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Multiple dimensions of regional economic growth: The Brazilian case, 1991-2000[1]

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Abstract:

This paper seeks to understand how and why the determinants of economic growth (including spatial spillovers) in Brazil may manifest themselves differently at different spatial scales (municipalities, micro-regions, spatial clusters, and states) between 1991 and 2000. Analysing this issue it sheds light on the geography of the structural process underlying the economic growth at different scales. It means that the definition of each scale level could have a well-defined role in the economic growth process. A complementary approach is related to the Modifiable Areal Unit Problem (MAUP) and Ecological Fallacy Problem. These two measurement problems stem from the fact that there is an aggregation problem which might prevent us from identifying the actual scale at which processes operate. This paper suggests a general framework that allows dealing with multiple spatial scales, spatial autocorrelation and model uncertainty. The analysis reveals that if single regression is estimated at the different scale 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 identifies that spatial spillovers are operating especially at finer scales. At municipal level, several variables exhibit externality effects across space in Brazil, such as physical capital, education and health capital and local infrastructure. Finally, the study also concludes that Brazil is a country that regions (at all scale levels) converged too slowly over the nineties.

Keywords: Spatial scales; Economic growth; Convergence; Spatial externality; Brazil.

JEL Classification: C21, O54, R11

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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[3] 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 may not be true at another. Indeed, recent geographic studies show that economic processes are dependent of scales at which subjects are viewed and studied (Sheppard & McMaster, 2004). For understanding the multiple dimensions of economic growth in Brazil between 1991 and 2000, I have prepared datasets to examine the economic growth determinants and convergence process at four spatial scales (states, municipalities, micro-regions and spatial clusters). In addition, recent empirical studies [for example, Magalhães 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. 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 convergence hypotheses) 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? In other words, do the determinants of economic growth in Brazil vary with different levels of spatial aggregation of the observational units, as well as the intensity of spatial spillovers? This question seeks to understand the geography of the causal (structural) process underlying the economic growth at different scales. It means that the definition of each scale level could have a well-defined role in the economic growth process. A complementary approach is related to the measurement issue, since for some reason we wish to identify the best scale to work (for example, to delineate the appropriate target boundaries or to choose the best spatial scale to implement and evaluate the effectiveness of public policies). In this case, efforts to identify the best scale have been concentrated on obtaining functional regions which would be "geographically meaningful" capturing the economic sphere of influence of a group of smaller administrative units[4]. 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. The statistical literature proposes two views to analyze this question: "Modifiable Areal Unit Problem" (MAUP) and Ecological Regression Problem. MAUP is the variability in statistical results endemic to the selection of different area units (Openshaw & Taylor 1979, 1981). Another related problem discussed in the literature is the ecological fallacy. It appears when parameters estimated from macro-level data are used to make inferences about behavioural and socio-economic relations at a more disaggregate level (micro-level). Basically, these two concepts can be related to the measurement issue, since both indicate that there is a problem to identify the actual scale at which processes operate. 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

[3] In this article the term "scale" is defined as nested sets of spatial units of different spatial resolution (e.g., municipalities nested within functional regions, nested in turn within states).

[4] For instance, in the European Union context, several studies use the functional urban regions (FUR) that was proposed by Cheshire & Hay (1989). Cheshire and Magrini (2000) state that FUR are self contained and relatively independent local economic systems. Economic shocks are relatively contained within them and have homogeneous impact. Moreover, they have identifiable economic structures which are meaningful.

time period allows me to collect information of four spatial scales from the last two Brazilian Population Censuses (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 and municipalities. Section 3 examines the role of spatial scales in the economic growth process in Brazil, namely the structural issue. Section 4 discusses the measurement issue related to the Modifiable Areal Unit Problem (MAUP) and the Ecological Fallacy Problem. Section 5 discusses the empirical model, the dataset and the spatial weight matrix. In section 6, 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. Whereas at the municipal level the ratio between higher and lower income per capita was 33.6, in 2000[5]. 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[6] and the main regional policy has been performed by the Constitutional Funds (FNE, FCO and FNO)[7] since 1989. For example, in the period 2000-2006, the Constitutional Funds invested € 10 (R$ 28) billion in Brazilian lagging regions. This amount represented 1.2% of national GDP in 2006[8]. However, some studies, such as Silva et al. (2009) 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)[9]. 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's (1956) growth model. This model, also called exogenous growth model, has been augmented by the inclusion of education capital (Mankiw et al., 1992), health capital[10] (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[11] 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, which assumes that economies are structurally similar as well as the production function is the same). The similarity in both cases (absolute and conditional) is that, at equilibrium, there is convergence in growth rates. However, only conditional β-convergence is compatible with the persistence of large differences in levels of development between regions where their steady-state levels are very different (Islam, 2003). The β-convergence (absolute or conditional) prediction arises because the assumption about diminishing marginal

[5] In 1991, these ratios were 5.9 (state level) and 23.3 (municipal level).

[6] 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 Federal Constitution of 1988 (Brazil, 2008) was translated by the author].

[7] 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.

[8] 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.

[9] See Pessôa (2001) for the discussion of regional problem vs. social problem.

[10] 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).

[11] See Barro & Sala-i-Martin (2003), Chapter 1.

productivity of production factors. That is as the economy grows and the capital-labour ratio increases, the marginal productivity of capital declines and consequently saving and capital accumulation increase at decreasing rates (Galor, 1996)[12].

After the Solow model, an alternative set of growth theories were 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[13]. These models are based on the presence of constant or increasing returns to capital that breaks down the prediction of convergence of the neoclassical model, leading to the conclusion that economies could 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. 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. 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 and an increasing number of papers in recent years that employ municipal aggregation of data.

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. Similar results are found for the period 1948-1995 (Azzoni, 2001). 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. Using ten cohort means (for a given state in a given year), 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

[12] 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).

[13] Other examples of endogenous growth models 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.

educational levels and manufacturing shares of the states, spatial dependence disappears over the period 1985–2001. Finally, Resende & Figueirêdo (2005) run two robustness tests[14] using 25 variables suggested by the literature for Brazilian states between 1960 and 2000. The estimations of panel data models show 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, they do not reject 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/Southeast/Centre-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.

Recently, growth regressions have been used to discuss economic growth among the Brazilian municipalities. Andrade et al. (2002) find evidence in favour of absolute and conditional β-convergence, for the period 1970-1996, using both OLS and quantile regressions[15]. When regional dummies are added to the estimation, results from OLS and quantile regression are not statistically different. The exceptions to this rule are the North and Northeast regions 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 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[16] have a positive effect on municipal economic growth.

3. The Structural Issue: The Role of Spatial Scales in Brazil

When economic growth process is analysed in multiple scales it is possible to get a better understanding of the geography that shapes economic growth. But how are the spatial scales defined in Brazil? Brazil is roughly twice the size of European Union (27 countries) and is divided in 27 states[17] that are the main political-administrative division. 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 are available at municipal level and can be combined to form other spatial scales. Municipalities are territorial units for the production of regional statistics for Brazil whose definition might not always approximate the functional borders of the regional economy.

[14] The first approach is the Extreme Bounds Analysis (EBA) test proposed by Levine & Renelt (1992). An alternative approach was considered by Sala-i-Martin (1997) where he 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.

[15] Coelho & Figueiredo (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.

[16] All variables are measured in 1970.

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

An effort to deal with this problem is the definition of functional regions. An example of these functional regions is the micro-regions defined by IBGE in 1990 as being a group of contiguous municipalities in the same state. They were grouped according to natural and production characteristics. Another example is the spatial clusters proposed by Carvalho et al. (2007). 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[18]. Figure 1 shows the four spatial scales and some statistics concerning their sizes (in square kilometres).

Figure 1 – Multiple spatial scales (Brazil)

States	Micro-regions	Spatial Clusters	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 = 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 = 5,507 Area Mean = 1,549 Km^2 Area Min = 3 Km^2 Area Max = 161,446 Km^2 Area Standard Deviation = 5,738

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

In section 2, I show that the processes of di/convergence and the determinants of the economic growth may vary with these different levels of spatial aggregation of the observational units. However, it is important to distinguish two different (although related) aspects of the study of economic growth at different scale levels. The first aspect is related to the measurement problems (MAUP and ecological fallacy that are discussed in section 4) since it may be difficult to properly observe the actual scale at which processes operate. For example, state level reflects the main political-administrative division in Brazil and it could not be fine enough to satisfactorily capture unobserved heterogeneity and may mask meaningful geographic variation evident with smaller units. On the other hand, the use of municipalities has a tendency to provide spatial autocorrelation that could arise as an artifact of slicing homogenous regions. An approach to overcome these two problems is to use of functional regions so as to capture the economic sphere of influence of a group of municipalities. In the case of this paper two kinds of functional regions are employed: micro-regions and spatial clusters.

The second aspect is related to a structural issue since 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 empirical model and respective exploratory variables discussed in section 5 show 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. Despite I do not have a theoretical reason (or growth model) to conclude that results should change at different scale levels; it is worth noting that each spatial scale can have a role[19], in terms of, for instance,

[18] 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.

[19] Oates (1999, p. 1131) points out that a rational set of levels of government and borders for the jurisdictions at each level of government would probably entail: "*(1) some fairly sizeable regional governments that extend over watersheds, air sheds, and other environmental resources; (2) metropolitan governments that encompass center cities and the suburbs that house many city workers; and (3) smaller local governments that allow groups of residents to determine services of relevance mainly to themselves*".

assignment of functions to levels of government that can differently influence economic growth at the four spatial scales discussed here.

Concerning the exploratory variables under study, the responsibility of each level of government (federal, state and municipal) is as follow. Education in Brazil is financed and provided by the three levels of government as well as by the private sector. The latter charges tuition fees and is free to be involved at all educational levels. Basically, the responsibility for public education is divided into (i) elementary education (states and municipalities), (ii) secondary education (states), and (iii) technical, technological and higher education (federal and states)[20]. According to the Constitution of 1988, the unified health system (Sistema Único de Saúde - SUS) was created in order to decentralise the provision of health services, increasing the autonomy of states and municipalities. In addition, there is a supplementary medical system, which includes the private plans and insurance companies[21]. Local infrastructure (housing infrastructure)[22] such as sewage, piped water and electricity provision is a joint responsibility of the three levels of government. Investments in transport infrastructure in order to reduce the transportation costs between municipalities in Brazil are carried out by federal and state governments. The impact of transport infrastructure on economic growth may vary as scale level changes, since if we analyze it at the functional region or state level the focus will be on the connectivity between these aggregate regions. On the other hand, at municipal level, the analysis allows an investigation of the impact of transportation costs reductions within the borders of the functional regions or states. Moreover, the last two variables examined in this paper – population density and personal income inequality – might present different results at the spatial scales under analysis since the strength of agglomeration and social tensions vary with the extent of the spatial units.

Finally, Oates (1999, p.1130) highlights that "*the existence and magnitude of spillover effects from localized public policies clearly depend on the geographical extent of the relevant jurisdiction*". For this reason, spatial spillovers of the exploratory variables are expected to be more evident at municipal level rather than at micro-regional, spatial cluster or state levels. As suggested by Oates (1999) it is possible to increase the size of the jurisdiction (municipalities, in the Brazilian case) in order to deal with such spillovers, thereby internalizing all the benefits and costs. In Brazil, since 2005 there has been some flexibility in terms of creating useful consortia[23] of municipalities to deal with particular issues (via inter-municipal coordinated decision-making), such as public utility service of water supply, sanitation, and health services. This paper employ two spatial scales, the so-called functional regions (micro-regions and spatial clusters), that seek to keep such externalities within their boundaries.

Given the discussion above, I would expect that the influence of all exploratory variables (including externalities effects) on economic growth can be better captured at the municipal level. However, an aggregated influence of education, health and local infrastructure on economic growth is expected to be observed at all spatial scales, since these factors are operating via public policies across all scales. Furthermore, the analysis of the influence of reductions in transportation costs on economic growth at multiple scale levels allows us to distinguish this influence within the borders of a functional region (or state) from that occurred between functional regions (or states). A good way to investigate 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[24]. This empirical exercise is carried out in section 6.

[20] For details, see Law Nº 9.394/1996 and Brazilian Federal Constitution of 1988 (Brazil, 2008) Art. 23, V. Art. 24, IX. Art. 30, VI. Art. 206, 208, 211, 212.

[21] For details, see Brazilian Federal Constitution of 1988 (Brazil, 2008) Art. 23, II. Art. 24, XII. Art. 30, VII. Art. 195 parágrafo 10. Art.196, 197, 198.

[22] See Brazilian Federal Constitution of 1988 (Brazil, 2008) Art. 23, IX.

[23] For details, see Law 11107/2005.

[24] Yamamoto (2008) applied this approach to examine regional per capita income disparities in the USA at multiple spatial scales between 1955 and 2003. The focus is on methods such as inequality indices, kernel density estimation and spatial autocorrelation statistics.

4. The Measurement Issue: Modifiable Areal Unit Problem (MAUP) and Ecological Fallacy

The previous section focused on the discussion of the structural issue underlying the economic growth at different scales. This section analyses the measurement issue that can cause variability in economic growth estimates due to the use of different levels of spatial aggregation of the observational units. This could occur because the existence of the Modifiable Areal Unit Problem (MAUP) and the ecological fallacy problem. These two problems stem from the fact that there is an aggregation problem which might prevent us from identifying the real scale at which processes operate. For instance, a cautious analysis of economic growth at different spatial scales may identify the best spatial scale to implement (or to evaluate the effectiveness of) public policies.

Section 2 showed that the studies do not employ a rigorous analysis of spatial scale choice and 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.

Recently, 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/scale) is prejudicial to economic geography estimations, whereas the second source (shape/zoning) 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[25]. 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 suggested by Duraton & Overman (2005)[26].

[25] 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, 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).

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

However, most of the empirical studies of economic growth performance has been an aggregated study, since the common way to calculate income growth between two or more periods is using aggregate data (countries, regional, counties, etc.), apart form the obvious macroeconomic variables (inflation, investment, roads, amenities, etc) which are by definition aggregate variables. Furthermore, as highlighted by Briant et al. (2007, p.1) "*authors do not work with the same economic specifications to evaluate one particular phenomenon, which is a further source of discrepancy between studies*". For this reason, the same econometric specifications are employed at all spatial scales in this paper.

There is another issue that is closely related to the aggregation problem. It is referred to as ecological regression, and often criticized as yielding invalid inference, the so-called ecological fallacy problem (Anselin, 2002). The ecological fallacy[27] happens when behavioural and socio-economic relations are inferred for a disaggregate level (micro-level) using parameters which are estimated at an aggregate level (macro-level). Anselin (2002) observes that even in very simple situations the ecological approach creates problems of interpretation[28].

Anselin (2002, p.21) provides a simple example, in which a regression model is specified at the individual level, where both individual-level variables [x_{ik} is a characteristic of individual *i* in group *k* (e.g., income for household *i* in municipality k)] and group-wise aggregates [$\overline{x_k}$ is the group average for that characteristic[29] (e.g., municipal average income)] are included:

$$y_{ik} = \alpha + x_{ik}\beta + \overline{x_k}\gamma + \varepsilon_{ik} \qquad (4.1)$$

In the literature, β corresponds to the *individual* effect and γ the *contextual* effect[30]. The macro regression that relates the group averages to each other (where, $\overline{y_k} = \sum_i y_{ik} / n_k$) is specified in the Eq. (4.2).

$$\overline{y}_k = \alpha + \overline{x_k}(\beta + \gamma) + \overline{\varepsilon}_{ik} \qquad (4.2)$$

The implications of this aggregated model are twofold. First, at this aggregate level, error term will become heteroskedastic since the groups do not have the same number of members. Second, separate identification of the individual and contextual effects are no longer possible since the coefficient of the average $(\beta + \gamma)$ in the aggregate model represents a blend of individual and contextual effects[31]. Here, it is worth noting that even if we assume that the municipal (or county) level is the micro-level of analysis (instead of the household), the problem appears again when the study is carried out using another aggregate level.

[27] "Perhaps more accurately termed cross-level bias in estimating individual effects from ecologic data" (Greenland, 2002, p.392).

[28] See Stoker (1993) for a discussion of relevant issues.

[29] Where, $\overline{x_k} = \sum_i x_{ik} / n_k$ (n_k is the group size).

[30] Manski (1993, p.532) provides a formal expression that contains three effects to explain the common observation that individuals belonging to the same group tend to behave similarly: $y_{ik} = \rho\overline{y_k} + x_{ik}\beta + \overline{x_k}\gamma + \mu_k + \varepsilon_{ik}$. These effects are: (i) *endogenous* effects, wherein the propensity of an individual to behave in some way varies with the behavior of the group (this effect is captured by the ρ); (ii) *contextual (exogenous)* effects, wherein the propensity of an individual to behave in some way varies with the exogenous characteristics of the group (captured by the γ), and; (iii) correlated effects, wherein individuals in the same group tend to behave similarly because they have similar individual characteristics or face similar institutional environment (captured by the μ_k , which is the unobserved common factors affecting the group k). In general, it is not possible to estimate all these parameters without excluding one type of effect.

[31] Anselin (2002, p. 22) points out that "*even when there is no within-group heterogeneity (all the groups have the same β and γ coefficients), the estimate from the aggregate model only corresponds with an individual-level coefficient when there is no contextual effect (γ = 0). Similarly, it only corresponds to a "pure" contextual effect when there is no individual effect (β = 0)*". See Greenland (2002) for more explanations.

Finally, as demonstrated by (Anselin, 2002) if the spatial dimension is added on the former example, some other complexities become evident. For example, it is common in spatial analysis, models with a spatially lagged dependent variable ($\rho\sum_{j=1}^{n} w_{ij} y_{jh}$) on the right-hand side of the Eq. (4.1). This specification is usually implemented to model a spatial reaction function for economic agents *i*. Formally, the neighbourhood rule is defined by the specification of the spatial weights matrix which is a $n \times n$ positive matrix (W). In each row *i*, a non-zero element w_{ij} defines *j* as being a neighbour of *i*. The diagonal elements are zero $(w_{ii} = 0)$ since an observation cannot be a neighbour of itself. At the aggregate level, the spatial lag dependent variable, for the groups g (g=1,…,G) would be: $\lambda\sum_{g=1}^{G} w_{kg} \overline{y}_g$. However, Anselin (2002) shows that the aggregate over groups of the individual-level spatial lag terms is not equal to the spatial lag of the aggregate values. Basically, if the individual spatial weights (W) included non-zero elements for individuals in the same group, then the aggregate weights should show non-zero diagonal elements, $w_{kk} \neq 0$, which is usually ruled out.

Having knowledge of theses issues, the present work aims at examining and understanding the variability of the coefficients of economic growth determinants and respective spillovers across different spatial nomenclatures. At present, these are worrying problems for the empirical economic growth literature, which has seen, in last years, an increasing diversity of spatial scales of analysis and a growing interest on spatial models. On the contrary of lay aside this empirical economic growth literature, I believe that further efforts need to be done in understanding the economic growth performance at different scale levels.

5. Model, Data and Spatial Weight Matrix

This section has a twofold purpose. First, it develops econometric specifications based on the spatially augmented Solow model formalized by López-Bazo et al. (2004) and Ertur & Koch (2007). Second, it discusses the dataset and the spatial weight matrix employed in the empirical strategy.

5.1. The Model

The theoretical framework underlying the empirical analysis in this paper is a neoclassical growth model with externalities in the production function as suggested by López-Bazo et al. (2004)[32]. The empirical model developed here does not make any distinction between the spatial scale choice, i.e., region in this model could be any spatial aggregation. Nonetheless, the model is important to show how economic growth spillovers work and how other exploratory variables impact economic growth. In addition, the following econometric specifications benefited from Manski's (1993) paper about neighbourhood effects.

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.

Traditionally, in empirical studies, the β-convergence hypothesis is tested by a simple linear regression model (for example, Barro & Sala-i-Martin, 1991, 1992) where the per capita income growth rate is estimated compared to the initial per capita income of the region, by means the Ordinary Least Squares (OLS) method. Eq. (5.1) is the basic equation of this test.

$$g = Y_0\beta_1 + \varepsilon \qquad (5.1)$$

[32] This spatially augmented Solow model takes into account technological interdependence among economies.

where g is $N \times 1$ column vector with observations for per capita income growth for each region[33], Y_0 is $N \times 2$ matrix including the constant term and the initial per capita income, ε is the $N \times 1$ vector of errors. A negative correlation between the growth rate and the initial per capita income (β_1<0) indicates that there is absolute β-convergence.

It is possible to modify Eq. (5.1) to include other regional characteristics (X matrix) important in the economic growth dynamics and avoiding the omission of relevant variables. Thus, the absolute β-convergence gives way to the conditional β-convergence which can be expressed by Eq. (5.2), the so-called Barro-regression.

$$g = Y_0\beta_1 + X\beta_2 + \varepsilon \qquad (5.2)$$

In section 6, the first step is to run Eq. (5.1) and (5.2) using OLS method to test for the existence of spatially auto-correlated errors at all scale levels. The next step is run Eq. (5.4) and (5.5) to deal with the problem of spatial autocorrelation in the growth regressions, when necessary. As proposed by López-Bazo et al. (2004), these spatially auto-correlated errors can be eliminated by the inclusion of two terms in the growth regressions: i) spatially lagged dependent variable (Wg), and ii) spatially lagged initial per capita income variable ($\mathrm{W}\,\mathrm{y}_0$). Eq. (5.3) is the basic econometric specification that deals with spatial dependence. Thus, it is possible to obtain an estimate for the measure of externalities (γ, ϕ) and for the rate of convergence (β) in Eq. (5.3)[34].

$$g = Y_0\beta_1 + \phi W y_0 + \gamma \mathrm{Wg} + \varepsilon \qquad (5.3)$$

where W is the row standardized $N \times N$ spatial weight matrix. 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)[35]. However, as Manski (1993) pointed out in his paper, Eq. (5.3) cannot be estimated consistently unless some restrictions are imposed. One option is to exclude the endogenous effect, γ, as shown in Eq. (5.4).

$$g = Y_0\beta_1 + \phi W y_0 + \varepsilon \qquad (5.4)$$

In Eq. (5.5) a set, X ($N \times K$ matrix), of exploratory variables that could cause differences in the rate of technological progress and the steady state across regions are added to the right hand side. Similarly to Eq. (5.2), to minimize the problem of endogeneity, these variables are included in its value at the start of the sampling period. For sake of simplicity, the X vector includes the initial per capita income and the constant vector (Y_0), as well as WX comprises the spatially lagged initial per capita income variable ($\mathrm{W}\,\mathrm{y}_0$) besides the other spatially lagged exploratory variables.

$$g = \mathrm{X}\beta_2 + \mathrm{WX}\beta_3 + \varepsilon \qquad (5.5)$$

Here again, the endogenous effect, γ, which capture the influence of Wg on g, is excluded. It is possible to demonstrate that the spatially lagged dependent variable (Wg) can be decomposed into

[33] $g = (1/T)*ln(y_{T,i}/y_{0,i})$, where $y_{T,i}$ and $y_{0,i}$, are, respectively, the final period and the initial period of per capita income and T is the time period in years,

[34] The estimation of Eq. (5.3) is done by López-Bazo et al. (2004) using European Union regions (NUTS2).

[35] It is important to note that if γ and ϕ are significantly different from zero, their omissions in a growth regression give us inconsistent parameters of β_1 and β_2. The omissions in Eq. (5.2) will cause the residuals to be spatially correlated. On the other hand, 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). Maximumlikelihood (ML)-based estimators provide consistent estimates of the parameters in Eq. (5.3). However, this approach has some drawbacks, such as: ML is only identified using parametric assumptions (such as normality, functional form), and; while ML is concerned with obtaining consistent estimates of the spatially lagged endogenous variable, it does not deal with the fundamental problem of unobserved similarity between neighbours.

two parts: (i) the spatially lagged exploratory variables, and (ii) the spatially auto-correlated errors, as follow:

$$Wg = WX\beta + \rho W^2 X\beta + \rho^2 W^3 X\beta + ... + W\varepsilon + \rho W^2 \varepsilon + \rho^2 W^3 \varepsilon + ... \quad (5.6)$$

If we assume that spatial autocorrelation in the error term is eliminated from the model by the inclusion of the spatially lagged exploratory variables[36] (WX), it is possible to say that this type of specification (Eq. 5.5) is a good option because it presents few estimation problems. None of the assumptions for OLS estimation of the linear model are violated. Furthermore, many studies of "neighbourhood effects" on individual outcomes use this type of model (Case, 1992). In Eq. (5.5), the coefficients β_2 represent effects from *individual* characteristics whilst β_3 represents *contextual (exogenous)* effects as discussed by Manski (1993)[37].

Also, it is important to note that the X vector can encompass several explanatory variables, proposed by many growth models, such as educational 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. 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 subsection 5.1.1 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 6, 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. Next subsection discusses the exploratory variables[38] that I employ to run the growth regressions using the four spatial scales. All models that I discuss 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.

5.1.1. Exploratory Variables

Here I discuss some forces that could be driving the regional performance of Brazil from 1991 to 2000. As highlighted by Ottaviano & Pinelli (2006) the economic growth literature (see, e.g., Temple, 1999) explains differences in economic performance across regions in terms of two main groups of variables: proximate sources of growth and wider influences. The first set of variables is production factors that have a direct influence on regional economic growth such as physical and human capital. The latter group comprises all other variables that have an indirect effect on growth by improving knowledge/technology transfer or efficiency of input allocation via infrastructure, population density, income inequality and their respective externalities, for example.

Proximate sources of growth:

- Physical capital. The initial level of income per capita is the proxy for decreasing returns to capital accumulation. A usual interpretation of this coefficient suggests that if the coefficient on

[36] In any case, the spatial autocorrelation in the error term is not important for consistency, as long as the errors are uncorrelated with the regressors.
[37] See section 4, (especially footnote 30) for details about Manski's paper.
[38] The construction of the dataset is discussed in section 5.2.

initial per capita income is inversely related to the per capita income growth, β-convergence prediction of Solow's (1956) model cannot be rejected. However, some authors such as Friedman (1992) and Quad (1993) highlight that a negative coefficient on initial per capita income can just be an example of the more general phenomenon of mean reversion[39], and, by reading convergence in it, growth researchers are falling into Galton's fallacy[40] (Islam, 2003). For this reason, instead of testing indirectly and perhaps erroneously convergence phenomenon, an alternative approach to test directly the convergence of per capita income is to evaluate the dynamics of dispersion of this variable. Given the importance of this approach, in the results section I verify if the dispersion of per capita income between regions falls over time, that is, if the so-called σ-convergence occurs. Islam (2003, p. 314) points out that despite the limitations of β-convergence results, researchers have continued to be interested in this concept, in part because the "*methodologies associated with investigation of β-convergence also provide information regarding structural parameters of growth models, while research along the distribution approach (σ-convergence) usually do not provide such information*".

- Human capital. Since human capital is a complex input that consists of more than educational capital (McDonald and Roberts, 2002), I decompose the stock of human capital in two parts: educational and health capital:
    - Educational capital. Theoretical and empirical papers have shown that increases in educational capital have positive impact on the growth rate of per capita income (Mankiw et al., 1992). I measure the stock of education capital by the average years of schooling which may raise productivity and ultimately fosters economic growth[41].
    - Health capital. The central reason to include health capital on growth equations is its importance in the human capital composition and ultimately its influence on economic growth[42]. As highlighted by Bloom et al. (2001) healthier workers have important characteristics: they are physically and mentally more energetic and robust; more productive and earn higher wages; less likely to be absent from work because of illness (or illness in their family). I use infant mortality rate as a proxy for health capital[43] to test whether there is an aggregated influence of population health on economic growth.

Wider influences on growth:

- Local infrastructure. The availability of local infrastructures is captured by an index that takes into account several dimensions of housing public services and utilities such as electricity, sewage, water provision and garbage collection[44]. Theoretical and empirical evidences (Aschauer, 1989; Barro, 1990; Easterly & Rebelo, 1993) have shown that infrastructure spending is likely to raise economic growth rates by improving the productivity of the private sector.

- Population density. New economic geography models (Baldwin & Forslid, 2000) shed light on the positive impact of agglomeration externalities on economic growth rates. Population density within regions is the proxy for the agglomeration externalities. Local density tries to capture the agglomeration effects within a region.

[39] It means that there is a tendency for a stochastic process to remain close, or tend to return over time to a long-run average value.
[40] Some authors (Bliss, 1999) criticise the terminology 'Galton's Fallacy'.
[41] There is a huge and controversial discussion in the literature about the influence of schooling on economic growth. See, for example, Pritchett (1996) and Temple (1999).
[42] For theoretical growth models that include health capital, see Bloom et al. (2001) and McDonald & Roberts (2002).
[43] Another proxy for health capital could be life expectancy. However, there is a high correlation between infant mortality rate and life expectancy. For instance, at municipal level in 1991, the correlation coefficient is -0.96. For this reason the results are very similar using infant mortality rate or life expectancy. Given this high correlation, I chose to discuss in the regression results section only the infant mortality variable.
[44] See Da Mata et al. (2007b) for further details of how this index was constructed.

- Income inequality. The theoretical literature says that high inequality is harmful for growth using the political economy argument. Basically, the argument is that if inequality on income and wealth is high, then the median voter will choose a higher level of taxation which lowers economic growth (see, Alesina & Rodrik, 1994). Temple (1999, p.146) points out that the literature seems to be moving away from the political economy line, towards an examination of the effects of inequality on fertility rates, investment in education, and political stability. In this paper, the measure of income inequality is the Gini index.

- Transportation costs. Theoretical models (Ottaviano & Puga, 1998; Lafourcade & Thisse, 2008) have shown that with decreasing transport costs regional inequalities will increase and then fall, in other words, total per capita income will first agglomerate in few regions and then spread across regions. However, when we look to the growth rate of per capita income the findings are not clear. Some empirical studies (Da Mata et al., 2007a) have found a negative correlation between transportation costs and economic growth rates.

- Spatial externalities of exploratory variables. The aim of this set of variables is to capture the influence of the neighbour's characteristics on regional economic growth. As discussed below, theoretical models assume a positive impact of the spatial externality variables on economic growth. The empirical model discussed earlier [see Eq. (5.5), section 5.1] tries to capture the externality effects (spillovers) of the explanatory variables by multiplying the spatial weight matrix[45] (W) by the corresponding variable[46]:
    - Spatial externalities of physical capital. The spatially augmented Solow model proposed by López-Bazo et al. (2004) assumes that technology in region *i* is dependent on the technological level of the neighbouring regions, which is in turn related to their stocks of both types of capital (physical and human). Given this assumption, López-Bazo et al. (2004) point out that economic growth will be higher in regions surrounded by other regions with high stocks of these factors. The spatially lagged initial per capita income variable is the proxy for the spatial externalities of physical capital variable. In addition, it is worth noting that some empirical studies use this variable as being a proxy for the so-called "nominal market potential" (Head & Mayer, 2004). In a new economic geography (NEG) framework, higher market potential, that is, better access to customers (demand or backward linkages) and suppliers (cost or forward linkages) is associated with higher regional economic growth[47] (Ottaviano & Pinelli, 2006).
    - Spatial externalities of education and health capital. As explained, human capital was decomposed into education and health capital. In the same way, spatial externalities of human capital are split into spatial externalities of education and health capital. Following López-Bazo et al. (2004) model, economic growth will be higher in regions surrounded by other regions with high stocks of education capital (and health capital).
    - Spatial externality of local infrastructure. Although the influence of infrastructure on economic growth is widely examined by the theoretical and empirical literature, the impact of its spatial externality on regional growth needs investigation. If regional performance is positively influenced by neighbourhood local infrastructure, then it is possible to argue that local infrastructure has positive spatial externalities by improving the productivity of the private sector in surrounding regions. However, it is possible to offer an opposite explanation for this relationship. If higher local

[45] See section 5.2 for details.

[46] I excluded the spatial externality of transportation cost because its correlation with transportation cost is very close to one at all scale levels (see Appendix A).

[47] It is interesting to note that, in different works the same variable (spatially lagged initial per capita income) is used to proxy for technological externalities and pecuniary externalities as well. In fact, López-Bazo et al. (2004) model focus on technological externalities, while pecuniary externalities is the focus of NGE models.

infrastructure in one region is likely to attract capital and labour from the neighbouring regions, then a negative effect on growth in these regions will occur.

- Spatial externality of population density. Population density could be a restrictive measure of agglomeration externalities since influences of neighbouring regions are not accounted for. The spatially lagged population density variable aims to capture the influence of surrounding density on economic growth.
- Spatial externality of income inequality. This spatially lagged variable tries to verify any impact of neighbourhood income inequality on economic growth rates.

5.2. 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. Thus, four spatial scales are used which include 27 states, 559 micro-regions, 5,507 municipalities and 91 spatial clusters. The data set is available at municipal level and it is combined to form other spatial scales. The zoning effect (shape) is not tackled in this work, first, because the Brazilian dataset does not allow for re-zoning. Secondly, because Briant et al. (2007) conclude that shape is of third-order concern only. Specification and scale (size) are the first and second-order issues.

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 boundaries of the 5,507 municipalities in 2000, instead of the existing 4,491 municipalities in 1991[48]. Thus, it is possible to calculate per capita income[49] growth between 1991 and 2000 at all scale levels. Indeed, the use of municipal data with constant borders limits the analysis to the 1991-2000 period. All exploratory variables are in levels of 1991. The (log of) transportation cost between all Brazilian municipalities and São Paulo are from IPEADATA[50]. The transportation cost data are for the years 1980 and 1995. I estimated this variable to 1991 via interpolation. Transportation cost to São Paulo is a result of a linear program procedure to calculate the minimum cost between the municipalities majors headquarter to São Paulo[51]. The local 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 provision and garbage collection and it is supposed to capture the quantity of housing infrastructure in Brazilian municipalities[52]. Finally, the econometric models include regional dummies for the Brazilian macro-regions: Northeast, Southeast, South and Centre-West[53].

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

[49] 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).

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

[51] 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. This procedure calculates the transportation cost variable, given road and vehicles conditions.

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

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

The use of spatial weight matrix is to model the spatial interdependence between regions. I consider pure geographical neighbouring, which is exogenous[54] so as to avoid 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. Two important reasons are because they connect the islands of Ilhabela and Fernando de Noronha to continental Brazil and force each unit to have the same number of neighbours thus avoiding rows and columns in W with only zero values[55]. 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.

6. Results

Firstly, results of the baseline specification and diagnostics for spatial dependence are discussed at four spatial scales. Next, spatial econometric specifications are employed to correct for potential errors in the empirical strategy. Finally, a variable uncertainty exercise is carried out to investigate robustness of the results.

6.1. Baseline Specification

The first step is to estimate the baseline specification [Eq. (5.1) and Eq. (5.2)] via OLS for the four spatial scales. In addition, checks for spatial dependence applying the (robust) Lagrange Multiplier (LM) tests in the error terms are carried out. Table 1 shows two set of results: first, absolute β-convergence equations are estimated [Eq. (5.1)] for the four spatial scales; second, in the last four 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). This means that states are not converging to the same steady-state level of per capita income. For the other scale levels (column 1b-1d), the absolute β-convergence hypothesis cannot be rejected, albeit with a low speed of convergence and an implied long half-life[56]. Despite this traditional interpretation of convergence, there is a vast literature that interprets this result as being reversion to the mean[57]. A more informative result of convergence is to verify if the cross-sectional dispersion of per capita income diminishes over time and this is the next step (see Table 2).

[54] It is worth noting that the regional definitions have not been randomly created since they depend on history, population, etc. However, this spatial weight matrix presents fewer endogeneity problems than those ones that use population or commerce flows as a measure of spatial dependence.

[55] 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.

[56] 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. 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 $-\ln(2)/\beta = HL(years)$, 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 the dependent variable is already calculated annually), and β is the speed of convergence. For instance, the half-life for municipalities and micro-regions are approximately 82 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.

[57] See Friedman (1992), Quad (1993), Lichtenberg (1994), and Bliss (1999).

Table 1 – OLS Baseline 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	(2a) states	(2b) municipalities	(2c) micro regions	(2d) spatial clusters
ln(income per capita in 1991)	-0.0085	-0.0085*	-0.0029**	-0.0058***	-0.0706*	-0.0608*	-0.0416*	-0.0677*
	(0.0061)	(0.0005)	(0.0012)	(0.0032)	(0.0209)	(0.0012)	(0.0035)	(0.0098)
ln(average years of schooling in 1991)					0.0112	0.0317*	0.0381*	0.0638*
					(0.0346)	(0.0013)	(0.0038)	(0.0153)
ln(Gini index in 1991)					0.1332**	-0.0070*	0.0076	-0.0343
					(0.0616)	(0.0027)	(0.0086)	(0.0341)
ln(infant mortality rate in 1991)					-0.0237***	-0.0127*	-0.0127*	-0.0113
					(0.0127)	(0.0010)	(0.0029)	(0.0110)
ln(transportation cost to SP in 1991)					-0.0065	-0.0055*	-0.0018	-0.0033
					(0.0066)	(0.0007)	(0.0014)	(0.0039)
ln(population density in 1991)					0.0059**	-0.0002	-0.0003	0.000004
					(0.0024)	(0.0003)	(0.0006)	(0.0017)
local infra-structure in 1991					0.0015	0.0039*	-0.0006	0.0025
					(0.0068)	(0.0004)	(0.0011)	(0.0038)
Constant	0.0733**	0.0766*	0.0483*	0.0608*	0.5786*	0.3693*	0.2456*	0.3300*
	(0.0314)	(0.0026)	(0.0058)	(0.0162)	(0.1698)	(0.0109)	(0.0286)	(0.0925)
Regional dummies	no	no	no	no	yes	yes	yes	yes
Observations	27	5,507	559	91	27	5,507	559	91
Adjusted R-squared	0.0348	0.0414	0.0092	0.0237	0.7211	0.3948	0.3961	0.4333
Diagnostic for spatial dependence								
Lagrange Multiplier-Lag	1.4698	2723.2495*	659.6293*	10.0987*	0.6069	1057.4634*	217.7062*	2.1582
Robust Lagrange Multiplier-Lag	7.0238*	492.7790*	8.13645*	4.7905**	0.0049	46.9791*	19.9950*	0.0340
Lagrange Multiplier-Error	4.0703**	3320.3407*	684.0900*	13.8398*	0.9813	2138.3393*	218.4065*	3.1039***
Robust Lagrange Multiplier-Error	9.6243*	1089.8702*	32.5972*	8.53156*	0.3793	1127.8550*	20.6953*	0.9798

Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%. Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

It is worth noting that at least theoretically it is possible for initially poor regions to grow faster than initially rich ones, without observing that the cross-sectional dispersion fall over time (Sala-i-Martin, 1996). In other words, it is possible to observe β-convergence without finding σ-convergence, which is a decrease of the dispersion of per capita income levels across economies over time. That is, if $\sigma_{t+T} < \sigma_t$, where σ_t, is the time t standard deviation of log (y_{it}) across i (Sala-i-Martin, 1996, p.1020)[58]. A consensus in the literature is that β-convergence does not necessarily imply σ-convergence[59].

[58] An alternative way of measuring the σ-convergence is to use the coefficient of variation (CV) which is obtained by dividing the standard deviation of the series by the mean of the sample. The results using this alternative approach were similar to the ones using standard deviation, i.e., they show a very slow convergence process at all scale levels. This comparison is important since Dalgard &Vastrup (2001) demonstrated (using a 121-country sample from Penn World Table) that the two measures of σ-convergence (standard deviation and CV) can lead to different conclusions, i.e., we can support or reject σ-convergence depending on the measure used. To save space, CV results are not reported; they will be provided upon request.

[59] Lichtenberg (1994) also show that (under the assumption that y_1 – final per capita income – and y_0 – initial per capita income – are generated by the same autoregressive process) σ-convergence does not necessarily imply β-convergence.

Table 2 shows the results for σ-convergence between 1991 and 2000 at all spatial scales. Note that, dispersion decreases (very slowly) at three spatial scales: states, spatial cluster and municipalities. It is interesting to verify that β-conditional convergence (columns 2a-2d) exhibits the same order, i.e., the β and σ-convergence are higher at the state level followed by spatial cluster level and municipal level. Finally, the per capita income distribution at micro-regional scale increases (or at least remains constant) from σ=0.574 in 1991 to σ=0.577 in 2000. The reason for this opposite result of β and σ-convergence is that these concepts capture two different aspects of the per capita income across regions. As highlighted by Sala-i-Martin (1996), σ-convergence relates to whether or not the per capita income distribution across regions shrinks over time. On the other hand, β-convergence relates to the mobility of different individual regions within the given distribution of Brazilian per capita income. Altogether, these results show evidence that Brazil is a country that regions converged too slowly over the nineties.

Table 2 - σ (sigma)-Convergence

Scale level	N	Standard Deviation of (log of per capita income 1991) (a)	Standard Deviation of (log of per capita income 2000) (b)	Variation= (b-a)/a
States	27	0.426	0.410	-3.65%
Municipalities	5,507	0.583	0.579	-0.62%
Micro region	559	0.574	0.577	0.55%
Spatial cluster	91	0.616	0.608	-1.30%

Note: Own elaboration.

Finally, the results in Table 1 also imply, similarly to the Brazilian empirical literature, that controlling variables are playing a role in the performance of per capita income growth 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 four spatial scales, since the magnitude and significance of the coefficients differ between the spatial scales. A consistent finding is that the standard deviations for the slope coefficients in the more aggregated models are larger than those in the municipal model. More precisely, there is a negative correlation between the number of spatial units and the magnitude of the standard deviations for the slope coefficients. This result suggests that the evidence of statistical significance of almost all coefficients at municipal level is related to this issue. Moreover, as the number of units increases, the model exploratory power (adjusted R-squared) decreases. For example, at municipal resolution (5,507 units), the adjusted R-squared is 0.39, whereas by state resolution (27 units)[60] the adjusted R-squared climbs to 0.72. 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 coefficient parameters can be biased or inefficient, depending on the kind of spatial dependence observed.

Table 1 also shows the results of a test proposed by Florax et al. (2003) to identify the presence of spatial dependence across the spatial units and to choose the best spatial econometric specification (spatial lag or spatial error). The strategy consists of the estimation of the standard OLS model to check for spatial dependence applying the (robust) Lagrange Multiplier (LM) tests[61]. For the absolute β-convergence equations (1a-1d), all specifications suffer from spatial autocorrelation since Lagrange Multipliers (LM) are statistically significant at all spatial scales. On the other hand, when controlling variables are added, these variables are able to deal with the spatial autocorrelation in the specification for states (2a) and spatial clusters (2d), since LM statistics are no longer significant at 1% and 5% level. 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. For this

[60] It is import to note that, the high R-squared for state level may be a symptom of micronumerosity, which simply means small sample size.
[61] See Florax et al. (2003) for further details.

reason, the next subsection shows the spatial correction only for the municipal and micro-regional levels. In this paper, I have preferred to run the model with spatially lagged explanatory variables (*WX*) discussed in section 5.1 [Eq. (5.4) and Eq. (5.5)] since the distinction between a spatial lag and a spatial error specification is often difficult in practice and the model with only the spatially lagged explanatory variables (*WX*) has some advantages as discussed earlier.

6.2. Spatial Correction

In this subsection, I report the estimation results for the spatial models. As pointed out by Anselin (2002) in contrast to the spatial lag model that demands Maximumlikelihood procedures, the spatial cross-regressive specification (*WX*) does not require specialized estimation methods and ordinary least squares (OLS) remains unbiased. The columns (3a-3b) of Table 3 show the absolute β-convergence results for municipal and micro-regional levels. First, the absolute β-convergence evidences cannot be rejected again. However, from the convergence perspective, Eq. (5.4) (see section 5.1, p.12) can be interpreted as a minimal conditional β-convergence model integrating a spatial environment variable (Ertur et al. 2006, p.23). For the two spatial scales, the coefficients of the spatially lagged per capita income variable are positive and significantly different from zero. This means that the per capita income growth rate of a municipality (or a micro-region) i is positively influenced by the initial per capita income of neighbouring regions.

However, previous results show that inclusion of other exploratory variables increases model exploratory power. Columns (3c-3d) show the results for the conditional β-convergence case using Eq. (5.5) discussed in section 5.1. 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 non-spatial results. Moreover, the negative correlation between number of scale units and standard deviations for the slope coefficients is found again, as well as, between model exploratory power (R-squared) and number of scale units.

From the measurement point of view, the results of Tables 1 and 3 clearly show that MAUP jeopardizes Brazilian economic growth estimates. The significance and magnitude of the coefficients vary at the four scale levels. In the state and spatial cluster levels, spatial dependence is not found. At this two scale levels, the estimated coefficients represent a blend of individual and contextual effects as suggested by the Ecological Fallacy approach. For municipal and micro-regional scales, some spatially lagged exploratory variables have significant coefficients – albeit with different magnitudes and significance levels. For instance, at municipal level (3c) the average initial per capita income level of neighbours has a positive impact on growth, i.e., a specific municipality located in a relatively poor (rich) neighbourhood will tend to have a lower (higher) per capita income growth (with other things being equal). On the other hand, at micro-regional level (3d) this same variable presents an opposite coefficient.

Table 3 – Spatial Model Results

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS				
	political-administrative region	functional region	political-administrative region	functional region
Exploratory variables	(3a) municipalities	(3b) micro regions	(3c) municipalities	(3d) micro regions
ln(income per capita in 1991)	-0.0298* (0.001)	-0.0069* (0.0022)	-0.0674* (0.0016)	-0.0363* (0.0039)
ln(average years of schooling in 1991)			0.0351* (0.0016)	0.0331* (0.0046)
ln(Gini index in 1991)			-0.0090* (0.0034)	-0.0144 (0.0100)
ln(infant mortality rate in 1991)			-0.0089* (0.0012)	-0.0119* (0.0037)
ln(transport cost to SP in 1991)			-0.0057* (0.0007)	-0.0046* (0.0016)
ln(population density in 1991)			0.0025* (0.0004)	0.0005 (0.0008)
local infra-structure in 1991			0.0043* (0.0005)	-0.0007 (0.0015)
ln(**W***income per capita in 1991)	0.0275* (0.0012)	0.0054** (0.0025)	0.0182* (0.0024)	-0.0173** (0.0072)
ln(**W***average years of schooling in 1991)			-0.0126* (0.0027)	0.0150 (0.0095)
ln(**W***Gini index in 1991)			0.0258* (0.0055)	0.0549* (0.0190)
ln(**W***infant mortality rate in 1991)			-0.0092* (0.0019)	-0.0028 (0.0056)
ln(**W***population density in 1991)			-0.0032* (0.0004)	-0.0021** (0.0009)
W*local infra-structure in 1991			-0.0020* (0.0007)	0.0022 (0.0021)
Constant	0.0471* (0.0028)	0.0410 0.0067	0.3626* (0.0156)	0.3493* (0.0475)
Regional dummies	no	no	yes	yes
Observations	5,507	559	5,507	559
Adjusted R-squared	0.1223	0.0157	0.4165	0.4198
<u>Diagnostic for spatial dependence (K=10)</u>				
Lagrange Multiplier-Lag	3618.2566*	689.9982*	1969.0396*	201.8220*
Robust Lagrange Multiplier-Lag	6.8936*	12.6088*	4.7276**	31.5279*
Lagrange Multiplier-Error	3657.2642*	699.5754*	2024.7512*	173.7352*
Robust Lagrange Multiplier-Error	45.9012*	22.1860*	60.4392*	3.4412***

Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%.
Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

Analyzing Tables 1 and 3 altogether, other exploratory variables also manifest differently at the four spatial scales. For example, there is a positive and significant impact of education capital (years of schooling) on economic growth at municipal, micro-regional and spatial cluster scale levels. On the other hand, the coefficient of local infrastructure seems to impact positively only at municipal level. Notwithstanding, before I make further analysis of the results shown in Tables 1 and 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; and (2) to carry out a sensitive analysis based on 5 and 15-nearest neighbours spatial weight matrix. These robustness checks can help us to identify common structural factors that are driving economic growth at different scale levels in Brazil.

6.3. Robustness Checks

I use the idea 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[62]. 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).

Since, there is not spatial autocorrelation at state and spatial cluster scales, I employed Eq. (5.2) described in section 5.1 to carry out the robustness test. On the other hand, Eq. (5.5) is the specification employed in the robustness test for municipal and micro-regional scales, since spatial dependence exists. Temple (2000, p.184) explains that "the central idea of EBA is to report an upper and lower bound for parameter estimates, thereby indicating sensitivity to the choice of specification". Basically, the EBA approach states that a coefficient is called "robust" if it remains significant (at 5% level) and does not change its sign across a set of combinations of other variables. Otherwise, the variable is coined as "fragile". Instead of presenting only the upper and lower bound of the coefficient, I follow Temple (2000) suggestion and present information about a variety of models[63].

In Appendix B, Tables B.1, B.2, B.3 and B.4 show the results of the robustness checks for states, municipalities, micro-regions and spatial clusters, respectively. Given the multicollinearity problem and the high correlation between variables (see Appendix A), I tried to run models eliminating variables that have high correlation coefficients. To minimize the omission of relevant variables, the regional dummies, the initial per capita income, and the spatial lag of initial per capita income (only for the municipal and micro-regional case) are included in all regressions. For each spatial scale, I run eight models that are similar across scale levels, that is, they include the same combination of variables.

Firstly, conditional β-convergence (or mean-reversion process) cannot be rejected for any spatial scale, since 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 the municipal scale, the coefficients of spatial lag of initial per capita income are positive and statistically significant at 1% level. It is useful to note that robustness checks at municipal level (Table B.2) support the results of Table 3, showing that all spatially lagged exploratory variables are statistically significant. For the micro-regional scale the externalities effects are considered "fragile", excepting the income inequality and schooling externalities. This result suggests that spatial spillovers are mainly operating among smaller scales, such as municipalities. Some of these externality effects are in line with the theory (see section 5.1.1); others not. For instance, at municipal level, economic growth will be higher in municipalities surrounded by other municipalities with high stocks of health (low levels of infant mortality rates) and physical (high levels of initial per capita income) capital. However, the externality effects of education capital and local infrastructure are negative. This result suggest that higher schooling (or local infrastructure) in one region is likely to attract capital and labour from the neighbouring regions, then a negative effect on growth in these neighbouring regions will occur.

Contrarily to the previous results (Table 3) that show distinct results among spatial scales, I find consistent results when robustness tests are carried out (Tables B.1 to B.4 in the appendix B). Indeed,

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

[63] "*The form of presentation of the EBA is important. The more information that can be presented about each regression, and particularly the ones generating the bounds, the better. Many of the traditional criticisms of EBA can be addressed simply through a relatively careful presentation of results*" (Temple, 2000, p. 201).

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[64] and better local infra-structure are related to higher economic growth rates. This finding is in line with my previous analysis that expected an aggregated influence of education, health and local infrastructure on economic growth at all spatial scales, since there are public policies related to these factors operating at all scale levels. From the measurement point of view, it also suggests that the variability in statistical results due to the selection of different spatial scales (i.e. MAUP) can be mitigated carrying out this kind of robustness test.

Moreover, the results show that the marginal impact of each one of these variables is greater at the spatial cluster level. Again, this result suggests that there is a blend with the individual and contextual effects (i.e. ecological fallacy) 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 higher as compared with municipal and micro-regional scale levels.

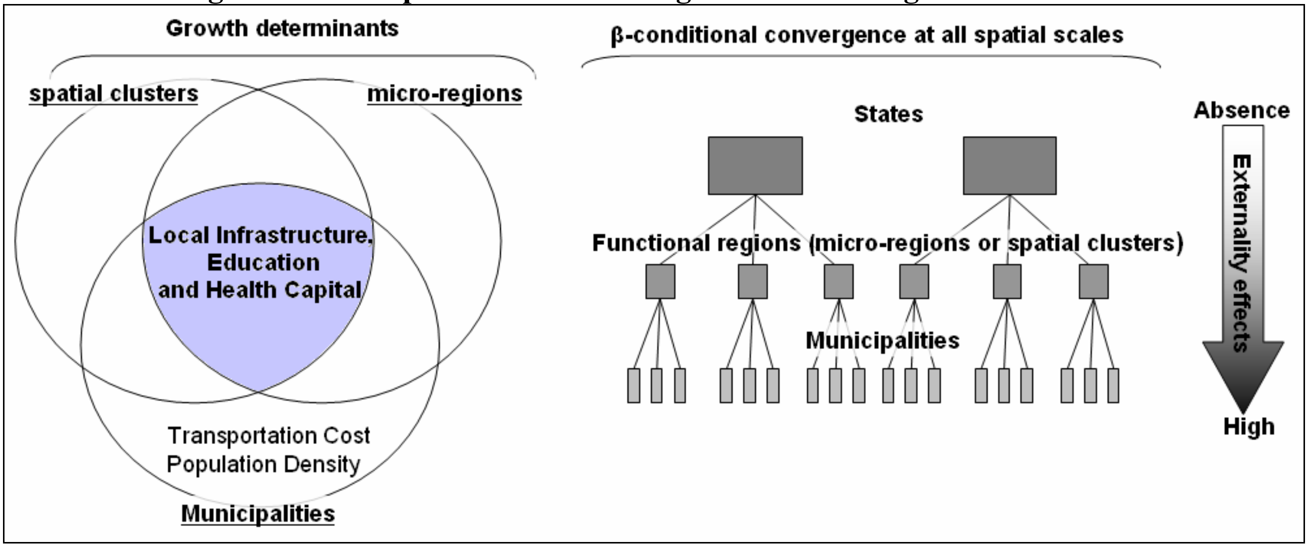
In addition, it seems that at municipal level more variables have influence on growth. It is worth noting that transportation costs coefficient is negative and statistically significant at 1% level in all specifications. Thus, reductions in transportation costs have a positive impact on municipal growth. The analysis at multiple scale levels reveals that despite there is not an impact of transportation costs between functional regions (micro-region, spatial cluster) or states, there might be an influence of reductions in transportation costs within the borders of a functional region or state. Also, population density coefficient is positive and statistically significant showing that agglomeration effects are operating at municipal scale, i.e., the most densely populated municipalities in Brazil are growing faster. Finally, state level results should be viewed with care regarding the small sample size with which the regression analysis was performed. At state level, higher population density, health capital and income inequality are correlated with higher economic growth rates. It is worth noting that population density (agglomeration effects) seems to be influencing economic growth at micro-regional and spatial cluster levels depending on the choice of the controlling variables in the model (see Tables B.3 and B4). For this reason this variable is not coined as robust. Although, EBA is a useful way of communicating any uncertainty surrounding parameter estimates, other kinds of model selection approaches and robustness tests can be carried out to study multiple dimensions of economic growth.

Figure 2 summarizes how scale levels are connected and how exploratory variables could differently impact economic growth at different spatial scales. First, conditional β-convergence (or at least mean-reversion process) is operating at all spatial scales, albeit the dispersion of per capita income (i.e., σ-convergence) decreased too slowly at three spatial scales between 1991 and 2000 and even increased at micro-regional level. Second, local infrastructure, education and health capital are robust at three scale levels (municipalities, micro-regions and spatial clusters). Third, spatial spillovers occur as geographic areas get smaller. It is worth noting that, although functional regions are good way to deal with MAUP, they do not tell us about the externalities operating within those functional regions, since the estimated coefficients are a blend of individual and contextual effects. For these reason, analyzing the lowest scale possible (municipalities, for example) is a good way to capture

[64] At the spatial cluster level, health capital (infant mortality rate) only appears statistically significant in the specification (7), Table B.4. However, this specification seems to be the best to verify the influence of health on growth since it avoids the multicollinearity problem, excluding education capital and local infrastructure which have a high correlation with health variable, respectively, -0.82 and -0.77. In the presence of multicollinearity, the standard errors of the affected coefficients tend to be large. For this reason, the test of hypothesis tends to accept the null hypothesis. On the other hand, when I drop the correlated explanatory variables (education capital and local infrastructure) from the model, I may incur on the problem of omission of a relevant variable that will bias the coefficient estimates for the remaining explanatory variables. Despite this problem of omission of relevant variable, it seems that health capital is a robust variable since it appears statistically significant at the other scale levels (state, municipalities and micro-regions) in all specifications.

those effects separately. Thus, the analysis of multiple scales altogether improves our understanding about the economic growth dynamics across space.

Figure 2 – Multiple dimensions of regional economic growth in Brazil



Note: Own elaboration. Due to the small sample size, state level results should be viewed with care and they are not showed in the figure. The robust coefficients for state level are: initial per capita income, population density, health capital, and income inequality.

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[65]. Furthermore, to investigate the extent of the externalities effects I calculate the Moran's *I* to the residuals of municipal and micro-regional specification in Table 1 (2b and 2c) using k= 5, 10, 15, 30, 60 and 120. Moran's *I* is a measure of global spatial autocorrelation[66] and it is used here simply to show that spatial dependence (at municipal and micro-regional level) wane away with an increase of the number of neighbour regions, suggesting that spillovers are bounded in space. Table C.1 (in Appendix C) shows the values of Moran's *I*. This result is in line with the first law of geography, which states that "*everything is related to everything else, but near things are more related than distant things*" (Tobler, 1970, p. 236).

7. Conclusions

The aim of this paper is to analyze Brazilian economic growth at different spatial scales, ranging from municipalities to state regions between 1991 and 2000. It suggests a general framework that allows dealing with multiple spatial scales, 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 multiple spatial scales analysis 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 four Brazilian spatial scales over the 1991–2000 period.

Four points are worth mentioning. First, the paper identified that if single regression is estimated at the different scale levels, the results change as scale level changes. This measurement issue, prevent us from identifying the actual scale at which economic growth processes operates. 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. I conclude that, concerning these three variables, the structural factors underlying the Brazilian economic growth are quite similar at different scales. In fact, it

[65] To save space, these results are not reported; they will be provided upon request.

[66] If Moran's *I* statistic is (approximately) equal to zero then there is no evidence of spatial autocorrelation. If Moran's *I* statistic is larger than zero, there is a positive autocorrelation. On the other hand, if Moran's *I* statistic is smaller than zero, there is a negative autocorrelation. See Cliff & Ord (1981) for details. The statistical significance of Moran's *I* is based on the permutation approach (Anselin, 1995).

demonstrates that since public policies (education, health and local infrastructure) are operating across all scale levels, it would be expected this common result across spatial scales.

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) can be employed, but this is beyond the scope of the present paper. Following this paper, future research should propose other robustness tests for multiple scale levels.

Third, the results for β-conditional convergence cannot be rejected indicating, at least, a process of mean-reverting at the four spatial scales. Given the weakness of this approach, I tested directly if the dispersion of per capita income between regions falls over time, that is, σ-convergence. This analysis shows that per capita income distribution at three spatial scales shrinks very slowly between 1991 and 2000. The per capita income dispersion falls only 3.65% at state level (the higher decreased among all scale levels) during the whole period. For the micro-regions the dispersion increased by 0.55%. The conclusion is that Brazil is a country that regions converged too slowly over the nineties

Fourth, spatial spillovers are operating especially at finer scales. Particularly, this work adopts a spatial cross-regressive specification (*WX*) which identifies the exploratory variables that have externality effects, instead of estimating the spatial lag model with the spatially lagged endogenous (dependent) variable. In doing so, it is possible to decompose the general "economic growth externalities" into several spatially lagged exploratory variables that spread to surrounding areas. At municipal level, several variables exhibit externality effects across space in Brazil, such as physical capital (proxied by initial per capita income), education and health capital and local infrastructure. The result shows evidence that externalities are confined to functional regions (spatial cluster level) since it was not detected spatial dependence at the spatial cluster level. It is worth noting that, at the spatial cluster level (micro-region and state as well) the estimated coefficients denote a blend of individual and contextual effects as suggested by the Ecological Fallacy problem. 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 problems) and the impact of a public policy may be amplified by the externality effects within each cluster. This conclusion also shed light on the relevance of co-ordination of government policies between jurisdictions (e.g. municipalities).

More specifically, 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 (see Figure D.1 in Appendix D), 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. It is important to clarify that the definition of the functional region suggested in this study, the spatial cluster level, is not the right or the best one to deal with all the factors that influence economic growth in Brazil. It is only a good starting point for the debate and sheds light on the proposal to work with groups of jurisdictions (municipalities, in the Brazilian case) in order to deal with spillovers, thereby internalizing all the benefits and costs (Oates, 1999). Also, it does not mean that similar policies should be implemented in all of these clusters. On the contrary, each cluster should have a well-designed policy package to deal with their needs.

All these results are dependent on the period used in this study. Spatial heterogeneity should be assessed since parameters might not be stable over space. Also, it is possible to include other exploratory variables if data are available. These issues are left for future research since they are beyond the scope of this paper.

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APPENDIX A

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

	Exploratory variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	ln(local infrastructure in 1991)	1	0.83	0.88	-0.14	-0.75	-0.78	0.62	0.73	0.57	0.61	-0.35	-0.62	-0.80	0.45
2	ln(income per capita in 1991)	0.83	1	0.97	0.22	-0.87	-0.59	0.20	0.64	0.70	0.70	0.02	-0.76	-0.62	0.15
3	ln(average years of schooling in 1991)	0.88	0.97	1	0.16	-0.86	-0.59	0.30	0.64	0.66	0.66	-0.08	-0.71	-0.64	0.18
4	ln(Gini index in 1991)	-0.14	0.22	0.16	1	0.01	0.38	-0.33	-0.28	-0.04	-0.11	0.19	0.07	0.31	-0.36
5	ln(infant mortality rate in 1991)	-0.75	-0.87	-0.86	0.01	1	0.62	-0.12	-0.79	-0.87	-0.87	-0.17	0.88	0.72	-0.34
6	ln(transportation cost to SP in 1991)	-0.78	-0.59	-0.59	0.38	0.62	1	-0.65	-0.89	-0.66	-0.72	0.36	0.65	0.93	-0.76
7	ln(population density in 1991)	0.62	0.20	0.30	-0.33	-0.12	-0.65	1	0.40	0.01	0.09	-0.65	-0.03	-0.56	0.64
8	W*local infrastructure in 1991	0.73	0.64	0.64	-0.28	-0.79	-0.89	0.40	1	0.89	0.92	-0.13	-0.87	-0.96	0.73
9	ln(W*income per capita in 1991)	0.57	0.70	0.66	-0.04	-0.87	-0.66	0.01	0.89	1	0.99	0.28	-0.96	-0.75	0.45
10	ln(W*average years of schooling in 1991)	0.61	0.70	0.66	-0.11	-0.87	-0.72	0.09	0.92	0.99	1	0.21	-0.97	-0.79	0.49
11	ln(W*Gini index in 1991)	-0.35	0.02	-0.08	0.19	-0.17	0.36	-0.65	-0.13	0.28	0.21	1	-0.20	0.37	-0.37
12	ln(W*infant mortality rate in 1991)	-0.62	-0.76	-0.71	0.07	0.88	0.65	-0.03	-0.87	-0.96	-0.97	-0.20	1	0.73	-0.35
13	ln(W*transportation cost to SP in 1991)	-0.80	-0.62	-0.64	0.31	0.72	0.93	-0.56	-0.96	-0.75	-0.79	0.37	0.73	1	-0.78
14	ln(W*population density in 1991)	0.45	0.15	0.18	-0.36	-0.34	-0.76	0.64	0.73	0.45	0.49	-0.37	-0.35	-0.78	1

Own elaboration.

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

	Exploratory variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	ln(local infrastructure in 1991)	1	0.83	0.82	0.08	-0.69	-0.76	0.48	0.89	0.77	0.75	-0.08	-0.70	-0.75	0.44
2	ln(income per capita in 1991)	0.83	1	0.86	0.24	-0.78	-0.68	0.23	0.76	0.87	0.80	0.02	-0.79	-0.67	0.19
3	ln(average years of schooling in 1991)	0.82	0.86	1	0.27	-0.75	-0.62	0.31	0.71	0.77	0.84	0.11	-0.75	-0.61	0.24
4	ln(Gini index in 1991)	0.08	0.24	0.27	1	-0.08	-0.01	-0.12	-0.05	0.03	0.08	0.49	-0.05	0.01	-0.21
5	ln(infant mortality rate in 1991)	-0.69	-0.78	-0.75	-0.08	1	0.64	-0.12	-0.72	-0.81	-0.81	-0.06	0.91	0.64	-0.13
6	ln(transportation cost to SP in 1991)	-0.76	-0.68	-0.62	-0.01	0.64	1	-0.37	-0.82	-0.74	-0.70	0.03	0.69	0.98	-0.42
7	ln(population density in 1991)	0.48	0.23	0.31	-0.12	-0.12	-0.37	1	0.40	0.13	0.19	-0.29	-0.09	-0.36	0.81
8	W*local infrastructure in 1991	0.89	0.76	0.71	-0.05	-0.72	-0.82	0.40	1	0.86	0.84	-0.07	-0.78	-0.84	0.50
9	ln(W*income per capita in 1991)	0.77	0.87	0.77	0.03	-0.81	-0.74	0.13	0.86	1	0.92	0.07	-0.88	-0.76	0.23
10	ln(W*average years of schooling in 1991)	0.75	0.80	0.84	0.08	-0.81	-0.70	0.19	0.84	0.92	1	0.16	-0.88	-0.72	0.30
11	ln(W*Gini index in 1991)	-0.08	0.02	0.11	0.49	-0.06	0.03	-0.29	-0.07	0.07	0.16	1	-0.07	0.02	-0.31
12	ln(W*infant mortality rate in 1991)	-0.70	-0.79	-0.75	-0.05	0.91	0.69	-0.09	-0.78	-0.88	-0.88	-0.07	1	0.70	-0.14
13	ln(W*transportation cost to SP in 1991)	-0.75	-0.67	-0.61	0.01	0.64	0.98	-0.36	-0.84	-0.76	-0.72	0.02	0.70	1	-0.42
14	ln(W*population density in 1991)	0.44	0.19	0.24	-0.21	-0.13	-0.42	0.81	0.50	0.23	0.30	-0.31	-0.14	-0.42	1

Own elaboration.

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

	Exploratory variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	ln(local infrastructure in 1991)	1	0.86	0.87	-0.02	-0.77	-0.78	0.55	0.87	0.73	0.75	-0.20	-0.72	-0.78	0.42
2	ln(income per capita in 1991)	0.86	1	0.92	0.15	-0.86	-0.67	0.26	0.74	0.84	0.80	-0.02	-0.81	-0.67	0.12
3	ln(average years of schooling in 1991)	0.87	0.92	1	0.20	-0.82	-0.63	0.35	0.69	0.73	0.76	0.02	-0.74	-0.63	0.16
4	ln(Gini index in 1991)	-0.02	0.15	0.20	1	-0.08	0.10	-0.28	-0.12	0.01	0.03	0.58	-0.07	0.10	-0.41
5	ln(infant mortality rate in 1991)	-0.77	-0.86	-0.82	-0.08	1	0.67	-0.15	-0.77	-0.86	-0.87	-0.06	0.93	0.67	-0.10
6	ln(transportation cost to SP in 1991)	-0.78	-0.67	-0.63	0.10	0.67	1	-0.49	-0.88	-0.76	-0.76	0.19	0.71	0.99	-0.52
7	ln(population density in 1991)	0.55	0.26	0.35	-0.28	-0.15	-0.49	1	0.42	0.09	0.15	-0.48	-0.08	-0.47	0.75
8	W*local infrastructure in 1991	0.87	0.74	0.69	-0.12	-0.77	-0.88	0.42	1	0.86	0.88	-0.17	-0.83	-0.89	0.49
9	ln(W*income per capita in 1991)	0.73	0.84	0.73	0.01	-0.86	-0.76	0.09	0.86	1	0.96	0.03	-0.93	-0.77	0.18
10	ln(W*average years of schooling in 1991)	0.75	0.80	0.76	0.03	-0.87	-0.76	0.15	0.88	0.96	1	0.09	-0.94	-0.78	0.25
11	ln(W*Gini index in 1991)	-0.20	-0.02	0.02	0.58	-0.06	0.19	-0.48	-0.17	0.03	0.09	1	-0.11	0.19	-0.54
12	ln(W*infant mortality rate in 1991)	-0.72	-0.81	-0.74	-0.07	0.93	0.71	-0.08	-0.83	-0.93	-0.94	-0.11	1	0.73	-0.10
13	ln(W*transportation cost to SP in 1991)	-0.78	-0.67	-0.63	0.10	0.67	0.99	-0.47	-0.89	-0.77	-0.78	0.19	0.73	1	-0.52
14	ln(W*population density in 1991)	0.42	0.12	0.16	-0.41	-0.10	-0.52	0.75	0.49	0.18	0.25	-0.54	-0.10	-0.52	1

Own elaboration.

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

	Exploratory variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	ln(local infrastructure in 1991)	1	0.88	0.90	0.13	-0.74	-0.68	0.73	0.76	0.64	0.66	-0.31	-0.63	-0.68	0.58
2	ln(income per capita in 1991)	0.88	1	0.95	0.33	-0.80	-0.55	0.54	0.59	0.63	0.61	-0.10	-0.65	-0.55	0.26
3	ln(average years of schooling in 1991)	0.90	0.95	1	0.36	-0.77	-0.50	0.61	0.56	0.56	0.56	-0.15	-0.59	-0.50	0.31
4	ln(Gini index in 1991)	0.13	0.33	0.36	1	-0.10	0.24	-0.10	-0.15	-0.04	-0.06	0.19	-0.03	0.20	-0.26
5	ln(infant mortality rate in 1991)	-0.74	-0.80	-0.77	-0.10	1	0.62	-0.34	-0.72	-0.81	-0.80	0.01	0.89	0.66	-0.33
6	ln(transportation cost to SP in 1991)	-0.68	-0.55	-0.50	0.24	0.62	1	-0.58	-0.83	-0.73	-0.71	0.45	0.66	0.96	-0.67
7	ln(population density in 1991)	0.73	0.54	0.61	-0.10	-0.34	-0.58	1	0.52	0.22	0.29	-0.49	-0.21	-0.50	0.61
8	W*local infrastructure in 1991	0.76	0.59	0.56	-0.15	-0.72	-0.83	0.52	1	0.88	0.92	-0.27	-0.81	-0.88	0.77
9	ln(W*income per capita in 1991)	0.64	0.63	0.56	-0.04	-0.81	-0.73	0.22	0.88	1	0.97	0.00	-0.93	-0.79	0.48
10	ln(W*average years of schooling in 1991)	0.66	0.61	0.56	-0.06	-0.80	-0.71	0.29	0.92	0.97	1	-0.02	-0.92	-0.77	0.58
11	ln(W*Gini index in 1991)	-0.31	-0.10	-0.15	0.19	0.01	0.45	-0.49	-0.27	0.00	-0.02	1	-0.03	0.43	-0.50
12	ln(W*infant mortality rate in 1991)	-0.63	-0.65	-0.59	-0.03	0.89	0.66	-0.21	-0.81	-0.93	-0.92	-0.03	1	0.73	-0.36
13	ln(W*transportation cost to SP in 1991)	-0.68	-0.55	-0.50	0.20	0.66	0.96	-0.50	-0.88	-0.79	-0.77	0.43	0.73	1	-0.68
14	ln(W*population density in 1991)	0.58	0.26	0.31	-0.26	-0.33	-0.67	0.61	0.77	0.48	0.58	-0.50	-0.36	-0.68	1

Own elaboration.

APPENDIX B

Table B.1 – Robustness test at state level

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS								
Exploratory variables	**(Scale level: States)**							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(income per capita in 1991)	-0.0672*	-0.0595*	-0.0697*	-0.0509**	-0.0684*	-0.0647*	-0.0612*	-0.0386*
	(0.0177)	(0.0188)	(0.0210)	(0.0205)	(0.0179)	(0.0191)	(0.0090)	(0.0091)
ln(average years of schooling in 1991)					0.0144	0.0243		
					(0.0305)	(0.0323)		
ln(Gini index in 1991)	0.1349**	0.1131***	0.1508**	0.0864	0.1270**	0.1060***	0.1237**	0.0999
	(0.0596)	(0.0635)	(0.0707)	(0.0687)	(0.0530)	(0.0557)	(0.0513)	(0.0661)
ln(infant mortality rate in 1991)	-0.0243***				-0.0236***		-0.0246***	
	(0.0122)				(0.0123)		(0.0119)	
ln(transportation cost to SP in 1991)	-0.0054	-0.0044	-0.0123***		-0.0062	-0.0063	-0.0044	-0.0093
	(0.0056)	(0.0061)	(0.0060)		(0.0063)	(0.0068)	(0.0048)	(0.0059)
ln(population density in 1991)	0.0062**	0.0061**			0.0060**	0.0057**	0.0066*	
	(0.0022)	(0.0024)			(0.0022)	(0.0024)	(0.0019)	
local infra-structure in 1991	0.0024	0.0030	0.0107	0.0064				
	(0.0060)	(0.0065)	(0.0066)	(0.0068)				
Constant	0.5721*	0.4178**	0.5654*	0.3284**	0.5569*	0.4221*	0.5257*	0.3477*
	(0.1638)	(0.1566)	(0.1666)	(0.1305)	(0.1330)	(0.1213)	(0.1127)	(0.1037)
Regional dummies	yes	yes	yes	yes		yes	yes	yes
Observations	27	27	27	27	27	27	27	27
Adjusted R-squared	0.7367	0.6906	0.5948	0.5254	0.7377	0.6968	0.7497	0.5595
Diagnostic for spatial dependence								
Lagrange Multiplier-Lag	0.5477	1.6069	1.5058	0.2660	0.6031	1.6987	0.5137	1.2771
Robust Lagrange Multiplier-Lag	0.0211	0.4986	0.1561	0.5000	0.0004	0.7203	0.0129	0.1800
Lagrange Multiplier-Error	0.9958	1.1082	1.3978	1.0228	0.9124	0.9979	0.9073	1.1203
Robust Lagrange Multiplier-Error	0.4691	0.00002	0.0481	1.2568	0.3097	0.0195	0.4065	0.0232

Own elaboration. Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%.
Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

Table B.2 – Robustness test at municipal level

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS								
Exploratory variables	**(Scale level: Municipalities)**							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(income per capita in 1991)	-0.0572*	-0.0538*	-0.0501*	-0.0499	-0.0633*	-0.0611*	-0.0422*	-0.0287*
	(0.0015)	(0.0016)	(0.0015)	(0.0015)	(0.0015)	(0.0015)	(0.0014)	(0.0012)
ln(average years of schooling in 1991)					0.0409*	0.0419*		
					(0.0015)	(0.0015)		
ln(Gini index in 1991)	0.0026	0.0001	-0.0056	-0.0050	-0.0112*	-0.0138*	0.0013	-0.0117*
	(0.0035)	(0.0036)	(0.0035)	(0.0036)	(0.0034)	(0.0034)	(0.0036)	(0.0037)
ln(infant mortality rate in 1991)	-0.0120				-0.0090*		-0.0134*	
	(0.0013)				(0.0013)		(0.0013)	
ln(transportation cost to SP in 1991)	-0.0048	-0.0029*	-0.0033*		-0.0059*	-0.0048*	-0.0051*	-0.0044*
	(0.0007)	(0.0007)	(0.0007)		(0.0007)	(0.0007)	(0.0008)	(0.0008)
ln(population density in 1991)	0.0038*	0.0039*			0.0031*	0.0031*	0.0059*	
	(0.0004)	(0.0004)			(0.0004)	(0.0004)	(0.0004)	
local infra-structure in 1991	0.0090	0.0092*	0.0104*	0.0104*				
	(0.0005)	(0.0005)	(0.0005)	(0.0005)				
ln(**W***income per capita in 1991)	0.0142*	0.0226*	0.0161*	0.0173*	0.0191*	0.0234*	0.0098*	0.0078*
	(0.0024)	(0.0023)	(0.0022)	(0.0022)	(0.0022)	(0.0021)	(0.0020)	(0.0016)
ln(**W***average years of schooling in 1991)					-0.0167*	-0.0109*		
					(0.0025)	(0.0025)		
ln(**W***Gini index in 1991)	0.0364*	0.0280*	0.0342*	0.0324*	0.0265*	0.0157*	0.0395*	0.0392*
	(0.0056)	(0.0057)	(0.0057)	(0.0057)	(0.0055)	(0.0055)	(0.0058)	(0.0059)
ln(**W***infant mortality rate in 1991)	-0.0113*				-0.0091*		-0.0104*	
	(0.0020)				(0.0019)		(0.0020)	
ln(**W***population density in 1991)	-0.0033*	-0.0039*			-0.0035*	-0.0042*	-0.0044*	
	(0.0004)	(0.0005)			(0.0004)	(0.0004)	(0.0005)	
W*local infra-structure in 1991	-0.0051*	-0.0047*	-0.0056*	-0.0053*				
	(0.0007)	(0.0007)	(0.0007)	(0.0007)				
Constant	0.3815*	0.2136*	0.2278*	0.1950*	0.3351*	0.2109*	0.3321*	0.1691*
	(0.0163)	(0.0122)	(0.0120)	(0.0094)	(0.0145)	(0.0099)	(0.0156)	(0.0103)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	5,507	5,507	5,507	5,507	5,507	5,507	5,507	5,507
Adjusted R-squared	0.3536	0.3202	0.3082	0.3058	0.4080	0.3897	0.3092	0.2422
Diagnostic for spatial dependence								
Lagrange Multiplier-Lag	1905.5552*	2262.9303*	2219.4081*	2245.8384*	1920.4179*	2124.2426*	1705.2045*	1965.8259*
Robust Lagrange Multiplier-Lag	7.7995*	10.3569*	2.4768	4.6021**	2.9971***	2.5130	0.4293	0.0516
Lagrange Multiplier-Error	1945.3615*	2306.4441*	2278.8489*	2290.9644*	1987.1507*	2202.3607*	1774.1069*	2023.5573*
Robust Lagrange Multiplier-Error	47.6058*	53.8706*	61.9175*	49.7282*	69.7299*	80.6311*	69.3317*	57.7830*

Own elaboration. Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%.
Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

Table B.3 – Robustness test at micro-regional level

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS								
Exploratory variables	**(Scale level: Micro-regions)**							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(income per capita in 1991)	-0.0261*	-0.0217*	-0.0198*	-0.0196*	-0.0368*	-0.0341*	-0.0178*	-0.0069*
	(0.0039)	(0.0039)	(0.0038)	(0.0038)	(0.0036)	(0.0036)	(0.0028)	(0.0021)
ln(average years of schooling in 1991)					0.0317*	0.0339*		
					(0.0041)	(0.0041)		
ln(Gini index in 1991)	0.0015	-0.0025	-0.0042	-0.0039	-0.0134	-0.0176***	0.0018	-0.0071
	(0.0105)	(0.0108)	(0.0106)	(0.0106)	(0.0099)	(0.0099)	(0.0106)	(0.0108)
ln(infant mortality rate in 1991)	-0.0162*				-0.0116*		-0.0177*	
	(0.0039)				(0.0037)		(0.0039)	
ln(transportation cost to SP in 1991)	-0.0034**	-0.0010	-0.0011		-0.0047*	-0.0035**	-0.0029***	-0.0011
	(0.0017)	(0.0017)	(0.0016)		(0.0016)	(0.0016)	(0.0017)	(0.0017)
ln(population density in 1991)	0.0014***	0.0014***			0.0006	0.0006	0.0021*	
	(0.0008)	(0.0008)			(0.0007)	(0.0008)	(0.0008)	
local infra-structure in 1991	0.0044*	0.0052*	0.0056*	0.0056*				
	(0.0014)	(0.0015)	(0.0014)	(0.0014)				
ln(**W***income per capita in 1991)	-0.0107	0.0003	-0.0029	-0.0020	-0.0143**	-0.0116***	-0.0097***	-0.0057
	(0.0068)	(0.0063)	(0.0060)	(0.0059)	(0.0065)	(0.0064)	(0.0052)	(0.0037)
ln(**W***average years of schooling in 1991)					0.0182**	0.0234*		
					(0.0090)	(0.0088)		
ln(**W***Gini index in 1991)	0.0812*	0.0792*	0.0852*	0.0828*	0.0520*	0.0461**	0.0814*	0.0834*
	(0.0192)	(0.0198)	(0.0194)	(0.0191)	(0.0188)	(0.0190)	(0.0194)	(0.0196)
ln(**W***infant mortality rate in 1991)	-0.0071				-0.0030		-0.0059	
	(0.0059)				(0.0056)		(0.0059)	
ln(**W***population density in 1991)	-0.0012	-0.0017***			-0.0021**	-0.0026*	-0.0012	
	(0.0009)	(0.0009)			(0.0009)	(0.0009)	(0.0009)	
W*local infra-structure in 1991)	-0.0009	-0.0017	-0.0020	-0.0019				
	(0.0021)	(0.0021)	(0.0021)	(0.0021)				
Constant	0.3665*	0.1781*	0.1858*	0.1702*	0.3322*	0.2254*	0.3141*	0.1307*
	(0.0512)	(0.0366)	(0.0352)	(0.0271)	(0.0428)	(0.0281)	(0.0465)	(0.0275)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	559	559	559	559	559	559	559	559
Adjusted R-squared	0.3251	0.2802	0.2771	0.2778	0.4207	0.4031	0.3128	0.2555
Diagnostic for spatial dependence								
Lagrange Multiplier-Lag	246.2410*	277.8168*	280.2039*	281.0590*	203.0224*	211.4081*	240.4631*	270.5711*
Robust Lagrange Multiplier-Lag	31.8348*	25.8536*	28.9218*	27.5569*	28.2560*	28.9776*	26.6222*	27.9097*
Lagrange Multiplier-Error	217.3522*	252.3101*	252.3017*	254.1472*	177.1165*	184.2359*	215.3236*	243.2958*
Robust Lagrange Multiplier-Error	2.9460***	0.3468	1.0196	0.6451	2.3501	1.8054	1.4827	0.6345

Own elaboration. Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%.
Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

Table B.4 – Robustness test at spatial cluster level

Dependent variable: income per capita growth between 1991 and 2000 - Estimation method: OLS								
Exploratory variables	**(Scale level: Spatial Clusters)**							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln(income per capita in 1991)	-0.0544*	-0.0508*	-0.0472*	-0.0469*	-0.0653*	-0.0626*	-0.0305*	-0.0114**
	(0.0102)	(0.0100)	(0.0098)	(0.0095)	(0.0091)	(0.0088)	(0.0077)	(0.0049)
ln(average years of schooling in 1991)					0.0694*	0.0729*		
					(0.0126)	(0.0122)		
ln(Gini index in 1991)	0.0300	0.0236	0.0118	0.0095	-0.0415	-0.0500	0.0194	-0.0125
	(0.0333)	(0.0332)	(0.0328)	(0.0296)	(0.0321)	(0.0312)	(0.0352)	(0.0352)
ln(infant mortality rate in 1991)	-0.0170				-0.0123		-0.0270**	
	(0.0120)				(0.0109)		(0.0123)	
ln(transportation cost to SP in 1991)	0.00001	0.0006	-0.0007		-0.0036	-0.0034	-0.0003	-0.0012
	(0.0042)	(0.0042)	(0.0042)		(0.0039)	(0.0039)	(0.0045)	(0.0046)
ln(population density in 1991)	0.0031***	0.0028			-0.0001	-0.0005	0.0042**	
	(0.0017)	(0.0017)			(0.0017)	(0.0017)	(0.0017)	
local infra-structure in 1991	0.0115*	0.0127*	0.0137*	0.0137*				
	(0.0035)	(0.0034)	(0.0034)	(0.0033)				
Constant	0.3759*	0.2845*	0.2758*	0.2670*	0.3120*	0.2404*	0.2817*	0.0778
	(0.1007)	(0.0780)	(0.0786)	(0.0580)	(0.0879)	(0.0608)	(0.1024)	(0.0675)
Regional dummies	yes	yes	yes	yes	yes	yes	yes	yes
Observations	91	91	91	91	91	91	91	91
Adjusted R-squared	0.3174	0.3088	0.2941	0.3024	0.4373	0.4355	0.2333	0.1608
Diagnostic for spatial dependence								
Lagrange Multiplier-Lag	2.1173	1.7848	2.6090	2.5382	1.8981	1.5697	1.0161	1.2343
Robust Lagrange Multiplier-Lag	0.4585	0.0726	0.7341	0.6980	0.0743	0.0713	0.5727	2.6631
Lagrange Multiplier-Error	3.5713***	2.4710	1.9252	1.8830	2.9404***	2.4790	1.9338	0.3723
Robust Lagrange Multiplier-Error	1.9125	0.7588	0.0503	0.0428	1.1166	0.9806	1.4904	1.8011

Own elaboration. Note: Standard errors in parentheses; * significant at 1%; ** significant at 5%; *** significant at 10%. Dependent variable = (1/9)*ln[incomepercapita_in_2000/incomepercapita_in_1991].

APPENDIX C

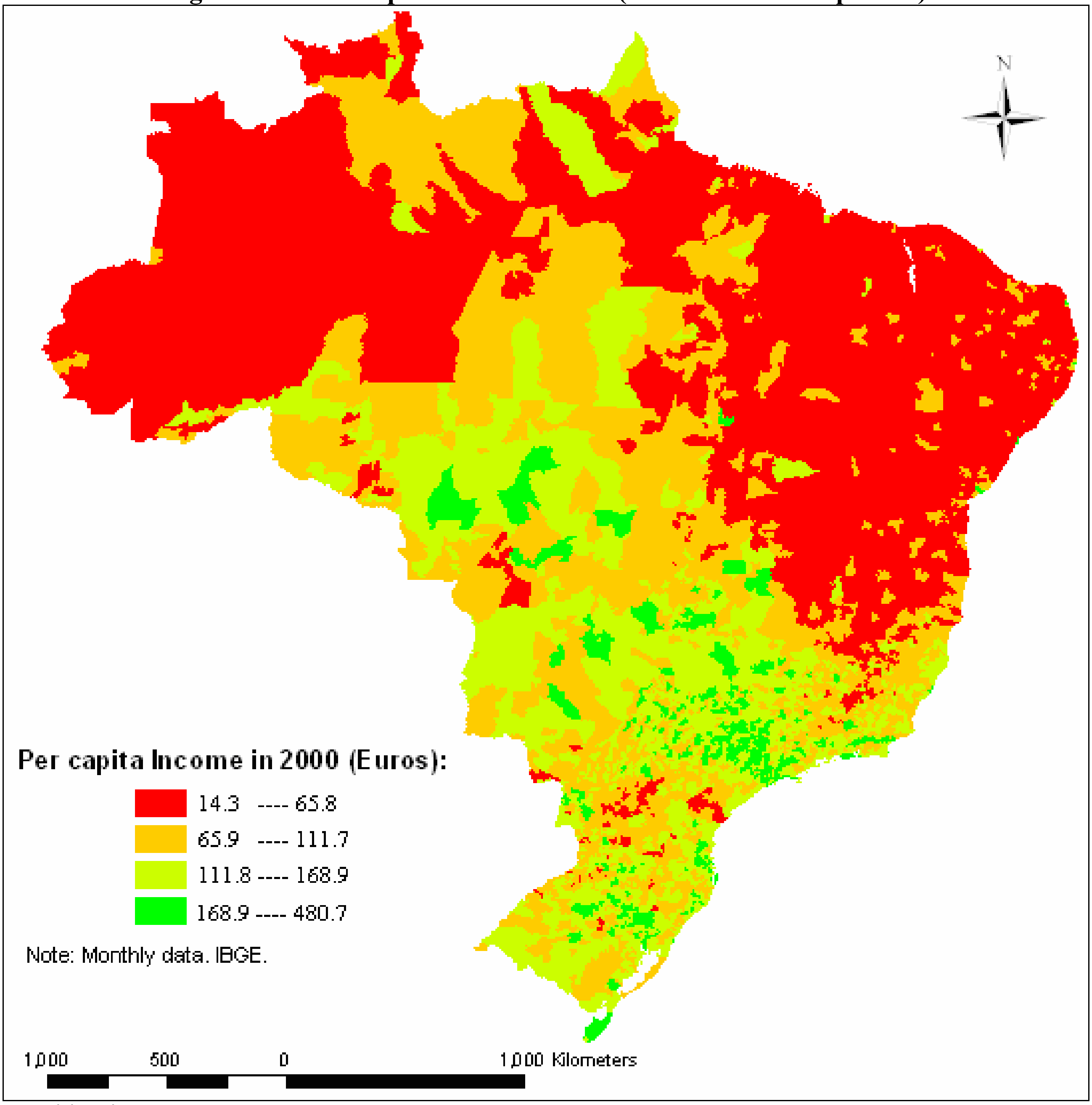
Table C.1 - Moran's *I* to the residuals of municipal and micro-regional specification

Scale level	k-nearest neighbours	k=5	k=10	k=15	k=30	k=60	k=120
Micro-regions	Moran's I	0.3205	0.2795	0.2186	0.1243	0.0346	0.0062
(559 units)	p-value*	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0004)	(0.0558)
Municipalities	Moran's I	0.3015	0.2787	0.2601	0.2309	0.1876	0.1268
(5,507 units)	p-value*	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)

Note: Based on the estimation of OLS Baseline Estimation for Diagnostics of Spatial Dependence (Table 1). Exploratory variables included in the model: ln(income per capita in 1991), ln(average years of schooling in 1991), ln(Gini index in 1991), ln(infant mortality rate in 1991), ln(transport cost to SP in 1991), ln(population density in 1991), local infra-structure in 1991 and Regional dummies.
*P-values are based on the permutation approach with ten thousand permutations.

APPENDIX D

Figure D.1 – Per capita income in 2000 (scale level: municipalities)



Own elaboration.