations. Thus, it is addressed

[2] In this article the term "scales" are defined as nested sets of spatial units of different spatial resolution (e.g., cities nested within micro-regions, nested in turn within states).

the important issue of the so called "Modifiable Areal Unit Problem" (MAUP). Section 3 relates the theoretical growth model with externalities which I use to develop the econometric specifications. Also, it describes the five spatial scales. Section 4 describes the dataset and the spatial weight matrix. In section 5, I report the main results. Final section presents the conclusions, along with some policy implications.

2. Literature Review

It is well known that income inequalities persist in Brazil despite the existence of regional policies during the last decades. For example, the ratio between higher and lower state income per capita was 5.5, in 2000. In a finer spatial scale, i.e., municipal level, the ratio between higher and lower income per capita was 33.6, in 2000[3]. These numbers highlight one of the paradoxes of our times: the existence of extreme economic affluence amidst enormous pockets of poverty. In Brazil, there is a constitutional objective for reducing inequalities across Brazilian regions[4] and the main regional policy has been performed by the Constitutional Funds (FNE, FCO and FNO)[5] since 1989. For example, in the period 2000-2006, the Constitutional Funds invested € 10 (R$ 28) billion in Brazilian lagging regions. It represented 1.2% of national GDP in 2006[6]. However, some studies, such as Silva et al. (2007) and Oliveira & Domingues (2005), have shown that this regional (subsidy) policy plays a limited role in reducing regional inequalities. In fact, Pessôa (2001) argues that a subsidy policy to industry is not the best recommendation to solve inequalities that are embodied in the persons (skill levels, for example)[7]. Thus, the existence of regional inequalities is just the starting point for debating economic growth.

In the mainstream of economic theory, the debate about factors that affect long run economic growth came with Solow (1956) growth model. This model also called exogenous growth model have been augmented by the inclusion of education capital (Mankiw et al., 1992), health capital[8] (Bloom et al. 2001; McDonald & Roberts, 2002), migration (Barro & Sala-i-Martin, 2003), and growth externalities (López-Bazo et al., 2004; Ertur & Koch, 2007). These theoretical models predict conditional β-convergence[9] which means that if regions differ in the parameters that determine their steady state (structural characteristics such as saving rates, schooling, infrastructure, etc), each region should be converging towards its own steady state level of per capita income and not to a common level (such as in the absolute β-convergence case). The β-convergence (absolute or conditional) prediction arises because the assumption about diminishing marginal productivity of factors of production. That is, as the economy grows and the capital-labour ratio increases, the marginal productivity of capital

[3] In 1991, these ratios were 5.9 (state level) and 23.3 (municipal level).
[4] Art. 3rd. The fundamental objectives of the Federative Republic of Brazil are:
III – To eradicate the poverty and the marginalization and **to reduce the regional** and social **inequalities**. (This extract from the Brazilian Constitution, 1988, was translated by the author).
[5] The Constitutional Funds are designed to lend money (subsidized interest rate) to firms in Brazilian lagging regions (Northeast, Center-West and North). See Almeida Junior et al. (2007) for an analysis of these funds.
[6] It is interesting to note that, between 2000 and 2006, the European Union (EU15) allocated €135 billion to regions with less than 75% of the average EU15 GDP per capita. Coincidentally, this expenditure represented 1.2% of EU15 GDP in 2006.
[7] See Pessôa (2001) for the discussion of regional problem vs. social problem.
[8] McDonald & Roberts (2002) develop an augmented Solow model that incorporates both health and education capital since human capital is a complex input that consists of more than the knowledge capital suggested by Mankiw et al. (1992).
[9] See Barro & Sala-i-Martin (2003), Chapter 1.

declines and consequently saving and capital accumulation increase at decreasing rates (Galor, 1996)[10].

After the Solow model, an alternative growth theory was developed, the so-called endogenous growth models. For instance, Romer (1986) stresses the externalities of knowledge investment and Lucas (1988) shows the positive externalities of human capital accumulation[11]. These models are based on the presence of constant or increasing returns to capital that allows inverting the prediction of convergence of the neoclassical model, leading to the conclusion that economies will diverge over time. The new economic geography (NEG) has been another economic field that since the beginning of 1990's has added new elements to the economic growth debate. The NEG theory analyzes spillover effects across regions with rigorous models (Krugman, 1991; Fujita et al., 1999; Fujita & Thisse, 2002; Baldwin et al., 2003). These models have focused on the role that agglomeration externalities play in generating increasing returns and ultimately economic growth (Baldwin & Forslid, 2000). Furthermore, transportation costs have an ambiguous impact on regional development. NGE predicts that falling transport costs would be associated with a bell-shaped curve of spatial development: spatial inequalities would first rise and then fall (Lafourcade & Thisse, 2008, p.4). In recent years the role of spatial spillover effects in convergence processes has been examined using the appropriate spatial statistics and econometric methods (Rey & Montouri, 1999; Fingleton, 1999; López-Bazo et al., 2004). The debate focus is on identifying and testing for factors involved in regional growth processes and respective spillovers.

The empirical literature about long run growth focuses on the determinants of the economic success of some regions and the causes of growth failure of other regions. Thus, this empirical literature review is intended to inform about papers that discuss the determinants of economic growth in Brazil at different scales. This discussion will show that if we take the papers about Brazil we are going to verify that both the process of (di)convergence and the determinants of the economic growth vary with different levels of spatial aggregation of the observational units (states, micro-regions, municipalities and urban agglomerations). This could occur because the existence of the Modifiable Areal Unit Problem (MAUP) and this issue will be my focus in the end of this section. Despite the existence of a rich literature about economic growth of Brazilian regions none of the papers compares the process of economic growth between the different scale levels. Surveying the Brazilian literature about the determinants of economic growth I have found plenty of papers discussing the theme using state level data, very few papers using micro-regions data, an increasing number of papers in recent years that employ municipal aggregation of data and only one paper that works with the concept of urban agglomeration. Next, I discuss the findings of a selected number of papers and their similarities and differences.

Most of papers use state level data to run growth regressions. Ferreira & Diniz (1995) find absolute β-convergence of per capita income among Brazilian states in the period 1970-1985.

[10] Another kind of convergence is called club convergence which means that regions will converge to one another if their initial conditions are in the basin of attraction of the same steady-state equilibrium (Galor, 1996, p.1056). Specifically, Galor (1996) "showed that multiplicity of steady state equilibria and thus club convergence is even consistent with standard neoclassical growth models that exhibit diminishing marginal productivity of capital and constant return to scale if heterogeneity across individuals is permitted" (Ertur et al., 2006, p.8).

[11] Other examples of endogenous growth model are Romer (1990), Barro (1990) and Alesina & Rodrik (1994). Romer's (1990) model shows that an economy with a larger total stock of human capital (that is devoted to research sector) will experience faster growth. Barro (1990) relates a high level of productive government spending (e.g., infra-structure) to high rates of economic growth. Alesina & Rodrik's (1994) growth model shows an inverse relationship between income inequality and economic growth.

Also, Azzoni (2001) indicates that there is absolute β-convergence among states in Brazil for the period 1948-1995. Actually, Ferreira (1999) shows that the results about absolute β-convergence among states in Brazil are robust with regard to period variations. On the other hand, some papers test the prediction of conditional β-convergence including some exploratory variables in economic growth regressions. Azzoni et al. (2000) reveal the existence of conditional β-convergence and indicate that the geographical variables (climate, latitude and rain) seem to be important determinants of economic growth. Furthermore, the results show that schooling and infrastructure variables (sewerage system and piped water) are some of the main factors behind the differences in steady-state rate of income growth in Brazil between 1981 and 1996. Silvera Neto (2001) shows empirical evidence of growth spillovers among Brazilian states economies in the period 1985-1997 by using spatial econometric models. However, Silvera Neto & Azzoni (2006) show that after conditioning on the initial educational levels and manufacturing shares of the states, spatial dependence disappears over the period 1985–2001. Finally, Resende & Figueirêdo (2005) ran two robustness tests[12] using 25 variables suggested by the literature for Brazilian states between 1960 and 2000. The estimations of panel data models found that urbanization, infant mortality rates, fertility rates, climate, tax burden and migration have a robust correlation with the growth rates of GDP per capita of the Brazilian states. Moreover, it was not denied the occurrence of conditional β-convergence for the Brazilian states.

Another spatial scale used to study Brazilian economic growth determinants is called micro-regions that are finer units than state regions. Vergolino et al. (2004) include initial income, regional dummies and education as exploratory variables to analyze the process of economic growth for the Brazilian micro-regions during the period 1970-96. They argue the existence of two clubs of convergence in Brazil: North/South and Northeast/Southwest/Center-West. In the former, it shows a high speed rate of convergence and in the latter there is not any signal of convergence process. Moreover, the results support the hypothesis under which human capital plays an important role in the economic growth of Brazilian micro-regions[13].

Recently, growth regressions have been used to discuss economic growth among the Brazilian municipalities. Andrade et al. (2002) found evidence in favour of absolute and conditional β-convergence, for the period 1970-1996, using both OLS and quantile regressions[14]. When regional dummies are added to the estimation, results from OLS and quantile regression are not significantly different. The exceptions to this rule are the regions North and Northeast that present different results from OLS when using quantile regression. However, the conclusion in favour of convergence still remains (Andrade et al., 2002). Also, De Vreyer & Spielvogel (2005) employ municipal units to analyze Brazilian economic growth for the period 1970-1996. The main equation includes the per capita GDP in 1970 to test for conditional β-convergence, spatial lags of GDP per capita in 1970 and economic growth rates, a set of controlling variables, and regional dummies that could cause

[12] The first approach is the Extreme Bounds Analysis (EBA) test proposed by Levine & Renelt (1992). An alternative approach to the previous one was considered by Sala-i-Martin (1997). The latter author argues that instead of analyzing the extremities of the coefficients estimates of a specific variable, it is necessary to make the analysis of the distribution of all coefficients of this variable.

[13] Souza (2007) found a positive relationship of market access and per capita income growth for the micro-regions of Brazil in the period 1970-2000. Also, the author confirms other results of the literature as the positive impact of human capital on economic growth and conditional convergence hypothesis. Finally, it was showed the existence of parameter heterogeneity.

[14] Coelho (2007) employ another technique to analyze economic growth of Brazilian municipalities over the period 1970-2000: the regression tree approach proposed by Durlauf & Johnson (1995) and Johnson & Takeyama (2003) that allows testing the club convergence hypothesis. The results based on the regression tree method demonstrate the importance of initial conditions such as income per capita and human capital.

differences in the rate of technological progress and the steady state across municipalities. By using spatial econometric models they found spatial externality effects and conditional β-convergence at work among municipalities. Furthermore, the illiteracy rate, the primary sector (agriculture) share and the share of urban population are negatively correlated with economic growth. On the other hand, the mean size of households and the share of households with electricity[15] have a positive effect on municipal economic growth. Finally, Da Mata et al. (2007a) constructed a dataset of 123 Brazilian urban agglomerations[16] to examine the determinants of Brazilian city growth between 1970 and 2000. The main findings are that decreases in rural income opportunities, increases in market potential for goods and labour force quality and reduction in intercity-transport costs have strong impacts on city growth. They also find that local crime and violence, measured by homicide rates impinge on growth (Da Mata et al., 2007a).

We have seen that these papers do not employ a rigorous analysis of spatial scale choice and they do not make any comparison between the spatial scales. Openshaw (1984) points out that this neglect is surprising because many of the basic problems associated with the analysis of aggregated census data have been recognized for a long time (Gehlke & Biehl, 1934; Robinson, 1950; Openshaw & Taylor, 1979). Gehlke & Biehl (1934) showed that variations in the size of the correlation coefficient seem conditioned upon changes in the size of the unit used. Indeed, Openshaw (1984) states that it is now known that the modifiable nature of areal units can be systematically exploited by heuristic procedures to produce a very wide range of different results, irrespective of what individual-level analysis would have produced (Openshaw & Taylor, 1979, 1981). This is known as Modifiable Areal Unit Problem (MAUP). According to Fotheringham et al. (2000, p.237) the two components of the MAUP are:

a. The scale effect: different results can be obtained from the same statistical analysis at different levels of spatial resolution.

b. The zoning effect: different results can be obtained owing to regrouping of zones at a given scale.

In a recent paper, Briant et al. (2007) evaluate, in the context of economic geography estimations, the magnitude of the distortions possibly induced by the choice of various French geographic stratifications. From this specific exercise they conclude that the first MAUP source (size) is prejudicial to economic geography estimations, whereas the second source (shape) is not. Furthermore, they found out that distortions due to specification choices are much larger than variations due to size and shape (Briant et al., 2007). Also, Briant et al. (2007) point out that there are many other questions in empirical economic geography on which the magnitude of the MAUP should be assessed. "*For instance, its impact for the dynamics of regional incomes and for the questions related to regional convergence could be studied, and the list could possibly include any empirical question in economic geography*" (Briant et al., 2007, p. 25).

Behrens & Thisse (2007) point out that from an empirical point of view, the concept of region one retains is often intrinsically linked to the availability of data. For this reason, the question of the spatial scale of analysis becomes a problematic issue in applied research[17].

[15] All variables are measured in 1970.

[16] Da Mata et al. (2007) adapt the concepts of agglomerations from a comprehensive urban study by IPEA, IBGE and UNICAMP resulting in a grouping of municipalities to form 123 urban agglomerations.

[17] Also, Behrens & Thisse (2007) discuss that the concept of region is problematic in theory. In this respect, they argue that "*it is well known how poorly representative the so-called "representative consumer" may be (Kirman, 1992). Likewise, the word "industry" is still in search of a well-defined theoretical meaning (Triffin,*

Additionally, Behrens & Thisse (2007) observe that some new techniques should alleviate the MAUP problem. They argue that the use of geographical information systems (GIS) and the increasing availability of micro-spatial data allow dealing with MAUP in a way suggest by Duraton & Overman (2005)[18]. Unfortunately, the empirical study of economic growth is intrinsically an aggregated study, i.e., the only way to analyze economic growth is using aggregated data. Thus, the motivation of this paper is to check if the variability of coefficients of economic growth determinants and of (di)convergence process are due to differences in the spatial nomenclature. The study is carried out by using five spatial scales for Brazil: states, micro-regions, municipalities, spatial clusters and urban agglomerations. More specifically, the focus is on the scale effect. The zoning effect is not tackled here, first, because the dataset does not allow for re-zoning. Secondly, because Briant et al. (2007) conclude that shape is of third-order concern only. Specification and size are the first and second-order issues. Therefore, we pay special attention to the specification choice in addition to the scale effect. Next section presents the theoretical framework and the respective econometric specifications that underlie the evaluation of the variability in statistical results due to the selection of different area units. Also, it discusses and explains the spatial scales that are employed in the empirical exercise.

3. Theoretical framework, econometric specifications and spatial scales

This section has a threefold purpose. First, it describes a spatially augmented Solow model which yields a conditional β-convergence equation with spatial externalities. Second, econometric specifications are developed to test spatial autocorrelation and the determinants of economic growth at different scale levels. Third, it discusses how spatial scales are defined and if the determinants of economic growth (and respective spatial spillovers) could impact themselves differently at the five spatial scales.

3.1. The model

The theoretical framework underlying the empirical analysis in this paper is a neoclassical growth model with externalities in the production function suggested by López-Bazo et al. (2004)[19]. This theoretical model does not make any distinction between the spatial scale choice, i.e., region in this model could be any spatial aggregation. Despite this fact, the theoretical model, discussed here, is important to show how economic growth spillovers work and how other exploratory variables impact economic growth.

The model consider a regional economy with income (Y) that is produced using labour (L), physical (K), and human (H) capital. The technology is of the Cobb-Douglas type with constant returns to scale. The per capita[20] income in region ***i*** in period ***t***, y_{it}, is a function of the levels of physical capital per capita (k_{it}), of human capital per capita (h_{it}) and of the state of technology (A_{it}):

1940). Grouping locations within the same spatial entity, called a region, gives rise to similar difficulties. It is, therefore, probably hopeless to give a clear and precise answer to our first question (What is a region?), which is essentially an empirical one. When we talk about a region, we must be happy with the same theoretical vagueness that we encounter when using the concept of industry. Note that both involve some "intermediate" level of aggregation between the macro and the micro" (Behrens & Thisse, 2007, p.459).

18 These authors employ a continuous space approach using micro-spatial data to determine the degree of spatial concentration of various industrial sectors.

19 Similarly, Ertur & Koch (2007) present an augmented Solow model which explicitly takes into account technological interdependence among economies.

20 I prefer to use the expression *per capita* instead of *per work* employed by Lopéz-Bazo et al. (2004) because in the empirical investigation the available data are only *per capita*.

$$y_{it} = A_{it} k_{it}^{t_k} h_{it}^{t_h} \quad (1)$$

where t_k and t_h are, respectively, internal returns to physical and human capital. The model assumes decreasing returns to all capital: $t_k + t_h < 1$, $t_k > 0$ and $t_h > 0$.

Technology in a region i, A_{it}, depends on the technological level of the neighbouring regions[21], which is in turn related to their stocks of both types of capital:

$$A_{it} = \Delta_t (k_{rit}^{t_k} h_{rit}^{t_h})^{g} \quad (2)$$

where Δ_t is common to all regions and exogenous component. Moreover, k_{rit} and h_{rit} denote, respectively, the average physical and human capital ratios in the neighbouring regions. The coefficient g measures the externality across regions. If its sign is positive it means that one percent increase in the level of the average physical stock per capita of neighbouring region (k_{rit}) increases technology in region *i* by $g t_k \%$. The same idea applies to h_{rit}. For these reason, a region benefits from investments made by its neighbours.

Combining Eq. (1) and (2) gives an expression that relates per capita income in a region to capital (physical and human) intensity in the same region and in its neighbours:

$$y_{it} = \Delta_t k_{it}^{t_k} h_{it}^{t_h} (k_{rit}^{t_k} h_{rit}^{t_h})^{g} \quad (3)$$

Eq. (3) shows up the externalities effects when an economy *i* increases its stock of physical and human capital. It obtains a return of $t_k + t_h$, whereas this return increases to $(t_k + t_h)(1+g)$ if its neighbours simultaneously increase their stocks of physical and human capital. It is important to note that per capita income in *i* will increase with physical and human stock per capita of neighbouring region even in the case of no further investments in *i*. This is justified by "the diffusion of technology from the neighbours, which makes the current stock of capital in *i* more productive" (López-Bazo et al., 2004, p. 47).

From Equation (3), and after some algebraic operations it is possible to derive the expression that summarizes growth in per capita income when there are externalities across economies in the process of production [see López-Bazo et al. (2004) for details][22]:

$$g_y = x - (1 - e^{-\beta T}) \ln y_0 + \frac{(1 - e^{-\beta T})\gamma}{1 - (t_k + t_h)} \ln y_{0r} + \gamma g_{y_r} + \frac{(1 - e^{-\beta T})}{1 - (t_k + t_h)} \left[t_k \left(\ln s_k - \ln(n + g + d) \right) + t_h \left(\ln s_h - \ln(n + g + d) \right) \right] \quad (4)$$

Note that Eq. (4) is the same as the one derived by Mankiw et al. (1992) if the terms related to the neighbours are excluded and g =0. In this case, economic growth is a function of the initial level of per capita income (y_0) and accumulation rates of both types of capital (s_k, s_h), population (n) and technology growth (g), and the rate of depreciation (d). As standard in the neoclassical growth models economic growth rates are inversely related to y_0, i.e., conditional β-convergence occurs. Now, under the assumption of externalities across regions two new elements appear in the growth equation: growth of per capita income (g_{y_r}) and its

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[21] r is used to refer to neighboring economies.

[22] x is used to refer to the constant term in Eq (4).

initial level (y_{0r}) in the neighbouring economies. So, if g >0, economic growth will be higher for regions having neighbours with large initial per capita income and high rates of growth (López-Bazo et al., 2004). As highlighted by López-Bazo et al. (2004), from an empirical point of view the omission of these variables would likely be biasing the estimate of the rate of convergence. The next subsection shows the econometric specifications of the theoretical equation (4) discussed here.

3.2. Econometric specifications

This subsection shows the econometric specifications that I run to evaluate the variability of the coefficients of economic growth determinants at the different spatial scales. Moreover, the following equations highlight the way to deal with the spatial autocorrelation that could exist in some scale levels.

Equation (5) is the counterpart of Eq. (4) and the basic econometric specification in this section. In Eq. (5) I omit the terms for physical capital accumulation and the effective rates of depreciation (n+g+d) because the lack of data for the empirical exercise. Also, the term for human capital accumulation is omitted and added in Eq. (7) where others controlling variables are included as well. For this reason, Eq. (5) does not allow from obtaining estimation for structural coefficients. But if I include the last term of Eq. (4) in the constant term[23] it is possible to obtain an estimate for the measure of externalities (g , f) and for the rate of convergence (β) in Eq. (5)[24].

$$g_y = constant - (1 - e^{-\beta T}) \ln y_0 + f_{W_f} \ln W y_0 + \gamma W g_y + e \tag{5}$$

Rewriting Eq. (5) in matrix form, we have:

$$g = Y_0 b + fWy_0 + gWg + e \tag{6}$$

where g is $N \times 1$ column vector with observations for per capita income growth for each region, Y_0 is $N \times 2$ matrix including the constant term and the initial per capita income, and W is the row standardized $N \times N$ spatial weight matrix. Wy_0 is the $N \times 1$ column vector of the spatially lagged initial per capita income, and Wg is the $N \times 1$ column vector of the spatially lagged dependent variable[25]. e is the $N \times 1$ vector of errors supposed identically and normally distributed so that $e \sim N(0, s^2)$.

In Eq. (7), it is added on the right-hand side a set, X ($N \times K$ matrix), of controlling variables that could cause differences in the rate of technological progress and the steady state across regions.

$$g = Y_0 b_1 + fWy_0 + gWg + Xb_2 + e \tag{7}$$

The X vector can encompass several explanatory variables, proposed by other growth models, such as education capital (Mankiw et al., 1992), health capital (Bloom et al., 2001; McDonald & Roberts, 2002), infrastructure (Barro, 1990), and income inequality (Alesina & Rodrik, 1994). As highlighted by Brock & Durlauf (2001) growth theories are open-ended.

[23] This same operation has been common practice, as in Barro & Sala-i-Martin (1992, p.227) and López-Bazo et al. (2004, p.51).

[24] This strategy is followed by López-Bazo et al. (2004).

[25] As highlighted by Ertur & Koch (2007, p.1044) "in the spatial econometrics literature, this kind of specification, including the spatial lags of exogenous variables in addition to the lag of the endogenous variable, is referred to as the spatial Durbin model (see Anselin, 1988, p.227). On the other hand, the model only with the spatially lagged endogenous variable is referred to as the spatial autoregressive model (SAR)".

By open-endedness (or model uncertainty), Brock & Durlauf (2001, p.234) "refer to the idea that the validity of one causal theory of growth does not imply the falsity of another". So, for example, the theory that education capital affects growth is compatible with any number of other theories, such as the claim that the income inequality affects growth (see Table 1 for other examples). Brock & Durlauf (2001, p.234) point out that "this issue of open-endedness has not been directly dealt with in the literature". Instead, robustness tests have been applied to check the empirical results of growth regressions. The first ones to introduce this approach in the economic growth literature were Levine & Renelt (1992) that employed a version of the extreme bounds analysis proposed by Leamer (1983). The Extreme Bounds Analysis (EBA) approach states that a coefficient is called robust if it remains significant and does not change its sign across a set of combinations of other variables. Following this idea, some authors have suggested other approaches (Sala-i-Martin, 1997; Fernandez et al., 2001; Brock & Durlauf, 2001; Sala-i-Martin et al., 2004).

In section 5, I employ a variable uncertainty exercise using the idea from Levine & Renelt (1992) that verifies the robustness of the coefficients by the inclusion of a set of controlling variables. Table 1 shows the exploratory variables[26] (and the expected signs for the coefficients) that I employ to run the growth regressions using the five spatial scales. All models listed in Table 1 make their predictions regardless the spatial scale choice, i.e., they assume that similar rules apply at all scales. However, from an empirical point of view, we do not know if the results of a single scale hold for another scale choice.

Table 1 –Expected coefficients signs based on the theoretical models

Exploratory Variable	Expected sign	Theoretical model
Externalities of economic growth	+	López-Bazo et al. (2004)
Externalities of initial per capita income	+	López-Bazo et al. (2004)
Income per capita (β-Convergence)	–	Solow (1956)
Average years of schooling (proxy for education capital)	+	Lucas (1988); Mankiw et al. (1992)
Gini index (proxy for income inequality)	–	Alesina & Rodrik (1994)
Infant mortality rate (proxy for health capital)	–	Bloom et al. (2001); McDonald & Roberts (2002)
Transportation Costs	– / +	Lafourcade & Thisse (2008)
Population density (*proxy* for agglomeration)	+	Baldwin & Forslid (2000)
Housing infrastructure (proxy for local infrastructure)	+	Barro (1990)

Own elaboration.

Finally, it is important to note in Eq. (7) that if g and f are significantly different from zero, their omissions in a growth regression give us inconsistent parameters of b_1 and b_2 in the Eq. (8), the so-called Barro-regression:

$$g = Y_0 b_1 + \mathrm{X} b_2 + e \quad , \qquad (8)$$

The omissions in Eq. (8) will cause the residuals to be spatially correlated. Also, the inclusion of the spatial lag of the endogenous variable (Wg) on the right-hand side causes the ordinary least squares (OLS) estimator to be inconsistent (Anselin, 1988). Instrumental variables (IV) and maximumlikelihood-based estimators[27] provide consistent estimates of a model such as Eq. (7). In section 5, the first step is to run Eq. (8) using OLS method to test for the existence

[26] The dataset is discussed in section 4.

[27] In the empirical section, the maximum-likelihood approach is employed rather than the IV method since the spatial lag of income per capita is included in the econometric specification. We know that IV method assumes that the neighbouring characteristics WX (the instruments) do not directly affect economic growth. This assumption is hard to defend since some authors (López-Bazo et al., 2004; Ertur & Koch, 2007) have shown that neighbouring characteristics affect economic growth.

of errors spatially auto-correlated. Thus, in this way it is possible to detect (using Eq.8) and deal with the problem of spatial autocorrelation (using Eq. 6 and 7) in the growth regression.

3.3. Spatial scales

Brazil has more than 8 millions square kilometres, roughly twice the size of European Union (27 countries). It is divided in 27 states[28], the main political-administrative division. In addition, municipalities are the smallest administrative level for local policy implementation and management. In Brazil, it is possible to observe many types of regions, ranging from densely settled urban centres to sparsely settled rural regions. Socioeconomic data in Brazil tend to be available by municipal level and they could be combined to form other spatial scales. However, it is useful to note that the unit of analysis in this case is the municipality, i.e., territorial units for the production of regional statistics for Brazil whose definition might not always approximate the functional borders of the regional economy.

An effort to overcome this problem is the definition of functional regions. An example of these functional regions is the micro-regions defined by IBGE in 1969 as being a group of contiguous municipalities in the same state. They were grouped according to natural and production characteristics. Other example are the urban agglomerations proposed by Da Mata et al. (2007a) that adapts the concepts of functional agglomerations from a comprehensive urban study by IPEA, IBGE and UNICAMP (2002) resulting in a grouping of municipalities to form 123 urban agglomerations[29]. A similar approach to the concept of functional urban agglomeration is carried out by Carvalho et al. (2007) but, unlike the latter, it is not restricted to urban areas. They defined 91 spatial clusters employing an original cluster methodology (algorithmic) that groups contiguous municipalities that share similar characteristics using 46 variables reported in the Brazilian Census of 2000[30].

It may be difficult to generalize how different spatial aggregations of datasets are affected by the MAUP. For example, state level reflects the main political-administrative division in Brazil and it could be not fine enough to satisfactorily capture unobserved heterogeneity and may mask meaningful geographic variation evident with smaller areal units. On the other hand, the use of municipalities has a tendency to provide spurious spatial autocorrelation that could arise as an artifact of slicing homogenous regions. An approach to overcome these two problems is the use of functional regions that attempt to capture the economic sphere of influence of a group of municipalities. In the case of this paper three kinds of function regions are employed: micro-regions, spatial clusters and urban agglomerations. This latter spatial scale is very different from the others because it consists of urban regions only. A priori, it is clear that the empirical analysis for urban agglomerations should have very different results from the other scales levels. Note that urban agglomerations comprise only 15% of the country area. For example, in 2000, the average per capita income for urban agglomerations was R$ 392.00 (or € 200.00, which is monthly data of 2000), 32% higher than the country mean, and population density was 76 (inhabitant per km^2), 380% higher than the country mean (20 inhabitant per km^2). Figure 1 shows the five spatial scales and some statistics concerning their sizes (in square kilometres).

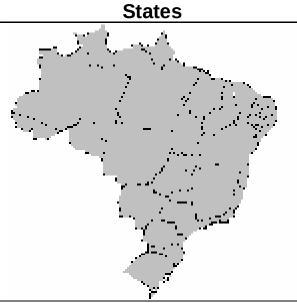
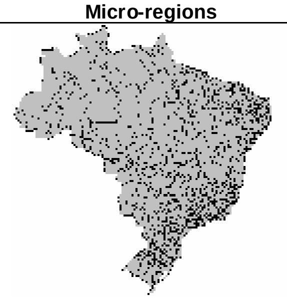
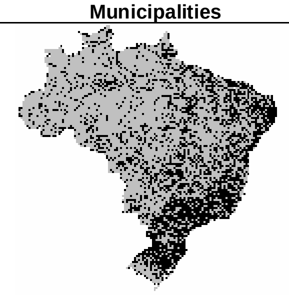
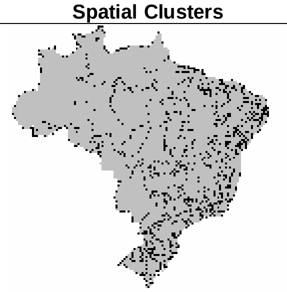
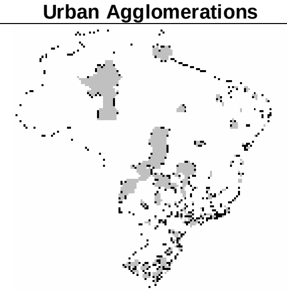
[28] More precisely, there are 26 states and one federal district.

[29] The resulting data set represents 123 urban agglomerations that consist of a total of 832 municipalities in 2000. For each agglomeration, they identified the municipalities that were a functional part of the urban area by using a range of census and other variables such as employed population in urban activities, urbanization rate, and population density.

[30] The variable list includes: employment in 17 sectors of economic activity, education, health, income, urbanization rate, violence rate, housing conditions and others. See Carvalho et al. (2007) for further details.

In the case of economic growth debate it would be useful to draw some relationships between the exploratory variables (including spillovers effects) and economic growth at different spatial scales. The augmented Solow model with externalities in addition to the controlling variables (Table 1, p.10) discussed earlier show up that the key for economic growth success in not unique, but a combination of multiple factors. A gap in the theoretical and empirical literature is the absence of a better understanding of how these factors work at different spatial scales. A priori, I do not have a theoretical reason to conclude that results should change at different scale levels. However, based on the evidences of empirical literature this conclusion could be wrong. This question is hard to deal with because the results that I have discussed in literature review section could be changing because of the estimation method and/or the time period and/or the controlling variables are not the same. A good way to verify the role of spatial scale in the economic growth dynamics is to systematically repeat a method using the same time period and exploratory variables, originally developed to examine this phenomenon at a single scale, to multiple scales. The empirical exercise carried out in section 5 applies this approach and aims to clarify some fuzzy results discussed in section 2.

Figure 1 – Multiple spatial scales (Brazil)

States	Micro-regions	Municipalities
		
n = 27 Area Mean = 315,982 Km^2 Area Min = 5,822 Km^2 Area Max = 1,577,820 Km^2 Area Standard Deviation = 378,718	n = 559 Area Mean = 15,262 Km^2 Area Min = 18 Km^2 Area Max = 333,857 Km^2 Area Standard Deviation = 29,659	n = 5,507 Area Mean = 1,549 Km^2 Area Min = 3 Km^2 Area Max = 161,446 Km^2 Area Standard Deviation = 5,738
Spatial Clusters	**Urban Agglomerations**	
		
n = 91 Area Mean = 93,753 Km^2 Area Min = 350 Km^2 Area Max = 1,340,216 Km^2 Area Standard Deviation = 196,110	n = 123 Area Mean = 10,387 Km^2 Area Min = 297 Km^2 Area Max = 361,329 Km^2 Area Standard Deviation = 38,446	

Source: Own elaboration from data of IBGE, Da Mata et al. (2007) and Carvalho et al. (2007).

4. Data and spatial weight matrix

To evaluate the magnitude of the determinants of economic growth at different scale levels, in the context of growth regression estimates, I employ all Brazilian geographic stratifications discussed in section 3.3. Thus, five spatial scales are used: 27 states, 559 micro regions, 5,507 municipalities, 91 spatial clusters and 123 urban agglomerations. The dataset were constructed for the five spatial scales.

Most of the socioeconomic data at municipal level, such as (log of) per capita income, (log of) average years of schooling, (log of) infant mortality rate, (log of) Gini index, and (log of) population density come from the "Atlas do Desenvolvimento Humano no Brasil" (IPEA, PNUD e FJP, 2003). The Atlas gives us the data from the Census of 1991 using the 5,507 municipalities in 2000, instead of the existing 4,491 municipalities in 1991[31]. Thus, it is possible to calculate per capita income[32] growth between 1991 and 2000 at all scale levels. All exploratory variables are in levels of 1991. The transportation cost between all Brazilian municipalities and the nearest state capital and between all Brazilian municipalities and São Paulo are from IPEADATA[33]. The transportation cost data are for the years 1980 and 1995. I estimated these variables to 1991 via interpolation. Transportation cost to the nearest state capital (or to São Paulo) is a result of a linear program procedure to calculate the minimum cost between the municipalities majors headquarter to the nearest state capital (or to São Paulo)[34]. The housing infrastructure index is made from a principal components analysis employed by Da Mata et al. (2007b). It takes into account several dimensions of housing public services and utilities such as electricity, sewage, water and garbage collection and it is supposed to capture the quantity and quality of housing infrastructure in Brazilian municipalities[35]. Finally, the econometric models include regional dummies for each one of the four Brazilian macro-regions[36]: Northeast, Southeast, South and Center-West.

The use of spatial weight matrix is to model the spatial interdependence between regions. I consider pure geographical neighbouring, which is indeed strictly exogenous that avoids the identification problems raised by Manski (1993) in social sciences. The spatial weight matrix W used here is based on the k-nearest neighbours calculated from the great circle distance between region centroids. As pointed out by LeGallo & Ertur (2003) these matrices are preferred to the simple contiguity matrix, as used for example by López-Bazo et al. (1999), for various reasons. One important reason is because they connect the islands of Ilhabela and Fernando de Noronha to continental Brazil and also they link the urban agglomeration regions, thus avoiding rows and columns in W with only zero values[37]. In the next section, I show the results using a spatial weight matrix based on 10-nearest neighbours. In addition, a sensitive analysis of the results was carried out using k = 5 and 15.

5. Results

First in this section, results of the baseline specification (ordinary least squares, OLS) and diagnostics for spatial dependence are discussed at five spatial scales. Next, spatial

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[31] See IPEA, PNUD e FJP (2003) for details.

[32] As discussed in Da Mata et al. (2005), per capita income is not the preferred proxy for productivity growth as it includes not only real wage income, but also transfer payments and dividends or capital gains that were not necessarily generated locally. However, there is a widespread use of income data in empirical papers and the overall quality of it is better than the wage information. Finally, the use of income data do not significantly affects the analysis because the correlation of income and wage data, both in terms of levels and growth rates, is very high (0.99 and 0.93, respectively).

[33] Available at www.ipeadata.com.br.

[34] The transportation cost variables were estimated via the Highway Design and Maintenance Standards Model (HDM-III) of the World Bank. That model predicts the various components of vehicle operating costs (VOC) in a roadway based on the roadway characteristics (pavement type and relief), vehicle characteristics (average capacity), and unit costs in a free-flow traffic environment. The result is the transport cost for two roadway categories (national or state roads). The results of the model were then used with one more variable: the minimum distance between two roadway nodes, i.e., the distance between the major headquarter of the municipality and São Paulo or the nearest state capital major headquarter. This procedure calculates the transportation cost variables, given road and vehicles conditions.

[35] I do not take log of this variable because it has positive and negative numbers.

[36] I exclude one of the dummy variables (North dummy) from the regressions to avoid perfect multicollinearity.

[37] LeGallo & Ertur (2003) note that with a simple contiguity matrix, unconnected observations are indeed implicitly eliminated from the computed global statistics but this leads to a change in the sample size and thus must be explicitly accounted for in statistical inference.

econometric specifications are employed to correct for potential errors in the OLS empirical strategy. Finally, a variable uncertainty exercise is carried out to investigate robustness of the results. Further details are discussed concerning the robustness test methodology in this sub-section.

5.1. Baseline specification

The first step is to estimate the baseline specification (Eq. 8) via OLS for the five spatial scales. In addition, checks for spatial dependence applying the (robust) Lagrange multiplier (LM) tests and Moran's *I* in the errors terms are carried out. Table 2 shows two set of results: first, absolute β-convergence equations are estimated (where X vector is excluded from Eq. 8) for the five spatial scales; second, in the last five columns, results for conditional β-convergence are shown. The latter specification recognizes growth as a multivariate process.

Concerning the absolute β-convergence results, the convergence hypothesis is rejected for state level, since the coefficient of initial income per capita is not statistically significant (column 1a). It means that states are not converging to the same steady-state level of income per capita. For the other scale levels (column 1b-1e), the absolute β-convergence hypothesis cannot be denied, albeit the low speed of convergence with an implied very long half-life[38]. From the initial income per capita coefficient, the speed of convergence and the half-life (HL) are calculated according to the following formulas, respectively: $-(1-e^{-\beta T})/T = b$ and $-\ln(2)/b = HL(years)$, where b is the OLS estimate of the initial income coefficient, T is the sample period (in the case of this study T=1, since dependent variable is already annually calculated) , and β is the speed of convergence. For instance, the half-life for municipalities and micro-regions are approximately 84 and 239 years, respectively. Thus, according to these estimates, if current trends continue, convergence will take a very long time, meaning a lack of evidence that regions are converging to the same steady-state level of income per capita.

The second set of equations (2a-2e) in Table 2 represents the results for the conditional β-convergence hypothesis. All the coefficients of the initial per capita income variable are negative and significant reflecting the faster growth of the poorest regions in Brazil between 1991 and 2000. Now, when controlling variables are included, the results show that regions at the five spatial scales are converging at a faster pace with an implied half-life of, respectively, 12 and 16 years for the case of municipalities and micro-regions for example. It is worth noting that conditional β-convergence means that the economies tend to different steady-state levels, where the regional disparities will persist.

The results in Table 1 also imply, similarly to the Brazilian empirical literature, that controlling variables are playing a role in the per capita income growth dynamics since the results of the conditional case are better than the unconditional case. It is useful to observe that exploratory variables seem to manifest differently at the five spatial scales, since the magnitude and significance of the coefficients differ between the spatial scales. A consistent finding is the increasing model exploratory power (adjusted R-squared) with increasing scale[39]. For example, at municipal resolution (5,507 units), the adjusted R-squared is 0.25, whereas by state resolution (27 units) the adjusted R-squared climbs to 0.71. However, before further comments about the results it is important to analyze the diagnostics for spatial dependence since in the presence of spatial autocorrelation, the OLS coefficients parameters can be biased or inefficient, depending on the kind of spatial dependence observed.

[38] The half-life is the number of years that the economy takes to transit half way to its steady-state level of income per capita.

[39] As highlighted in section 3.3, urban agglomeration scale only encompass urban regions and represents 15% of Brazilian territory, thus results for this spatial scale may have distinct behavior.

The first approach to test for possible presence of spatial dependence is an application of Moran's *I* to the residuals of each specification in Table 2. For the absolute β-convergence equations (1a-1e), all specifications suffer from spatial autocorrelation since Moran's *I* is statistically significant in the five specifications. On the other hand, when controlling variables are added, these variables can deal with the spatial autocorrelation in the specification for states (2a) and can reduce the problem for spatial cluster (2d) and urban agglomeration (2e) regressions. Another approach to identify the spatial dependence and to choose the best spatial econometric specification (spatial lag or spatial error) is proposed by Florax et al. (2003). The strategy consists of the estimation of the standard OLS model to check for spatial dependence applying the (robust) Lagrange Multiplier (LM) tests[40]. In this paper, I have preferred to run the spatial Durbin model specification suggested by the theoretical model (Eq. 6 and Eq. 7) since the distinction between a spatial lag and a spatial error specification is often difficult in practice.

[40] See Florax et al. (2003) for further details.

Table 2 – OLS Estimation Results and Diagnostics for Spatial Dependence

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS

	political-administrative regions		functional regions			political-administrative regions		functional regions		
Exploratory variables	(1a) states	(1b) municipalities	(1c) micro regions	(1d) spatial clusters	(1e) urban agglomerations	(2a) states	(2b) municipalities	(2c) micro regions	(2d) spatial clusters	(2e) urban agglomerations
ln(income per capita in 1991)	-0.0085	-0.0083*	-0.0029**	-0.0058***	-0.0113*	-0.0707*	-0.0602*	-0.0421*	-0.0659*	-0.0301*
	(0.0061)	(0.0007)	(0.0012)	(0.0032)	(0.0025)	(0.0214)	(0.0017)	(0.0034)	(0.0090)	(0.0057)
ln(average years of schooling in 1991)						0.0080	0.0301*	0.0385*	0.0655*	0.0196***
						(0.0359)	(0.0018)	(0.0038)	(0.0140)	(0.0111)
ln(Gini index in 1991)						0.1329***	-0.0043	0.0085	-0.0326	-0.0273**
						(0.0631)	(0.0038)	0.0085	(0.0311)	(0.0137)
ln(infant mortality rate in 1991)						-0.0245***	-0.0131*	-0.0121*	-0.0102	-0.0018
						(0.0131)	(0.0014)	(0.0029)	(0.0101)	(0.0039)
ln(transport cost - TC- to SP in 1991)						-0.0054	-0.0067*	-0.0019	-0.0014	-0.00004
						(0.0070)	(0.0009)	(0.0014)	(0.0036)	(0.0017)
ln(TC to the nearest capital in 1991)						0.0021	0.0003	0.0028*	0.0124*	-0.0002
						(0.0038)	(0.0006)	(0.0009)	(0.0030)	(0.0012)
ln(population density in 1991)						0.0062**	0.0001	0.0007	0.0035**	0.0007
						(0.0025)	(0.0004)	(0.0007)	(0.0018)	(0.0009)
Index housing infra-structure in 1991						0.0030	0.0038*	-0.00003	0.0038	-0.0023
						(0.0075)	(0.0005)	(0.0011)	(0.0035)	(0.0022)
Constant	0.0733**	0.0756*	0.0483*	0.0608*	0.0924*	0.5658*	0.3751*	0.2270*	0.2163**	0.1277*
	(0.0314)	(0.0033)	(0.0058)	(0.0162)	(0.0134)	(0.1755)	(0.0158)	(0.0290)	(0.0889)	(0.0392)
Regional dummies	no	no	no	no	no	yes	yes	yes	yes	yes
Observations	27	5,507	559	91	123	27	5,507	559	91	123
Adjusted R-squared	0.0348	0.0249	0.0092	0.0237	0.1420	0.7074	0.2502	0.4058	0.5274	0.4152
Diagnostics for spatial dependence (10-nearest neighbours weight matrix)										
Moran's I (error)	0.1736*	0.2228*	0.4947*	0.1744*	0.2294*	-0.0812	0.1463*	0.2640*	0.0966*	0.0538*
Lagrange Multiplier-Lag	1.4698	1147.6887*	659.6293*	10.0987*	18.4703*	0.4326	357.9077*	202.9278*	2.0532	8.2255*
Robust Lagrange Multiplier-Lag	7.0238*	311.4292*	8.13645*	4.7905**	3.8884**	0.0429	26.2029*	24.0110*	0.2608	11.9060*
Lagrange Multiplier-Error	4.0703**	1367.3630*	684.0900*	13.8398*	32.3566*	0.8911	589.1311*	194.7735*	4.2474**	1.7774
Robust Lagrange Multiplier-Error	9.6243*	531.1035*	32.5972*	8.53156*	17.7748*	0.5014	257.4263*	15.8567*	2.4550	5.4578**

Obs: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%;. Dependent variable = (1/9)*ln[incomepercapita in 2000/incomepercapita in1991].

5.2. Spatial correction

Next I report the estimation results for the spatial models. The columns (3a-3e) of Table 3 show the absolute β-convergence results. However, from the convergence perspective, Eq. (6) (see section 3.2, p.9) can be interpreted as a minimal conditional β-convergence model integrating two spatial environment variables (Ertur et al. 2006, p.23). For all spatial scales, the coefficients g and f are significantly different from zero. It means that the average growth rate of a region *i* is positively influenced by the average growth rate of neighbouring regions. In the same sense, economic growth seems to be influenced by the initial per capita income of neighbouring regions.

However, previous results show that inclusion of other exploratory variables increases model exploratory power. Thus, columns (4a-4e) show the results for the conditional β-convergence case using Eq. (7) discussed in section 3.2. Note that, even though spatial autocorrelation has not been detected in the error term (see Table 2, column 2a) for the state scale (4a), I run a spatial regression which confirms that OLS specification is better than the spatial one (see Likelihood Ratio Test in Table 3, column 4a). Indeed, Silvera Neto & Azzoni (2006) show that after conditioning on other important variables that have very strong regional or geographic patterns across Brazilian states over the period 1985–2001, spatial dependence disappears. Silvera Neto & Azzoni (2006) suggest that the significant exploratory variables show up the potential channels through which the strong spatial dependence in the process of convergence of per capita income of Brazilian states occurs. All the coefficients of the initial per capita income are negative and statistically significant reflecting similar speed of convergence and half-life to the case of OLS results. Moreover, the finding of negative correlation between model exploratory power (R-squared) and number of scale units is found[41] again.

The results of columns 4a-4e clearly show that MAUP jeopardizes Brazilian economic growth estimates. The significance and magnitude of the coefficients vary at the five scale levels. In the state level, spatial dependence is not found. On the other hand, for the other spatial scales, the spatially lagged dependent variables have positive and significant coefficients (g) – albeit with different magnitudes – showing that more a region is surrounded by dynamic regions with high growth rates, the higher will be its growth rate. Moreover, only in the case of municipal and spatial cluster levels the average initial per capita income level of neighbours has a positive impact on growth (f), i.e., a specific region located in a relatively poor (rich) neighbourhood will tend to have a lower (higher) income growth (with other things being equal).

Other exploratory variables also manifest differently at the five spatial scales. For example, there is a positive and significant impact of years of schooling (proxy for education capital) on economic growth at municipal, micro-regional and spatial cluster scale levels. On the other hand, the coefficient of housing infrastructure, a proxy for local infrastructure, seems to impact positively only at municipal level. Notwithstanding, before I make further analysis of the results shown in Table 3, it is important to check the robustness of these results in two ways: (i) to verify if each coefficient remains significant and does not change its sign across a set of combinations of variables; (2) to carry out a sensitive analysis based on 5 and 15-nearest neighbours spatial weight matrix.

[41] In Table 3, I show the R-squared instead of the adjusted R-squared. It is import to note that, the high R-quared for state level may be a symptom of micronumerosity, which simply means small sample size.

Table 3 – Spatial Model Results

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: Maximum Likelihood										
	political-administrative regions		functional regions			political-administrative regions		functional regions		
Exploratory variables	(3a) states	(3b) municipalities	(3c) micro regions	(3d) spatial clusters	(3e) urban agglomerations	(4a) states	(4b) municipalities	(4c) micro regions	(4d) spatial clusters	(4e) urban agglomerations
Spatial lag income per capita growth (g)	0.6253*	0.4189*	0.6352*	0.5120*	0.522*	-0.4627	0.2692*	0.4217*	0.4286*	0.3185**
	(0.2061)	(0.0176)	(0.0413)	(0.1449)	(0.1238)	(0.4258)	(0.0187)	(0.0476)	(0.1495)	(0.1506)
ln(income per capita in 1991)	-0.0262*	-0.0315*	-0.0075*	-0.0116*	-0.0164*	-0.0701*	-0.0598*	-0.0346*	-0.0666*	-0.0258*
	(0.0066)	(0.0013)	(0.0017)	(0.0039)	(0.0033)	(0.0155)	(0.0019)	(0.0033)	(0.0079)	(0.0056)
Spatial lag income per capita in 1991 (f)	0.0365*	0.0303*	0.0067*	0.0134**	0.0128*	-0.0064	0.0118*	0.0025	0.0188**	-0.0096
	(0.0099)	(0.0015)	(0.0020)	(0.0057)	(0.0045)	(0.0154)	(0.0021)	(0.0035)	(0.0078)	(0.0099)
ln(average years of schooling in 1991)						0.0081	0.0277*	0.0322*	0.0706*	0.0158
						(0.0263)	(0.0018)	(0.0036)	(0.0125)	(0.0104)
ln(Gini index in 1991)						0.1395*	-0.0032	-0.0048	-0.0407	-0.0335*
						(0.0494)	(0.0040)	(0.0080)	(0.0272)	(0.0129)
ln(infant mortality rate in 1991)						-0.0229**	-0.0100*	-0.0095*	-0.0081	-0.0021
						(0.0111)	(0.0014)	(0.0028)	(0.0089)	(0.0036)
ln(transport cost - TC- to SP in 1991)						-0.0084	-0.0044*	-0.0015	0.0007	-0.0021
						(0.0059)	(0.0010)	(0.0015)	(0.0034)	(0.0019)
ln(TC to the nearest capital in 1991)						0.0016	0.0004	0.0018**	0.0137*	0.0004
						(0.0027)	(0.0005)	(0.0008)	(0.0027)	(0.0011)
ln(population density in 1991)						0.0056*	0.0002	-0.00004	0.0047**	0.00003
						(0.0018)	(0.0004)	(0.0006)	(0.0017)	(0.0009)
Index housing infra-structure in 1991						0.0031	0.0035*	0.0003	0.0020	-0.0008
						(0.0055)	(0.0005)	(0.0011)	(0.0032)	(0.0021)
Constant	-0.0423	0.0273*	0.0153*	0.0067	0.0336***	0.6322*	0.2853*	0.1659*	0.0706	0.1633**
	0.0359	(0.0034)	(0.0054)	(0.0218)	(0.0181)	(0.2010)	(0.0184)	(0.0358)	(0.0989)	(0.0656)
Regional dummies	no	no	no	no	no	yes	yes	yes	yes	yes
Observations	27	5,507	559	91	123	27	5,507	559	91	123
R-squared	0.440	0.199	0.397	0.200	0.311	0.850	0.291	0.512	0.635	0.511
<u>**Diagnostic for spatial dependence**</u> (10-nearest neighbours weight matrix)										
Likelihood Ratio Test	4.1003**	578.4964*	216.2454*	9.0593*	17.7447*	0.9405	213.7857*	76.9657*	5.1123**	4.4080**

Obs: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%;. Dependent variable = (1/9)*ln[incomepercapita in 2000/incomepercapita in1991].

5.3. Robustness checks

I use the approach proposed by Levine & Renelt (1992) which is a variant of Learner's (1983) extreme-bounds analysis (EBA) to test the robustness of coefficient estimates to alterations in the conditioning set of information. The basic framework employed in this test aims at dealing with model uncertainty[42]. As highlighted by Sala-i-Martin et al(2004) some empirical economists have simply "tried" combinations of variables which could be potentially important determinants of growth and report the results of their preferred specification. "Such 'data-mining' could lead to spurious inference" (Sala-i-Martin et al., 2004, p.814).

Eq. (7) described in section 3.2 is the specification employed in the robustness test. The right-hand variables in this equation are divided in three parts as shown in Eq. (9): (i) a set of variables always included in the regression; (ii) the variable of interest which will be tested; and (iii) a subset of variables chosen from the pool of exploratory variables described in the data section. Concerning part (i), the regional dummies, (log of) initial per capita income, and the spatial lags of initial per capita income and per capita income growth are included in all regressions. Thus, the EBA approach states that a coefficient (part ii) is called "robust" if it remains significant (at 5% level) and does not change its sign across a set of combinations of other variables (part iii). Otherwise, the variable is coined as "fragile". In Table 4, upper and lower bounds of each coefficient are shown.

$$g = \underbrace{D\beta_1 + Y_1\beta_1 + \phi W y_1 - \gamma W g}_{(i)} + \underbrace{\beta_2 z}_{(ii)} - \underbrace{\beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5}_{(iii)} + \varepsilon \qquad (9)$$

To avoid multicollinearity I restrict the EBA in two ways. First, part (iii) comprises a combination of only thee variables. Second, given the multicollinearity problem and the high correlation between variables (see Appendix I), for each variable test, I chose a set of four variables with the lowest correlation[43] to do the combinations. This rule ensures that none variable with correlation coefficient higher than 0.7 will be included on the same time in the regression. This methodology is applied for each spatial scale. Finally, it important to point out that "*finding a robust partial correlation certainly does not imply that the variable of interest causes growth. The crucial, though nettlesome, issue of empirically identifying causal channels has not been adequately addressed by the cross-country growth literature*"[44] (Levine & Renelt, 1992, p.944).

Table 4 shows the robustness test of each variable[45] at the five spatial scales. First, it is clear that conditional β-convergence cannot be denied for any spatial scale, since upper and lower coefficients are negative and significant in all specifications. However, the coefficients vary across different specifications and at different spatial scales. Another conclusion is that only at municipal level the theoretical model described in section 3.1 is valid, since both coefficients of spatial lags of income per capita growth and initial per capita income are all positive and statistically significant at 5% level. Robustness of spatially lagged dependent variable is verified at micro-regional level. For the other spatial scales the externalities effects are considered "fragile". This result suggests that spatial spillovers are operating within the functional regions: spatial clusters and urban agglomerations.

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[42] See Brock & Durlauf (2001), Temple (2000) and Brock et al. (2003) for further discussion about model uncertainty.

[43] It means that for each variable I ran four models, i.e., $C_3^4 = 4!/[(4-3)!3!] = 4$.

[44] See Brock & Durlauf (2001) for a discussion of causality vs. correlation in growth literature.

[45] I collected the coefficients of those variables that were kept fixed and I also reported their upper and lower coefficients.

Table 4 – Robustness checks

Dependent variable: income per capita growth between 1991 and 2000

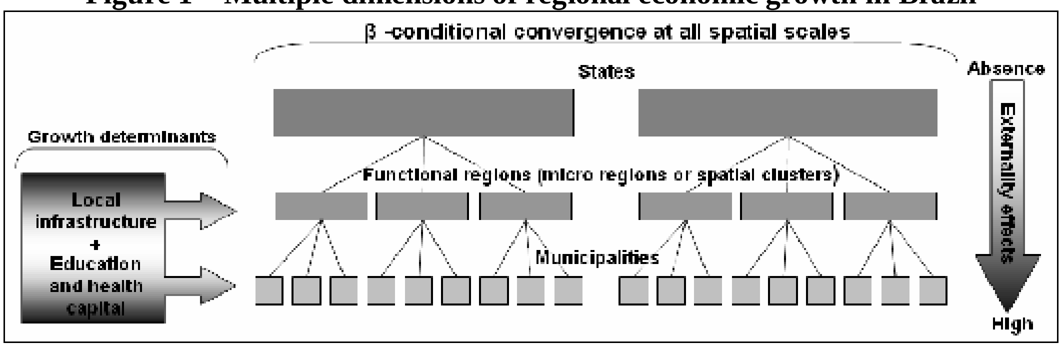
		political-administrative regions		functional regions		
		(5a)	(5b)	(5c)	(5d)	(5e)
		states	municipalities	micro regions	spatial clusters	urban agglomerations
Estimation method		OLS	ML	ML	ML	ML
Exploratory variables						
Spatial lag income per capita growth (g)	Lower Coef.	-	**0.2664***	**0.4177***	0.2883	0.2997***
	Std. Error	-	**(0.0188)**	**(0.0476)**	(0.1854)	(0.1535)
	Upper Coef.	-	**0.3205***	**0.5080***	0.4255*	0.3300**
	Std. Error	-	**(0.0189)**	**(0.0484)**	(0.1509)	(0.1495)
ln(income per capita in 1991)	Lower Coef.	**-0.0798***	**-0.0566***	**-0.0345***	**-0.0668***	**-0.0258***
	Std. Error	**(0.0204)**	**(0.0017)**	**(0.0030)**	**(0.0074)**	**(0.0056)**
	Upper Coef.	**-0.0444***	**-0.0362***	**-0.0088***	**-0.0162****	**-0.0189***
	Std. Error	**(0.0151)**	**(0.0016)**	**(0.0021)**	**(0.0071)**	**(0.0036)**
Spatial lag income per capita in 1991 (f)	Lower Coef.	-	**0.0088***	-0.0042	-0.0049	-0.0135
	Std. Error	-	**(0.0021)**	(0.0028)	(0.0080)	(0.0090)
	Upper Coef.	-	**0.0200***	0.0072**	0.0230*	0.0022
	Std. Error	-	**(0.0019)**	(0.0031)	(0.0075)	(0.0076)
ln(average years of schooling in 1991)	Lower Coef.	0.0090	**0.0329***	**0.0340***	**0.0716***	0.0110
	Std. Error	(0.0266)	**(0.0016)**	**(0.0034)**	**(0.0097)**	(0.0096)
	Upper Coef.	0.0601***	**0.0342***	**0.0348***	**0.0857***	0.0149
	Std. Error	(0.0330)	**(0.0016)**	**(0.0033)**	**(0.0098)**	(0.0094)
ln(Gini index in 1991)	Lower Coef.	0.0755	0.0049	0.0110	-0.0038	**-0.0326***
	Std. Error	(0.0678)	(0.0039)	(0.0080)	(0.0270)	**(0.0120)**
	Upper Coef.	0.1035	0.0086	0.0082	0.0301	**-0.0290****
	Std. Error	(0.0704)	(0.0039)	(0.0080)	(0.0276)	**(0.0123)**
ln(infant mortality rate in 1991)	Lower Coef.	-0.0246***	**-0.0148***	**-0.0152****	**-0.0262****	-0.0037
	Std. Error	(0.0119)	**(0.0014)**	**(0.0029)**	**(0.0109)**	(0.0035)
	Upper Coef.	-0.0196	**-0.0142***	**-0.0147****	**-0.0237****	-0.0013
	Std. Error	(0.0133)	**(0.0014)**	**(0.0029)**	**(0.0110)**	(0.0035)
ln(transport cost -TC- to SP in 1991)	Lower Coef.	-0.0158**	-0.0043*	-0.0004	-0.0026	-0.0019
	Std. Error	(0.0066)	(0.0010)	(0.0014)	(0.0033)	(0.0019)
	Upper Coef.	-0.0105	-0.0018***	0.0018	0.0054	-0.0009
	Std. Error	(0.0065)	(0.0010)	(0.0016)	(0.0044)	(0.0018)
ln(TC to the nearest capital in 1991)	Lower Coef.	-0.0020	-0.0024*	0.0002	0.0030	-0.0005
	Std. Error	(0.0041)	(0.0005)	(0.0007)	(0.0030)	(0.0010)
	Upper Coef.	0.0009	-0.0001	0.0020*	0.0099*	-0.0002
	Std. Error	(0.0044)	(0.0005)	(0.0007)	(0.0024)	(0.0010)
ln(population density in 1991)	Lower Coef.	**0.0069***	0.0004	-0.0005	0.0006	-0.0002
	Std. Error	**(0.0021)**	(0.0004)	(0.0005)	(0.0016)	(0.0008)
	Upper Coef.	**0.0073***	0.0027*	-0.0008	0.0080*	0.0008
	Std. Error	**(0.0018)**	(0.0004)	(0.0006)	(0.0019)	(0.0008)
Index of housing infra-structure in 1991	Lower Coef.	-0.0022	**0.0065***	**0.0033***	**0.0130***	0.0003
	Std. Error	(0.0062)	**(0.0005)**	**(0.0011)**	**(0.0033)**	(0.0019)
	Upper Coef.	0.0077	**0.0070***	**0.0041***	**0.0159***	0.0012
	Std. Error	(0.0078)	**(0.0005)**	**(0.0011)**	**(0.0032)**	(0.0019)
Regional dummies		yes	yes	yes	yes	yes
Observations		27	5,507	559	91	123

Obs: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%;. Dependent variable = (1/9)*ln[incomepercapita in 2000/incomepercapita in1991]. Inside bold box, variables that are coined as robust.

Contrarily to the previous results (Table 3) that show distinct results among spatial scales, I found consistent results when robustness tests are carried out (Table 4). Indeed, three factors suggested by the growth theory seem to affect economic growth at three spatial scales: municipalities, micro-regions and spatial clusters. The results show up that higher education and health capital and better local infra-structure are related to higher economic growth rates. Moreover, the results suggest that the marginal impact of each one of these variables is greater at the spatial cluster level. Since this spatial scale captures the economic sphere of influence of a group of municipalities, it might be true that the spillover effects are bounded within each cluster and could amplify the outcomes of those variables on economic growth rates. Approximately, the spatial cluster coefficients are two times high as compared with municipal and micro-regional scale levels.

Figure 1 summarizes how scales levels are connect and how exploratory variables could differently impact economic growth at different spatial scales. First, conditional β-convergence is operating at all spatial scales, albeit with different speed of convergence. Second, spatial spillovers occur as geographic areas get smaller. Third, local infrastructure, education and health capital are robust at three scale levels (municipalities, micro-regions and spatial clusters).

Figure 1 – Multiple dimensions of regional economic growth in Brazil



Own elaboration.

Urban agglomerations have a distinct behaviour. Besides the evidence of conditional convergence, it seems that only income inequality is correlated with economic growth at urban agglomeration level. The negative coefficient shows that lower income inequality is related to higher economic growth rates. In fact, high income inequality can be seen as proxy for social instability and this is one of the major problems of Brazilian urban centres and it has impinged on growth in some regions. Finally, state level results should be viewed with care regarding the small sample sizes with which the regression analysis was performed. At state level, higher population density is correlated with higher economic growth rates.

The transport cost (both to São Paulo and to the nearest capital) variable is coined as "fragile" at all spatial scales. This result seems to suggest that transport cost coefficient does not deliver a simple and unambiguous message about it impact on regional development. As pointed out by Lafourcade & Thisse (2008) spatial inequalities would first rise and then fall in the presence of falling transport costs. In fact, ambiguous results appear since some coefficients have opposite sings at different spatial scales. It is worth noting that if significance level rule is relaxed to 10%, transport costs variable (to São Paulo) becomes "robust" at municipal scale. Thus, reductions in transport costs have a positive impact on municipal growth. Additionally, at 10% level significance rule, the spatially lagged dependent variable becomes "robust" at urban agglomeration level. Although, EBA is a useful way of communicating any uncertainty surrounding parameter estimates, other kinds of model selection approaches and robustness tests should be carried out to study multiple dimensions of economic growth. Finally, a sensitive analysis of the results was carried out using k = 5 and 15-nearest neighbours spatial weight matrix and it has shown similar results of those discussed here.

7. Conclusions

The aim of this paper is to analyze Brazilian economic growth in multiple dimensions. This paper suggests a general framework that allows dealing simultaneously with “Modifiable Areal Unit Problem” (MAUP), spatial autocorrelation and model uncertainty. Indeed, the latter two issues have been treated in relative isolation, by focusing only on spatial autocorrelation (Magalhãe et al., 2000; Silvera Neto, 2001; Lall & Shalizi, 2003, Silveira Neto & Azzoni, 2006), or on model uncertainty (Levine & Renelt, 1992; Sala-i-Martin, 1997; Sala-i-Martin et al., 2004; and for the Brazilian case, Resende & Figueirêdo, 2005), while MAUP has been neglected by economic growth literature. With this framework, this paper seeks to understand how and why the determinants of economic growth may manifest themselves differently at different spatial scales. An application is provided using five spatial scales over the 1991–2000 period.

Four points are worth mentioning. First, the paper identified that MAUP jeopardizes Brazilian growth estimates. If single regression is estimated at the different scales levels, the results change as scale level changes. However, the robustness test was able to identify variables that are simultaneously significant at different spatial scales: higher education and health capital and better local infra-structure are related to higher economic growth rates.

Second, model specification matters as highlighted by Briant et al. (2007). The present investigation employed a variable uncertainty exercise to shed some light on this question. A deeper investigation of the coefficient robustness in the estimated growth regressions as proposed by Sala-i-Martin (1997) and Sala-i-Martin et. al (2004) is therefore needed, but this is beyond the scope of the present paper. Following this paper, future research could integrate other robustness tests both for variable inclusions and scale levels.

Third, spatial spillovers are operating especially at finer scales. The results show evidences that externalities are confined to functional regions. These results suggest that public policies should be implemented at these functional region levels (e.g. spatial clusters) since municipalities within a functional region share similar characteristics and the impact of a public policy may be amplified by the externality effects.

Fourth, the results for β-conditional convergence cannot be denied indicating that poor municipalities tend to catch up with richer ones over time[46] at the five spatial scales. In addition, at municipal level as found by De Vreyer & Spielvogel (2005) the average per capita income level of neighbours has a positive impact on growth. Keeping constant other factors, it means that a municipality located in a relatively poor neighbourhood will tend to have a lower income growth. Given the uneven distribution of per capita income across space in Brazil, this result suggests that some regions in Brazil are trapped in lower levels of income. Hence, public policies could focus on low income functional regions (e.g. spatial clusters) benefiting from the spatial spillovers within these regions. Furthermore, at municipal and micro-regional levels it was found that if a region is surrounded by dynamic regions with high growth rates, the higher will be its growth rate.

All these results are dependent on the period used in this study. They should be reassessed using a larger number of periods. Spatial heterogeneity should be assessed since parameters might not be stable over space. Also, it is possible to include other exploratory variables if data is available. Finally, a further investigation about the links between exploratory variables and spatial scales is needed. These issues are left for future research.

[46] At equilibrium, there is only convergence in growth rates so that conditional β-convergence is compatible with the persistence of large differences in levels of development between regions if their steady-state levels are very different (Islam, 2003).

References

ALESINA, A. & RODRIK, D. (1994) Distributive politics and economic growth. Quarterly Journal of Economics, v.109, n.2, p.465-490.

ALMEIDA JUNIOR, M.; RESENDE, G. M.; SILVA, A. M. (2007) Distribuição espacial dos fundos constitucionais de financiamento do Nordeste, Norte e Centro-Oeste. Revista de Economia, Editora UFPR, v. 33, n. 2, p. 115-137.

ANDRADE, E., LAURINI, M., MADALOZZO, R., PEREIRA, P.(2002). Testing Convergence Across Municipalities in Brazil Using Quantile Regression,Ibmec Workin Papers,n. 14.

ANSELIN, L. (1988) Spatial econometrics: methods and models. Dorddrecht: Kluwer.

AZZONI, C. R. (2001) Economic growth and regional income inequality in Brazil. The annals of Regional Science, v.35, p.133-152.

AZZONI, C. R.; MENEZES-FILHO, N.; MENEZES, T.; SILVEIRA-NETO, R. (2000) Geography and income convergence among Brazilian states. Research NetworkWorking Paper R-395, Inter-American Development Bank, Washington, DC.

BALDWIN, R. & FORSLID, R. (2000). The core-periphery model and endogenous growth: stabilizing and destabilizing integration. Economica, n. 67, p. 307-324.

BALDWIN, R.; FORSLID, R.; MARTIN, P.; OTTAVIANO, G.; ROBERT-NICOUD, F. (2003). Economic Geography and Public Policy. Princeton University Press.

BARRO, R. J. (1990) Government spending in a simple model of endogenous growth. Journal of Political Economy, v.98, n.8, p.103-125.

BARRO,R. & SALA-I MARTIN,X.(1992)Convergence.J. of Political Economy,100,223–51.

BARRO, R., & SALA-I MARTIN, X. (2003) Economic growth. Cambridge,Mass.:MIT, 2ed.

BEHRENS, K. & THISSE, J-F. (2007) Regional economics: A new economic geography perspective. Regional Science and Urban Economics, v. 37, p. 457–465.

BLOOM, D. E.; CANNING, D.; SEVILHA, J. (2001) The effect of health on economic growth: theory and evidence. Cambridge, Mass.: NBER, 26p. (Working Papers, n.8587)

BRIANT, A.; COMBES, P-P.; LAFOURCADE, M. (2007). Does the size and shape of geographical units jeopardize economic geography estimations? Processed, Paris Sciences Economiques.

BROCK, W. & DURLAUF, S. (2001) Growth empirics and reality. World Bank Economic Review, v. 15, p. 229–272.

BROCK, W.; DURLAUF, S.; WEST, K. (2003) Policy evaluation in uncertain economic environments. Brookings Papers of Economic Activity, p. 235–322.

CARVALHO, A. Y.; DA MATA, D.; RESENDE, G. M. (2007). Clusterização dos municípios brasileiros, in: Dinâmica dos Municípios, Brasília: IPEA.

COELHO, R. L. P. (2007) Dois Ensaios sobre a Desigualdade de Renda dos Municípios Brasileiros, dissertação de mestrado, CEDEPLAR/UFMG.

DA MATA D.; DEICHMANN U.; HENDERSON J.V.; LALL S.V.; WANG H.G. (2007a). Determinants of city growth in Brazil. Journal of Urban Economics, v.62, p. 252–272.

DA MATA, D.; PIN, C; RESENDE; G. M. (2007b) Composição e Consolidação da Infraestrutura Domiciliar nos Municípios Brasileiros,in: Dinâmica dos Municípios, Brasília: IPEA.

DE VREYER, P. & SPIELVOGEL, G. (2005). Spatial externalities between Brazilian municipios and their neighbours. Ibero America Institute for Econ. Research (IAI) Discussion Papers 123, Ibero-America Institute for Economic Research.

DURANTON, G. & OVERMAN, H.G. (2005). Testing for localisation using micro-geographic data. Review of Economic Studies, v. 72, p.1077–1106.

DURLAUF, S. N., JOHNSON, P. A. (1995). Multiple regimes in cross-country growth behavior. Journal of Applied Econometrics, v. 10, n. 4, p. 365-384.

ERTUR C. & KOCH, W. (2007). Growth, Technological interdependence and spatial externalities: theory and evidence. *Journal of Applied Econometrics*, 22: 1033–1062.

ERTUR C., LE GALLO J., BAUMONT C. (2006). The European Regional Convergence Process, 1980-1995: Do Spatial Regimes and Spatial Dependence Matter? International Regional Science Review, v. 29, p. 3-34.

FERNANDEZ, C.; LEY, E.; STEEL, M. F. (2001) Model uncertainty in cross-country growth regressions. Journal of Applied Econometrics, v. 16, p. 563–576.

FERREIRA, A. H. B. (1999) Concentração regional e dispersão das rendas per capita estaduais : um comentário. Estudos Econômicos, São Paulo: IPE, v. 29, n. 1, p. 47-63.

FERREIRA, A. H. B. & DINIZ, C. C. (1994) Convergência entre as rendas per capita estaduais no Brasil. Belo Horizonte: UFMG/CEDEPLAR, 27p. (Texto para Discussão, n.79).

FINGLETON, B. (1999). Estimates of time to economic convergence: an analysis of regions of the European Union. International Regional Science Review, v.22, n.1, p.3-34.

FLORAX, R. J.; FOLMER, H.; REY, R. J. (2003). Specification searches in spatial econometrics: the relevance of Hendry's methodology. Regional Science and Urban Economics, v.33, p.557-579.

FOTHERINGHAM, A.;BUNSDEN, C.; CHARLTON,M.(2000). *Quantitative Geography*.

FUJITA, M. & THISSE, J. F. (2002) Economics of agglomeration: cities, industrial location and regional growth. Cambridge, UK.: Cambridge University.

FUJITA, M., KRUGMAN, P., VENABLES, A. (1999). The spatial economy. Cambridge.

GALOR, O. 1996. Convergence? Inference from theoretical models. Economic Journal, v. 106, p. 1056-69.

GEHLKE,C. & BIEHL,K.(1934).Certain Effects of Grouping Upon the Size of the Correlation Coefficient in Census Tract Material. *J. of American Statistical Association*,29,169-170.

IPEA, IBGE, and UNICAMP (2002). Configuração atual e tendências da rede urbana. Serie Configuração Atual e Tendências da Rede Urbana. Brasília.

IPEA, PNUD, FJP. *Atlas do Desenvolvimento Humano no Brasil*. Brasília, 2003.

ISLAM, N. (2003). What have we learnt from the convergence debate? Journal of Economic Surveys, v.17, p.309–362.

JOHNSON, P. A. & TAKEYAMA, L. N. (2003). Convergence Among the U.S. States: Absolute, Conditional, or Club? <http://irving.vassar.edu/VCEWP/ VCEWP50.pdf>

KIRMAN, A. (1992). Whom and what does the representative individual represent? Journal of Economic Perspectives, v. 6, p.117–136.

KRUGMAN, P. (1991) Increasing returns and economic geography. Journal of Political Economy, v.99, n.3, p.483-499.

LAFOURCADE, M. & THISSE, J. (2008). New economic geography: A guide to transport analysis. PSE Working Papers 2008-02, PSE (Ecole normale supérieure).

LALL, S.V. & SHALIZI, Z. (2003). Location and growth in the Brazilian Northeast. Journal of Regional Science, 43, 4: 663-681.

LE GALLO, J.; ERTUR, C. (2003) Exploratory spatial data analysis of the distribution of regional per capita GDP in Europe, 1980–1995.Papers in Regional. Science, v.82, p.175–201.

LEAMER, E.E. (1983) Let's take the Con out of Econometrics. American Economic Review, v. 73, p. 31–43, 1983.

LEVINE, R. & RENELT, D. (1992). A sensitivity analysis of cross-country growth regressions. American Economic Review, v.82, n.4, p.942-963.

LÓPEZ-BAZO, E.; VAYÁ, E.; MORA, A.; SURINACH, J. (1999) Regional economic dynamics and convergence in the European union.Annals of Regional Science,v.33,p.343–70.

LÓPEZ-BAZO, E., ARTÍS, M., VAYÁ, E. (2004). Regional externalities and growth: evidence from European regions. Journal of Regional Science, v. 44, n. 1, p. 43–73.

LUCAS, R. (1988) On the mechanics of economic development. Journal of Monetary Economics, v.22, n.1, p.3-42.

MCDONALD, S. & ROBERTS, J. (2002). Growth and Multiple Forms of Human Captial in an Augmented Solow Model: a panel data investigation, Economics Letters, 74, p. 271-276.
MAGALHÃES, A.; HEWINGS, G.; AZZONI, C. (2000). Spatial dependence and regional convergence in Brazil. Chicago: University of Illinois, 2000. (Working Papers REAL).
MANKIW, N. G.; ROMER, D.; WEIL, D. N. (1992) A Contribution to the Empirics of Economic Growth, Quarterly Journal of Economics, 107, 407-37.
MANSKI, C. F. (1993). Identification of endogenous social effects: The reflection problem. Review of Economic Studies 60: 531-42.
OLIVEIRA, H. & DOMINGUES, E. P. (2005). Considerações sobre o impacto dos FNO e FCO na redução da desigualdade regional no Brasil.In: XXXIII Encontro Nacional de Econ.
OPENSHAW, S. (1984) Ecological fallacies and the analysis of areal census data. Environment and Planning A, v. 16, n.1, jan, p. 17-31.
OPENSHAW, S. & TAYLOR, P.J. (1979). A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In: N. Wrigley, ed. *Statistical Applications in the Spatial Sciences.* London: Pion, p.127-44.
OPENSHAW, S. & TAYLOR, P.J. (1981). The Modifiable Unit Problem. In: N. Wrigley and R. Bennett; Quantitative Geography, a British View. London: Routledge and Kegan, p.60-69.
OVERMAN, H. G. (2004). Can we learn anything from economic geography proper? Journal of Economic Geography, v.4, p. 501–506.
PESSÔA, S. (2001). Existe um Problema de Desigualdade Regional no Brasil? In: Anais do XXIX Encontro Nacional de Economia – ANPEC, 2001, Salvador/BA, Anais. Salvador.
RESENDE, G. M. & FIGUEIRÊDO, L. (2005) Testes de Robustez: uma aplicação para os determinantes das taxas de crescimento do produto interno bruto *per capita* dos estados brasileiros. Brasília: IPEA, 49p. (Texto para Discussão, n.1124).
REY, S. J. & JANIKAS, M. V. (2005). Regional convergence, inequality, and space. Jounal of Economic Geography, 5, p. 155-176.
REY, S. J. & MONTOURY, B. D.(1999) U.S. regional income convergence: a spatial econometric perspective. Regional Studies, v.33, n.2, p.143-156.
ROBINSON, W. S. (1950). Ecological correlations and the behaviour of individuals. American Sociological Review, v.15 p.351-357.
ROMER, P. (1986) Increasing returns and long-run growth. Journal of Political Economy, v.94, n.5, p.1002-1037.
ROMER, P. (1990). Endogenous technological change. J. of Pol. Econ., v.98, n.5, p.71-102.
SALA-I-MARTIN, X. (1997). I Just Ran Two Million Regressions. American Economic Review 87, p. 178–83.
SALA-I-MARTIN, X.; DOPPELHOFER, G.; MILLER, R. (2004) Determinants of long-term growth: a Bayesian averaging of classical estimates (BACE) approach. American Economic Review v. 94, p. 813–835.
SHEPPARD E. & MCMASTER R. B. (2004) (eds). Scale and Geographic Inquiry: Nature, Society, and Method. London Blackwell.
SILVA, A. M.; RESENDE, G. M.; SILVEIRA NETO, R. (2007). Eficácia do gasto público: uma avaliação do FNE, FNO e FCO. Brasilia: IPEA, (Texto para Discussão IPEA nº 1259).
SILVEIRA NETO, R. M. (2001) Crescimento e spillovers: a localização importa? Evidências para os estados brasileiros. Revista Econômica do Nordeste, Fortaleza, v.32, p.524-545.
SILVEIRA NETO, R. M. & AZZONI C. (2006) Location and regional income disparity dynamics: The Brazilian case. Papers in Regional Science, v. 85, n. 4, p.599-613.
SOLOW, R. M. (1956) A contribution to the theory of economic growth. Quarterly Journal of Economics, v.70, n.1, p.65-94.
SOUZA, C. C. A. (2007). A Nova Geografia Econômica: Três Ensaios para o Brasil. Tese de doutorado. CEDEPLAR/UFMG.

TRIFFIN, R. (1940). Monopolistic Competition and General Equilibrium Theory. Harvard University Press, Cambridge, MA.
VERGOLINO, J.; NETO, A. P.; BARROS, M. (2004). Crescimento econômico regional no Brasil: Educação como fator de convergência,1970/96.Economia,Curitiba,v.30,n.2, p.79-103.

APPENDIX I

Table A.1 – Correlation matrix of the exploratory variables (states)

	Exploratory variables	1	2	3	4	5	6	7	8
1	ln(housing infrastructure in 1991)	1	0.831	0.885	-0.138	-0.748	-0.783	-0.529	0.619
2	ln(income per capita in 1991)		1	0.965	0.217	-0.869	-0.589	-0.199	0.204
3	ln(average years of schooling in 1991)			1	0.160	-0.863	-0.591	-0.289	0.300
4	ln(Gini index in 1991)				1	0.010	0.380	0.157	-0.328
5	ln(infant mortality rate in 1991)					1	0.618	0.077	-0.115
6	ln(transport cost -TC- to SP in 1991)						1	0.309	-0.650
7	ln(TC to the nearest capital in 1991)							1	-0.641
8	ln(population density in 1991)								1

Own elaboration.

Table A.2 – Correlation matrix of the exploratory variables (municipalities)

	Exploratory variables	1	2	3	4	5	6	7	8
1	ln(housing infrastructure in 1991)	1	0.832	0.815	0.083	-0.690	-0.757	-0.379	0.482
2	ln(income per capita in 1991)		1	0.863	0.239	-0.784	-0.682	-0.219	0.229
3	ln(average years of schooling in 1991)			1	0.269	-0.752	-0.622	-0.268	0.307
4	ln(Gini index in 1991)				1	-0.077	-0.015	0.075	-0.120
5	ln(infant mortality rate in 1991)					1	0.635	0.100	-0.118
6	ln(transport cost -TC- to SP in 1991)						1	0.306	-0.372
7	ln(TC to the nearest capital in 1991)							1	-0.587
8	ln(population density in 1991)								1

Own elaboration.

Table A.3 – Correlation matrix of the exploratory variables (micro regions)

	Exploratory variables	1	2	3	4	5	6	7	8
1	ln(housing infrastructure in 1991)	1	0.861	0.868	-0.019	-0.767	-0.784	-0.433	0.552
2	ln(income per capita in 1991)		1	0.917	0.147	-0.856	-0.674	-0.226	0.260
3	ln(average years of schooling in 1991)			1	0.201	-0.816	-0.628	-0.300	0.350
4	ln(Gini index in 1991)				1	-0.081	0.105	0.154	-0.280
5	ln(infant mortality rate in 1991)					1	0.665	0.099	-0.152
6	ln(transport cost -TC- to SP in 1991)						1	0.313	-0.489
7	ln(TC to the nearest capital in 1991)							1	-0.689
8	ln(population density in 1991)								1

Own elaboration.

Table A.4 – Correlation matrix of the exploratory variables (spatial clusters)

	Exploratory variables	1	2	3	4	5	6	7	8
1	ln(housing infrastructure in 1991)	1	0.876	0.902	0.125	-0.745	-0.680	-0.682	0.733
2	ln(income per capita in 1991)		1	0.947	0.329	-0.798	-0.554	-0.541	0.541
3	ln(average years of schooling in 1991)			1	0.361	-0.769	-0.500	-0.597	0.607
4	ln(Gini index in 1991)				1	-0.096	0.239	-0.063	-0.096
5	ln(infant mortality rate in 1991)					1	0.617	0.308	-0.344
6	ln(transport cost -TC- to SP in 1991)						1	0.418	-0.575
7	ln(TC to the nearest capital in 1991)							1	-0.814
8	ln(population density in 1991)								1

Own elaboration.

Table A.5 – Correlation matrix of the exploratory variables (urban agglom.)

	Exploratory variables	1	2	3	4	5	6	7	8
1	ln(housing infrastructure in 1991)	1	0.791	0.735	-0.630	-0.723	-0.729	-0.140	0.475
2	ln(income per capita in 1991)		1	0.817	-0.566	-0.738	-0.673	-0.116	0.311
3	ln(average years of schooling in 1991)			1	-0.339	-0.606	-0.400	-0.318	0.385
4	ln(Gini index in 1991)				1	0.591	0.585	0.037	-0.260
5	ln(infant mortality rate in 1991)					1	0.652	-0.080	-0.073
6	ln(transport cost -TC- to SP in 1991)						1	0.014	-0.314
7	ln(TC to the nearest capital in 1991)							1	-0.551
8	ln(population density in 1991)								1

Own elaboration.