Economic growth in Brazilian micro-regions: a spatial panel approach

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ABSTRACT

The aim of this study is to identify the determinants of economic growth and analyze the dynamics of income considering a panel of 1970-2010 with 522 Brazilian micro-regions. Based on the theoretical model of Mankiw-Romer-Weil with the spatial expansion proposed by Ertur and Koch (2006), we employed a Spatial Durbin Model (SDM) with fixed-effects, an empirical strategy that simultaneously considers the spatial dependence and specific heterogeneity of each economy. Added to this the estimation of direct impacts and indirect impacts (spillovers) of the determinants of regional growth. The results indicate a strong spatial dependence among Brazilian micro-regions, moreover, there is evidence that both investment in physical capital and investment in human capital matter not only for the growth of the economy itself, but also for the growth of neighboring economies.

Keywords: Economic growth, Spatial Spillovers, Spatial Panel.

JEL classification: C23, O47, R11.

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1. Introduction

With its big continental area and diverse regional environment conditions, Brazil is country with a significant and persistent regional income disparities (AZZONI, 2001; SHAKAR and SHAH, 2003; BAER, 2001; VELEZ *et al.*, 2004). This situation was a resulted of its colonial economic history, when export based activities were based in natural local resources, with poor transport connections among the regions of the country and, during twenty century, the concentration of industrialization in its Southeast region (CANO 1985; BAER 2001). The lack of education investment and degree of closure of its economy during almost all twenty century, on one hand, and agglomeration forces, on the other, have contributed to preserve the past regional distribution of activities (SILVEIRA NETO and MENEZES, 2008; ÖZYURT and DAUMAL, 2013).

This characteristic is commonly and clearly illustrated though the situations of Northeast (the poorest region) and of Southeast (the richest region) macro regions of the country, the two most populous regions of Brazil. The Northeast and Southeast regions presented, respectively, 34,7% and 44,6% of Brazilian population and 17% and 63% of Brazilian GDP in 1939; in the final of twenty the regional inequality still persisted: while 28,1% and 46% of Brazilian population were located to Northeast and Southeast regions, respectively, and the share of PIB of these regions were 12,4% and 58,3% in 2000 (AZZONI, 2001). In fact, during all the period for which macro regional data are available (1939 on), Northeast per capita GDP was never higher than half of the national level and the region presented levels of poverty more than the double of the one registered for Southeast region (ROCHA, 2003**;** SILVEIRA NETO, 2005).

As expected, the situation has motivated regional policies that, historically, have mainly focused on directed increasing of physical capital though attraction of manufacturing to less developed regions (CANO, 1980; BAER, 2001). The results of these politics appear to be mixed, resembling those of European Structural Funds (MARTIN, 1999; HUSRT and VANHOUDT, 2000; PUGA, 2002). For example, FERREIRA (2004) suggest that these traditional regional policies focused on capital subsidies in Brazilian Northeast did not contributed to reduce regional disparities. CARVALHO *et al*. (2005), on the other hand, pointed out that these policies had positive effects in attracting manufacturing to Brazilian poorest regions, a result also obtained by MANOEL *et al*. (2009). In fact, Brazilian experience in evaluating "placed-based" regional policies presents the classical problem of inexistence of a good contra factual, in other words, it is not possible to know what would be the economic and social situation of the poorest regions without the implementation of the traditional policies direct to augment the stock of regional capital by attracting manufacturing. As in the case of European experience (DURANTON and MONASTITIOTIS, 2002; OVERMAN and PUGA, 2002), this Brazilian mixed results have motivated a debate about the potential greater efficacy of more "spatial blind" policies specifically focused on improving the level of education of Brazilian population, with stronger influence on poorest regions (SILVEIRA NETO and MENEZES, 2008).

In Brazilian case, the argument for improving the level of regional education is based both on evidence obtained from micro data regressions analysis, where it is estimated the impact of schooling on regional labor income (SILVEIRA NETO and MENEZES, 2008; DUARTE *et al.*, 2004), and on aggregated variable growth regressions, where it is estimated the impact of an schooling variables on the regional per capita GDP level or growth (AZZONI *et al*. 2000, FERREIRA 2000, SILVEIRA NETO and AZZONI 2006, RESENDE 2011). This first approach presents the problem of the incapacity of adequately separating supply and demand factors that simultaneously affect the level of labor income in the regions. So, apart from the potential problem of reverse causality, by considering the levels of income, it is not sure that the effect of education does not capture part of the effect of the presence of capital. The growth regression evidence presents a similar problem: without exception, because of a non-utilization of a regional physical capital measure, the set of available evidence only consider the effect schooling on regional per capita GDP and, of course, does not generate a confident measure of the importance of education to regional growth.

Besides, apart from this problem of adequately consider both the influence of human and physical capital on Brazilian regional GDP growth, the evidence about the impact of these factors obtained from growth regression barely considers the presence of spatial dependence of the variables, which makes the estimative potentially biased (ANSELIN, 1988). As recently highlighted by ARBIA and PIRAS (2005), FINGLETON and LÓPEZ-BAZO (2006) and ELHORST *et al*. (2010), for the case of European regions, and REY and MONTOURIO (1999), for the American states, the dynamics of growth of geographic units are strongly associated to the dynamics of their spatial neighbors and, in order to correctly estimate the influence of growth determinants, this spatial dependence has to be to explicitly considered in the econometric model.

In fact the works of MAGALHÃES *et al*. (2005), SILVEIRA NETO and AZZONI (2006), RESENDE (2011) and ÖZYURT and DAUMAL (2013) are among the few exceptions in dealing with spatial dependence in regional growth regression in Brazilian case and these works confirm the importance of explicitly taking into account spatial dependence. None of these works for Brazilian regions, however, simultaneously use a spatial panel data and interpret adequately the estimated effects of the variables on regional per capita GDP or Income growth. More specifically, RESENDE *et al*. (2012) was the first to use a spatial panel data approach to measure the impact of schooling on regional income growth in Brazil, but the author does not consider simultaneously the influence of physical capital and, because he does not considers the role of regional spillovers, neither measure correctly the estimative of the influence of human capital variable on regional per capita Income. ÖZYURT and DAUMAL (2013), on the other hand, although correctly interpret the influence of the variables (including human capital and degree of regional openness) on regional per capita GDP, use only a cross section data structure in their work and a very short period of analysis (2004-2007). Both characteristics make their estimative for the importance of human capital much less reliable.

Given the above context and situation, the contribution of this paper is twofold. By considering a new robust measure of regional physical capital, we first simultaneously estimate the influence of physical and human capital to regional economic growth in Brazil using a spatial panel data base for the period 1970-2010. This permits a more precise control to the influence of time invariant factors that are potentially associated to each kind of capital. Until now there is not available information about the relative importance of these capitals for the Brazilian regional case. Second, to account to the spatial dependence and based on ERTUR and KOCH (2007) argument to spatial dependence of growth rates, we consider an empiric spatial panel econometric model (*Durbin Model*) that permits to measure the spatial spillovers potentially arising from regional growth and from the levels of regional utilization of both physical and human capital. The methodology not only makes possible to obtain unbiased estimative of the model's parameters in the presence of spatial dependence (ELHORST, 2003), but also, following the methodology of LESAGE and PACE (2009), to correctly interpret the estimated coefficients and the associated direct and indirect of the variables. Both contributions come together and enable a much more precise understood of the roles of physical and human capital for Brazilian regional income dynamic.

The main results of the paper indicate that there was strong positive spatial dependence among per capita income dynamic of Brazilian micro-regions between 1970 and 2010 and that both human and physical capital matter for understanding the Brazilian regional per capita income dynamic in this period. By calculating direct and indirect effects of the two kinds of capital, we also show that the spatial dependence imply that the coefficients estimated of the spatial panel growth regression underestimate the influence of these factors on Brazilian regional per capita income growth. Furthermore, at least for the measures of capital we have used, we found that the magnitudes of influence of both kinds of capital on Brazilian regional growth are very similar.

In addition to this introduction, the paper is structured on more four sections. In the next section, we present some review of Brazilian empirical literature about regional economic growth and human and physical capital. In the section three, we present the data and methodology of the paper. The results and discussion are presented in section four and the final remarks are in section five.

2. Regional growth, physical and human capitals and spatial dependence in Brazil

The works of FERREIRA (2000) and AZZONI (2001) can be considered pioneers in the study of determinants of regional growth in Brazil based on regressions with specifications derived from the traditional Neo-classical model of growth. Both investigations showed that the process of income convergence among Brazilian states appeared sensitive to the period of analysis and to the set of variables included in the regressions. But, besides using of a cross section data base structure, which does not allowed to consider the influence of the heterogeneity of state economies on its growth trajectory, these two articles present two additional limitations: they did not consider the spatial dependence of the state's growth rate trajectories, neither used a measure or proxy to the rate of saving or investment in physical capital.

Following the pioneer paper of REY and MOUNTOURI (1999), which used spatial growth regressions and identified the presence of positive spatial dependence among the economic growth rates of U.S. states, the works of MAGALHÃES *et al*. (2005) and SILVEIRA NETO and AZZONI (2005), still using a cross section of Brazilian states, have incorporated spatial dependence in the regressions of growth and also identified a positive spatial dependence among the rates of growth. In the same way, DE VREYER and SPIELVOGEL (2009), using a cross section of Brazilian municipalities, also showed that that the growth rate of neighboring economies and their initial levels of GDP per capita are important variables to explain the dynamics of income of a particular economy. RESENDE (2011) analyzes the Brazilian regional growth considering multiple geographic scales for the period 1991-2000 and shows that, regardless of geographic scale used, a good infrastructure and high levels of education and health capital are associated with higher rates of economic growth.

More recently, ÖZYURT and DAUMAL (2013) investigated the influence of international trade and human capital on GDP per capita of Brazilian micro-regions. The results show that although the opening to the international market is beneficial to a micro-region in particular, it ends up hurting the neighboring micro-regions, indicating that international trade can generate negative spillovers. Moreover, ÖZYURT and DAUMAL (2013) observed that human capital is important in explaining both the GDP per capita of a particular economy and the GDP per capita of neighboring economies. In other words, they found evidence of positive spillovers of human capital.

These empirical results to Brazilian regional growth appear consistent with recent theoretical extension of Neoclassical model proposed by LÓPEZ-BAZO *et al*. (2004) and ERTUR and KOCH (2007). In this context of economic dependence and based in the evidence obtained by KELLER (2002) that technological diffusion decreases with geographic distance between regions, LÓPEZ-BAZO *et al*. (2004) and ERTUR and KOCH (2007) proposed an extension to the Solow (1956) growth model and its extended version for human capital (MANKIW *et al*., 1992) that considers the technological interdependence among economies. One implication of the model proposed by ERTUR and KOCH (2007) is that both the characteristics of a specific economy (such as investment in physical and human capital) as the characteristics of neighboring economies are important in explaining regional economic growth.

In other words, ERTUR and KOCH (2007) point to the spillovers of physical and human capital as important variables to explain the growth of a particular economy.

By using only cross sections of Brazilian geographic unities, nevertheless, neither of these cited works for Brazilian regional experience allowed for the influence of the heterogeneity of the economies on its growth trajectory or on its GDP, nor considered any measure for the influence of physical capital on income growth or income level. As pointed out by ISLAM (1995), an appropriate way to allow heterogeneity in the production function of each economy is to estimate the growth regressions using panel models, which consider fixed and specific characteristics of each region (regional effects). From a methodological point of view, the estimation of panel models allows to separate the effects of variables included in the model (such as investment in physical and human capital) of the effects of unobservable characteristics (such as technology and institutional quality) and additionally reduces the bias of omitted variables fixed in time, potential sources of endogeneity. In the case of Brazilian regions, these specific regional effects appears important; as shown by AZZONI *et al*. (2000), the geographical characteristics (rainfall, temperature and latitude) of a Brazilian region are important in explaining differences in income levels and in the growth rates.

The first of these problems was addressed by NAKABASHI and SALVATO (2007) and CRAVO (2012) by considering a panel data structure of Brazilian regions. NAKABASHI and SALVATO (2007) work examined the role of human capital and CRAVO (2012) investigated the role of entrepreneurship on regional economic growth and found evidence that, respectively, human capital and entrepreneurship matters for regional growth. But, despite using more appropriated strategies to address the heterogeneity of economies (regional fixed effects), such studies ignored the possibility of spatial dependence among the growth rates and their determinants and again did not consider any measure of physical capital influencing the Brazilian regional growth.

Following the works of ARBIA and PIRAS (2005) and ELHORST *et al*. (2010) that consider a spatial panel approach to study regional growth, only the work of RESENDE *et al*. (2012) used this methodology to the Brazilian case. RESENDE *et al*. (2012) showed that, for Brazilian municipalities, micro-regions and meso-regions, there was a positive spatial dependence among the income growth of spatial regional unities even after considering specific regional fixed effects. Additionally, for the micro-regions, the authors found no evidence of the relationship between human capital (and its spillovers) in the regional economic growth

But the work of RESENDE *et al*. (2012) still presents two important limitations. The first one is that the role of physical capital is totally neglected. This limitation hampers the theoretical consistency of its empirical results, since the theory shows that both investment in physical capital as its potential spillovers are important in explaining the regional economic growth (ERTUR and KOCH, 2007). Note that, on one hand, under an econometric point of view, this limitation can biased the parameters of growth equations; on the other hand, under regional policy perspective, the limitation avoid to know the influence of physical capital on regional growth. The second limitation is that the article presents an inaccurate interpretation of the estimated parameters of the spatial models. As showed LESAGE and FISCHER (2008), when considering growth models that explicitly incorporate the influence of the growth of neighboring economies, it is necessary to calculate the direct impacts and indirect impacts to know the true effect of a marginal change in the independent variable, and to make inferences about the sign, magnitude and significance of the explanatory variables. As shown FISCHER (2011), the error of interpreting parameters of spatial models as models that do not consider the space (the usual regressions) can be very costly: the conclusions and implications of the empirical model can be changed in a meaningful way.

Thus, this paper aims to contribute to the debate on the Brazilian regional economic growth by directly addressing these limitations. Specifically, for studying Brazilian regional growth from 1970 to 2010, we explicitly consider both the role of human and physical capital in a spatial panel model that allows us to control both for spatial dependence and for unobservable factors that are fixed in time. This approach permits us to obtain more reliable estimative of the parameters of the theoretical model. Additionally, the correct interpretation of spatial parameters of this work allow us to generate more reliable evidence regarding the importance of both kinds of capital (physical ad human) and their potential spatial spillovers.

3. Theory, Methodology and Data

3.1 Theory and model empirical specification

From theoretical perspective, the empirical strategy is motivated by the recent extension of the Neoclassical growth model proposed by ERTUR and KOCH (2007), in which different economies interact through technological interdependence. Thus, there is a relaxation of the assumption of a closed economy, imposed in the SOLOW (1956) classical model and its main extensions. From this spatial extended version of the traditional growth model proposed by these authors, it is possible explicitly express not only the influence of both physical and human capital on economic growth of the regional, also to considers spatial spillovers arising from the levels of these factors of neighbors economies.

As a starting point, the Cobb-Douglas production function proposed by ERTUR and KOCH (2007) assume the traditional specification:

$$y_{it} = A_{it} k_{it}^{\alpha} h_{it}^{\beta} \quad , \qquad (1)$$

where y_{it} is the per capita output for the specific region "i" at time "t", A_{it} is the aggregate level of technology, k_{it} is the stock of physical capital per worker and h_{it} is the stock of human capital per worker. The spatial interactions among economies are introduced though the level of technology as follows:

$$A_{it} = \Omega_t h_{it}^{\omega} k_{it}^{\phi} \prod_{j \neq i}^{N} A_{jt}^{\rho w_{ij}} \qquad (2)$$

Where Ω_t is the amount of technology ever created in the world and available for any region and grows at an exogenous rate μ, so that $\Omega_t = \Omega_0 e^{\mu t}$, where Ω_0 is the initial level of exogenous knowledge. Furthermore, it is assumed that the level of technology also depends on the cumulative production factors, that is, economies with higher levels of physical and human capital experience a higher degree of technology, like a learning-by-doing process (ROMER, 1986; LUCAS, 1988). The parameters ω and ϕ represent the magnitude of the externalities generated by human capital and physical capital, respectively.

The last term of the expression shows the technological interdependence among economies, so that the technical progress in a particular region depends positively on technology level from other regions, $j \neq i$, for $j = 1, \ldots, N$. The parameter ρ measures the overall degree of interdependence and w_{ij} are the spatial weights and represent the connectivity between the region "i" and region "j". These terms are assumed non-stochastic, non-negative and finite. It is assumed that: $0 \leq w_{ij} \leq 1$ and, incorporating empirical evidence of KELLER (2002) that technological diffusion between two distinct regions decreases with geographic distance, it is supposed that the closer the region "i" is for region "j", the greater will be the term w_{ij}. Thus, economies more nearby from economy "i", will influence them (in terms of technological diffusion) in a more significantly manner.

To find the level of output per capita in steady state and consequently study the dynamics of economic growth when there is technological interdependence, it is necessary to consider the laws of motion for physical and human capital. These laws of motion follow traditional specifications and show how the physical and human capital accumulates considering a rate of investment in physical capital, s_{it}^{K}, a rate of investment in human capital, s_{it}^{H}, the depreciation rate of capital (for simplicity, it is assumed that the rate of depreciation of physical and human capital are equal), δ, and the rate of population growth, n_{it}. From equation (1) and these laws of motions, it is possible to express the rate of growth of a region as:

$$\begin{aligned} g_{it} = {} & \beta_0 + \beta_1 \ln(y_{i0}) + \beta_2 \ln\left(s_{it}^{k}\right) + \beta_3 \ln\left(s_{it}^{h}\right) + \beta_4 \ln(\delta + \psi + n_{it}) \\ & + \theta_1 \sum_{j \neq i}^{N} w_{ij} \ln s_{jt}^{k} + \theta_2 \sum_{j \neq i}^{N} w_{ij} \ln s_{jt}^{h} \\ & + \theta_3 \sum_{j \neq i}^{N} w_{ij} \ln(\delta + \psi + n_{it}) + \theta_4 \sum_{j \neq i}^{N} w_{ij} \ln\left(y_{j0}\right) + \rho \sum_{j \neq i}^{N} w_{ij} g_{jt} \\ & + \eta\, \Omega_t \end{aligned} \qquad (3)$$

Where ψ is the growth rate of physical and human capital in the steady state, g_{it} is the growth rate of per capita output for economy “i” at time “t”, g_{jt} is the growth rate of per capita output for neighbor regions and β_s (s = 0, 1, 2, 3, 4), θ_s (s = 1, 2, 3, 4) and η are combinations of parameters of the model. It is interesting to note that if $\rho = \omega = \phi = 0$, technology in the region "i" is just relying on exogenous term, so that equation (3) becomes the traditional convergence equation of MANKIW *et al*. (1992). As can be observed from equation (3), that the growth rate of the economy “i” depends positively of the degree of investment in human capital and physical capital and negatively of the rate of population growth and its initial level of income, as indicated by the model of MANKIW *et al*. (1992). But now, given the assumed interactions expressed in equation (2), the economic growth also come to depend positively of the investment in physical capital, human capital and the rate of output growth in neighboring regions and negatively of the rate of population growth and initial income of neighbors.

From an empirical point of view, there are two important issues relating to equation (3). Firstly, as argued MANKIW *et al*. (1992), the term Ω_t can represent not only the degree of technology, as well as endowment resources, institutions and climate, and so may differ between different economies. As this variable is not observable, it is considered at the error term ($\eta\Omega_t = \varepsilon_{it}$) of empirical model. To proceed with the estimation of equation (3) using ordinary last squares (OLS), the identification assumption that ε_{it} is independent of the variables included in the model is required, but this kind of assumptions sounds too strong. For example, it is unconvincing to argue that the level of capital investment in an economy is not somehow related to its institutional quality. As argued by ISLAM (1995), an appropriate way to solve this problem is to use panel models and consider the existence of a regional effect (μ_i) in the unobservable term ($\eta\Omega_t = \mu_i + \varepsilon_{it}$) that is correlated with the variables included in the model.

The second issue relates to the interpretation of the parameters β_s and θ_s, where $s = 1, \ldots, 4$, of this spatial extended model. Note that, due to spatial interactions that imply feedbacks arising from the changes in production factors and technology, we now have the initial income, the rate of growth, human capital and physical capital variables of neighbors economies in the right side of equation (3). So, the marginal effects of the changes of variables on the rate of growth of the regions are not any more given by the estimative of β_s, but by a combination of parameters involving β_s, θ_s and ρ. To make this point clearer, we rewrite equation (3) in matrix form and explicitly consider the panel data structure of our data through a regional effect (μ) in the unobservable term:

$$y = \rho(I_t \otimes W)y + (I_t \otimes W)X\theta + X\beta + (\iota \otimes I_n)\mu + \varepsilon \quad (4)$$

Where y is a vector $nt \times 1$ of observations of per capita income growth rate of "n" regions for "t" periods of time, X is a matrix of explanatory variables (initial income level, investment in human and physical capital and population growth) of length $nt \times K$, W is a matrix $n \times n$ of spatial weights, ρ is the coefficient of spatial correlation, I_t is a identity matrix $t \times t$, I_n is a identity matrix $n \times n$, ι is a vector $t \times 1$ of ones, μ is a vector of unobserved specific characteristic of each region of dimension $n \times 1$ and ε is a vector $nt \times 1$ of idiosyncratic errors with $\varepsilon \sim N(0, \sigma_\varepsilon^2)$. We will suppose that the vector ε is uncorrelated with explanatory variables and with vector μ. The symbol $\otimes$ represents the Kronecker product. This model, a non-deterministic version of equation (3), includes explicit spatial dependence in both dependent and explanatory variables and is known in the literature of spatial econometrics by Spatial Durbin Model (SDM).

It is assumed that each element μ_i of vector μ is an unobserved singular characteristic of a particular region "i", which is constant in the time and is correlated with the explanatory variables included in the model, the elements of μ are known as regional fixed effects. According to ISLAM (1995), these assumptions are appropriate in the context of economic growth models. For example, we can interpret μ_i as a measure of institutions of a particular region. Institutions are a classic example of a feature that is fairly independent of time, which is not observed and that has relation with characteristics observed and included in the model. When considering the regional effects, we will be reducing the bias of omitted variables, and consequently, obtaining more reliable estimators. Another advantage of using panel models with fixed effects is that if there are distinct regions with the same inputs, the rate of growth of per capita GDP of these regions will be different due to the inclusion of the parameter μ_i. Therefore, the use of panel models allows the existence of heterogeneous production functions. Moreover, BALTALGI (2005) argues that panel data showed a larger variability, a lower degree of collinearity between variables and provide more efficient estimators.

Thus, the approach of spatial panel models enables us to control simultaneously for spatial dependence and for unobserved fixed effects, potential sources of endogeneity (ARBIA and PIRAS, 2005). Therefore, through this methodology, we can verify the existence of spatial spillovers arising from physical and human capital and analyze the dynamics of income with non-biased and consistent estimators. The traditional (and strong) assumptions of closed economies and homogenous productions functions imposed in the cross-sectional growth studies are relaxed.

With the objective of estimating equation (4), we use the suggestion of ELHORST (2003) of transforming the variables (that is made by subtracting the average time for each observation in cross-section) in order to eliminate the fixed-effects. As suggested by LESAGE and PACE (2009) and ELHORST (2003), the parameter $\hat{\rho}$ can be obtained by a concentrated[i] likelihood function, and then substituted in likelihood function to obtain the values of θ, β and σ_ε^2.

As we argued, due to spatial dynamic incorporating in the equation (3), a marginal change in the explanatory variable of region "i" can affect not only the income growth of region "i", but can affect the growth of all other regions, $i \neq i$, for $j = 1, \ldots, N$. To interpret the parameters obtained from a SDM, consider the reduced form of equation (4):

$$y = [I_{nt} - \rho(I_t \otimes W)]^{-1}[(I_t \otimes W)X\theta + X\beta + (\iota \otimes I_n)\mu + \varepsilon] \quad (5)$$

Taking the partial derivative of y with respect of the explanatory variable "r", we get the following expression:

$$\frac{\partial y}{\partial X_r} = [I_{nt} - \rho(I_t \otimes W)]^{-1}[(I_t \otimes W)\theta_r + I_{nt}\beta_r] \quad (6)$$

The resulting expression is a matrix of dimension $nt \times nt$. The elements of main diagonal of the matrix (6) reflects the effects of a change in y_i in response to variations of the explanatory variables of the same region x_{ir}, these own-partial derivatives are known direct impact[ii]. The elements outside the diagonal of the matrix (6), reflects the effects of a change in y_i in response to variations of the explanatory variables of different regions, x_{jr} , $j \neq i$. These cross-partial derivatives are known indirect impacts or spillovers effects. As the direct and indirect impacts can vary according to regions/observations, LESAGE and PACE (2009) proposed a measure of the direct and indirect effects that correspond to average of elements, respectively, in and out of main diagonal of the matrix (6).

3.2 Data and spatial matrices

To estimate the parameters of the model specification of equation (4), it is necessary to find adequate ways to regionally measure GDP per capita, investment in physical and human capital and population growth rate. For this proposal, we used official data of Brazilian Demographic Census of 1970, 1980, 1991, 2000 and 2010, produced by the IBGE (Brazilian Institute of Geography and Statistics), and processed by IPEADATA (Institute of Applied Economic Research), a Brazilian government institute.

We use Brazilian micro-regions as the spatial scale[iii] to be analyzed. The micro-regions are formed by a group of adjacent municipalities and were defined according to similar characteristics in relation to the agricultural, mining and industrial production structure, where social factors are also taken into consideration. (MAGNAGO, 1995). An alternative would be to choose larger geographical units (states or meso-regions), however, apart from the more reduced number of observations, states and meso-regions are include localities with very different economic characteristics, which makes the analysis of regional growth less accurate.

In Brazil, there is a problem associated to creation of new municipalities[iv] and, as the micro-regions are sets of adjacent municipalities, these are also subject to changes in their geographical areas. To solve this issue, we adopted the same approach adopted by RESENDE *et al*. (2012); specifically, the micro-regions analyzed were constructed from the aggregation of data obtained from minimum comparable areas[v] (MCAs), which generated a sample of 522 micro-regions with constant bordering in time.

Regarding the variables, we used the *total income*, which corresponds to the sum of gross income from all sources, as a proxy for GDP (gross domestic product) of the micro-regions. Ideally use GDP, but this variable was not calculated in 1991. In any case, as shown by MENEZES *et al*. (2012), the regional dynamics of variation of these aggregates is quite similar. To calculate the annual growth rate of per capita income (the dependent variable), we assume exponential income growth. The total income was deflated by the INPC (national consumer price index from IBGE) to real (R$) in 2000. As a proxy for human capital, we used the *average years of schooling of the population over 25 years old*, who reside in a given micro-region. In relation to proxy for physical capital, we use the *stock of residential capital*, which corresponds to this constant perpetual flow of rents discounted at a discount rate of 0.75% per month value, deflated by IGP (general price index) to thousand reais in 2000.

In order to verify the accuracy of this last variable as a measure of physical capital, BARROS *et al*. (2013) calculated the correlation of it with the others measures for physical capital, only available for more aggregated geographic unities: measures of gross fixed capital (available at the national level) and of consumption of industry electric power (available at the state level). Table 1 shows the correlation coefficients between the stock of residential capital and each of other measures of physical capital. As it can be noted from table 1, the residential capital is strongly correlated with all others measures of physical capital. As argued by BARROS *et al*. (2013), as the marginal product of capital tends to be the same in different segments, it is expected that that regions that have a larger stock of residential physical capital are the same that have a larger stock of nonresidential fixed capital.

Table 1 – Correlation between the stock of residential capital and commonly proxies of physical capital

Variables	Correlation Coefficient
Gross fixed capital – Nonresidential building	0,9649
Gross fixed capital – Machinery and equipment	0,847
Gross fixed capital – total	0,9424
Industrial electric power consumption – 1970	0,9372
Industrial electric power consumption – 1980	0,9433
Industrial electric power consumption – 1991	0,937
Industrial electric power consumption – 2000	0,9445

Source: Ipeadata and BARROS *et al*. (2013). Note: for the gross fixed capital (Nonresidential building, Machinery and equipment and total), the coefficient was calculated using national information from 1970 to 2000; for the industrial electric power consumption, the coefficient was calculated using information of states.

Population data are readily available and were obtained from IPEADATA. Following MANKIW *et al*. (1992), ISLAM (1995), FISCHER (2011), among others, we assume that the sum of the rate of technological growth with the rate of depreciation is equal to 0.05 for all the micro-regions in analysis.

Regarding the spatial weight matrices used to capture the spatial relationships between neighboring economies, we initially use the more traditional normalized *Queen matrix* (W1), where $w_{ij} = 1$ if the regions share a common border, and otherwise $w_{ij} = 0$. LESAGE and PACE (2010) argue that it is a myth to believe that the estimates and inferences of spatial regressions are conditioned by the choice of a particular structure for the matrix. These authors show that when the model is interpreted appropriately (considering the direct and indirect impacts), the results regarding the estimation and inference do not vary significantly. We adopt a more flexible approach and, for robustness checks, also consider the *4^{th} nearest neighbors matrix* (W2) and *8^{th} nearest neighbors matrix* (W3). These matrices incorporates the fact that regions with greater geographical proximity will receive a higher weight, which is consistent with the hypothesis of Keller (2002), that the higher the geographical proximity between two regions, the higher the interdependence (technology) in between.

4. Results

4.1 Descriptive Statistics and Model Estimation

In this section, we present evidence about the influence of both physical and human capital to regional growth in Brazil using a spatial panel data empirical model that explicitly also considers the characteristics of neighboring regions (ERTUR and KOCH, 2007). From Brazilian Demographic Census of the years 1970, 1980, 1991, 2000, and 2010, it is possible to build four time periods for per capita income variations. The time periods and the average values of the variables used in the regressions are displayed in the following table 2.

Table 2 – Descriptive Statistics of the variables

	1970-1980		1980-1991		1991-2000		2000-2010	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Income growth	0.091	0.019	-0.015	0.014	0.065	0.016	0.070	0.021
Human capital	0.256	0.618	0.711	0.553	1.160	0.433	1.451	0.329
Physical capital	0.542	0.700	0.804	0.725	0.825	0.712	1.281	0.635
Income	0.050	0.029	0.127	0.070	0.108	0.061	0.195	0.106
Popul. Growth	0.018	0.025	0.016	0.019	0.012	0.012	0.010	0.009

Source: Brazilian Demographic Census of 1970, 1980, 1991, 2000, and 2010. SD corresponds to the standard deviation. Income growth refers to annualized per capita income relative variation and Income refers to initial level of the log. of per capita income of the micro-regions; Human capital, and Physical capital correspond to the logarithmic of the initial values of the respective variable; Popul. growth refers to annualized relative variation of the micro-region population.

From the numbers of table 2, we note higher growth of per capita income during the periods 1970-1980 and 2000-2010 than for the other two periods. The lower income growth of the periods of 1980-1991 and 1991-2000 coincided with periods of very high inflation and macroeconomic instability (BAER, 2001). We also note that the mean of both human capital variable (*average years of schooling of the population over 25 years old*) and the physical capital proxy (*stock of residential capital*) presented positive growth between the periods. As for the population growth, we notice that it presented a monotonic decrease.

Table 3 presents the estimative of the parameters of equation (4), the spatial Durbin with fixed effects. The explanatory variables are in logarithm format and, for eliminate the endogeneity by simultaneity, we use the explanatory variables in their initial values (t) while the growth of per capita income (dependent variable) is given between the time (t) and (t +1). Table 3 also shows the t-values associated with each parameter. In order to obtain consistent estimators for the variance parameters of the spatial models, we use the bias correction proposed by LEE and YU (2010). Column 1 presents the results of estimating the empirical model without considering the space and the role of physical capital, i.e., equation (3) by imposing the restriction that $\alpha = \rho = \omega = \phi = 0$. Column (2) presents the classical model of MANKIW *et al*. (1992), which disregards any interaction between economies, such that $\rho = \omega = \phi = 0$.

Column (3) presents a panel version of the ERTUR and KOCH (2007) model without the physical capital $\alpha = \phi = 0$ and Column 4 shows the complete version of the model (without any restrictions). Regarding non-spatial models (columns (1) and (2)), we notice that the variables included have the sign predicted by the theoretical model. Moreover, the inclusion of physical capital as an explanatory variable improves the fit of the model (as seen by the adjusted R), a result that reinforces our measure of physical capital (residential capital) as an appropriate proxy. Additionally, the inclusion of investment in physical capital also diminishes the importance of human capital (as can be seen by the reduction of human capital coefficient), increases the speed of convergence of the economy and allows a better control to investigate the role of population growth in regional growth. These results indicate that the omission of the physical variable reduces not only the theoretical consistency of the empirical model, but also brings a strong bias in the estimators[vi].

Table 3 – Determinants of Brazilian regional growth - Panel estimative - Dependent variable is the growth of per capita income.

	Non-Spatial Panel (1)	Non-Spatial Panel (2)	SDM Panel (3)	SDM Panel (4)
ρ	-	-	0.828**	0.808**
			(71.55)	(65.93)
Per capita income	-0.109**	-0.151**	-0.024**	-0.030**
	(-40.57)	(-48.72)	(-13.95)	(-14.14)
Human capital	0.096**	0.079**	0.022**	0.021**
	(33.22)	(29.31)	(12.77)	(12.67)
Physical capital	-	0.103**	-	0.010**
		(21.10)		(4.54)
Popul. Growth	-0.110	-0.250**	-0.050*	-0.070**
	(-1.62)	(-4.10)	(-2.01)	(-2.57)
W Per capita Inc.	-	-	0.005*	0.004
			(2.51)	(1.58)
W Human capital	-	-	-0.004*	-0.005*
			(-1.96)	(-2.21)
W Physical capital	-	-	-	0.002
				(1.03)
W Popul. Growth	-	-	0.025	0.019
			(0.56)	(0.44)
R	0.51	0.62	-	-
Adjusted R	0.36	0.46	-	-
LogLik	-	-	735.27	744.34
Akaike Criterion (AIC)	-	-	-1456.5	-1470.7
Scharz Criterion (BIC)	-	-	-1447.3	-1458.8
Number of observations	2088	2088	2088	2088

Source: Author's estimative. The variables W Per capita Inc., W Human capital, W Physical capital and W Popul. growth correspond to lag spatial variables, respectively, of initial per capita income, human capital, physical capital and the population growth. "**" and "*" indicate statistical significance at, respectively, 1% and 5%. The non-spatial models were estimated by *within* estimator and the spatial models were estimated by maximum likelihood.

Column (3) and (4) shows the SDM with fixed effects, the estimations were obtained with the *Queen* matrix, which, according with the measures of goodness of fit (log-likelihood, Akaike and Scharz Criterion), provides the best fit over the others spatial matrix considered (4th and 8th nearest neighbors). As can be observed, the spatial model that includes investment in physical capital (column (4)) has a better fit to the data. Thus, all subsequent analyzes will be based on this model, the full version of the model proposed by ERTUR and KOCH (2007), equation (4), with the *Queen* matrix.

Firstly, we can observe that the parameter of spatial dependence (ρ) is high and statistically significant, indicating that the higher (lower) is the growth rate of neighboring micro-regions, higher (lower) is the growth rate of a particular micro-region. These findings show that Brazilian micro-regions cannot be treated as independent economies and reveals that the location of an economy is important for defining its growth trajectory. Under an econometric point of view, to ignore this kind of spatial dependence generates an omitted variable bias and leading to inconsistency of the estimators.

As emphasized in the last section, in the presence of spatial dependence thought the dependent variable, that implies spatial feedbacks effects arising from the variation of the determinants of micro-region growth, the estimative of coefficients do not represent marginal effects of the explicative variables on the dependent variables. So, to obtain measures of the impacts of the variables on the growth of Brazilian micro-regions, we follow the suggestion of LESAGE and PACE (2009) and use the estimative of the coefficients of table 3 in the expression (6). The estimated impacts are presented[vii] in Table 4.

Table 4 – Direct and Indirect impacts of the variables on regional growth

	Direct	Indirect	Total
Per capita income	-0,037**	-0,101**	-0,138**
	(-15,108)	(-7,223)	(-9,02)
Human capital	0,024**	0,055**	0,079**
	(11,858)	(3,900)	(5,144)
Physical capital	0,013**	0,053**	0,067**
	(4,809)	(3,638)	(4,236)
Popul. Growth	-0,083*	-0,187	-0,271
	(-2,260)	(-0,778)	(-1,001)

Source: Author's estimative. The numbers of ythe table are obtained using the matrix W1 (*Queen*). The standardized deviations and *z* values are obtained by simulation, assuming normal distribution "**" and "*" indicate statistical significance at, respectively, 1% and 5%.

From Table 4, we can observe that all the effects of the variables have the predicted signs by the theoretical model of ERTUR and KOCH (2007). It is noteworthy that the indirect impacts are statistically significant, indicating that the characteristics of neighboring economies (per capita income and investment in human and physical capital) are important to explain the process of economic growth in a particular economy. These spatial spillovers represent further evidence of about the importance of correctly interpreting the estimative of the coefficients of the regressions[viii].

It is interesting to note that the indirect impacts have a higher magnitude than the direct impacts, which is completely feasible, as argued by LESAGE and FISCHER (2008). As the average indirect impact is calculated as a change in the explanatory variable of *all neighbors* on the dependent variable of region "i", is perfectly plausible that this is higher than the direct impact, when the spatial interaction parameter (ρ) is high. Moreover, the difference between the estimates of the direct impact and the respective coefficients of the SDM (Table 3, column 4) is due to feedback effects.

Regarding the initial level of per capita income, table 4 shows that economy that is richer and has richer neighbors tend to have lower growth rates in the future, an indication that the hypothesis of conditional convergence holds. Specifically, a 1% increase in per capita income of an economy in the initial period leads to a reduction in its growth rate 0.037 percentage points, while a 1% increase in initial income of all the neighboring regions leads to a reduction of 0.101 percentage point. While such negative spillovers may appear to be contradictory, they are a natural consequence of the process of convergence: economies that have high levels of income, tend to have low rates of economic growth, and due to positive spatial dependence, these economies generate negative effects in the growth of surrounding regions.

Table 4 shows that there are indeed, the presence of positive spillovers of human and physical capital (as the indirect impacts are positive and statistically significant). Thus, the micro-regions that has neighbors with high rates of investment in physical and human capital end up being benefited. In the light of the theoretical model developed in section 3, higher levels of investment in physical and human capital generate a larger stock of technology (learning-by-doing*)* for a given economy. Due to technological interdependence described by ERTUR and KOCH (2007), equation (2), this additional technology stocks in a given region flows into neighboring regions, causing higher rates of economic growth for them. With respect to the magnitude of the direct and indirect impacts, it is observed that an increase of one standard deviation in investment in human and physical capital of an economy generate similar variations in growth, while the second presents a slightly greater impact[ix]. In relation to the investment of neighboring economies, physical capital ends up being relatively more beneficial for the surrounding economies[x]. One possible reason for this is that physical capital is related to infrastructure, which unlike human capital, is often non-excludable and non-rival, and so, benefits the neighborhood with a higher degree of intensity. Thus, these results indicate that investment in physical capital contributes more significantly to both economic growth itself and to the growth of neighboring micro-regions.

Finally, Table 4 also shows that the direct impact of population growth is negative and statistically significant, a result that is consistent with theoretical models of growth. However, the indirect impact of population growth is not significant; indicating that the increase in rates of population growth in neighboring economies does not cause changes in the rate of economic growth of an economy, i.e. there is no spatial spillovers.

4.2 Regions fixed effects

From the estimative of model parameters, it is possible to obtain the micro-regions fixed effects. These effects represent time invariant characteristics of the localities that affect their economic growth during the period 1970-2010. Although it is not possible here to know exactly what these effects capture (the range of factors goes from geographic to persistent institutional characteristics), this set of evidence can reveal the consistency of certain known time invariant favorable and unfavorable characteristics of Brazilian localities as determinants of economic performance or suggest unknown spatial regularities the matters for the growth of the localities.

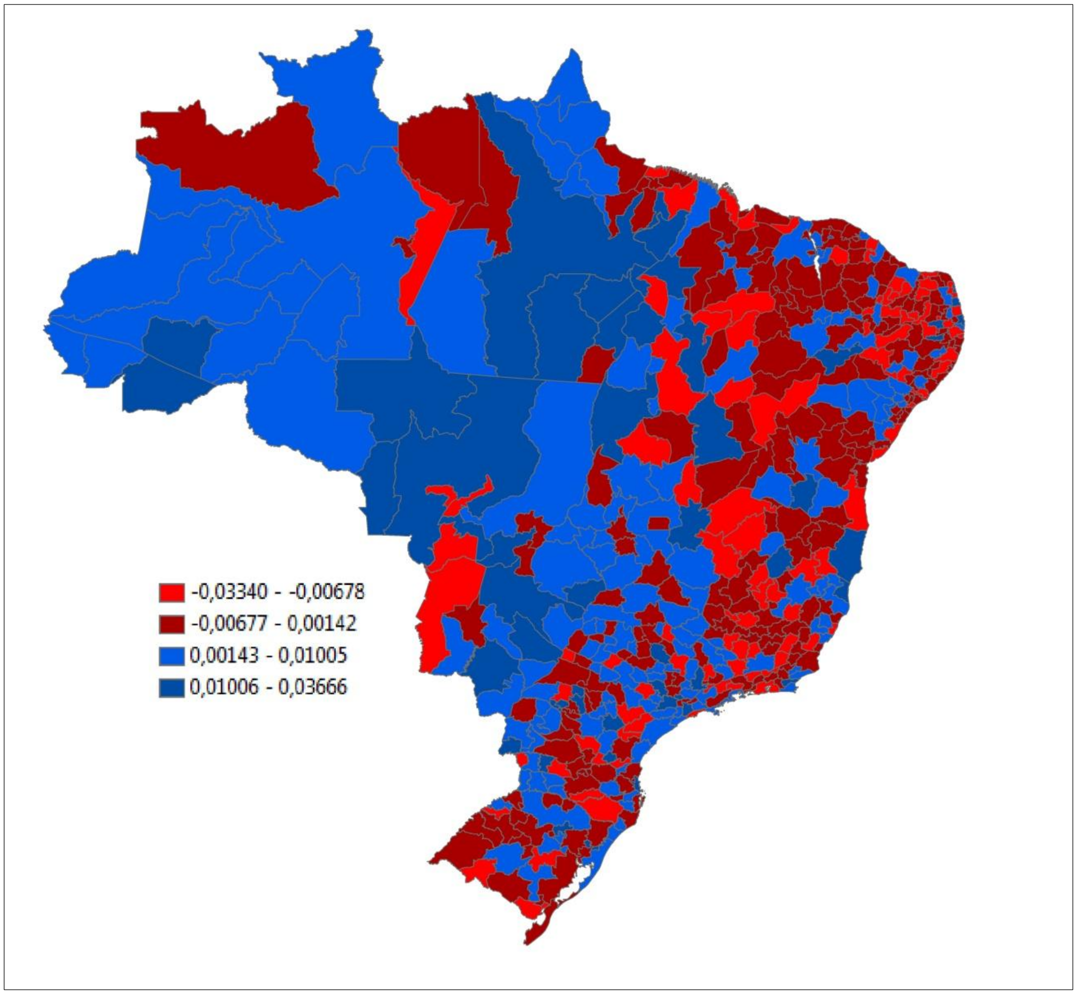
To obtain each Brazilian micro region fixed effect, we use the parameters estimative of the econometric model (vector β,θ and the spatial coefficient ρ) and the data in following expression:

$$\mu_i = \frac{1}{T}\sum_{t=1}^{T}\left(y_{it} - \rho\sum_{j=1}^{N} w_{ij}y_{jt} - x_{1it}\beta_1 \ldots - x_{kit}\beta_k - \sum_{j=1}^{N} w_{ij}x_{1jt}\theta_1 \ldots - \sum_{j=1}^{N} w_{ij}x_{kjt}\theta_k \right) \quad (7)$$

where μ_i is the fixed effect of the region i, y_{it} is the rate of growth of the region i in the period t, y_{jt} is the rate of growth of the neighbor region j, x_{kit} is the explicative variable k of the region i and β_k is its coefficient, x_{kjt} is the explicative variable k of the neighbor region j and θ_k is its coefficient.

The results are presented though the following map of figure 1. There are at least two set of evidence that deserve to be highlighted. First, the fixed effects estimative indicate a much favorable situation for the micro regions located in North and, mainly, in Mid-West regions of Brazil. More specifically, confirming the visual apprehension, we registry that 69.0% of the micro regions located in Mid-West and 61.0% of the micro regions locate in Brazilian North macro region present fixed effects in the two most favorable categories of the figure. On the other hand, there is clear negative featured: only around 27% of micro regions located in Brazilian Northeast macro region present fixed effects in these two most favorable categories. Second, we also note that the magnitude of these fixed effects influence is far from negligible. According to the estimative, the range of the effects on economic growth are situated between -3,34% and 3,66%, and this last value is approximately equivalent to the expansion of a standardized deviation of human capital variable.

Figure 1 –Fixed effects of Brazilian micro-regions



Source: Author's estimative. The estimative are obtained using the estimative of the parameters of the model (4) of table 3.

Of course, we cannot be sure about the explanations to these results, but we just notice that they are consistent with one of most notable economic fact about Brazilian regional growth between 1970 and 2010: the above of mean performance of the most of micro-regions of Brazilian Mid-West (of its micro region have grew above of national average). As these micro regions present stronger dependence on the production of the exportation agriculture sector that use the factor land, which quality is not explicitly considered during the estimative, this characteristic of Brazilian regional growth appears to be captured by micro-regional fixed effects. On the other hand, these effects also can potentially capture the worst physical geographic conditions associated to semi-arid climate present in the most of micro-regions of Brazilian Northeast.

5. Conclusions

The High and persistent regional income inequality in Brazil has motived different kinds of policies to attenuate its regional disequilibrium. Traditionally, these policies were based on improving the physical capital stock of poorer regions by spatial directing public investment and by conceding manufacturing capital subsides. More recently, federal policies are relying on different kinds of spatial blind policies as social programs of cash transfers and, mainly, schooling expansion. Although of the different focus of these two kinds of policies, both intend to expand per capita income of the Brazilian poorest regions. This works is the first to provide evidence of the influence of both physical capital and human capital to the regional to Brazilian regional per capita income growth during the period 1970-2010 using a panel data approach and explicitly allowing to the possibility of spatial spillovers arising from the levels of physical capital and human capital.

Besides to control to the influence of (omitted) fixed effects of the regions on their economic growth, the empirical approach adopted allows to the influence of neighbors regions variables on the per capita income growth of a specific region and provides precise measures of the influence of human capital and physical capital on economic growth that account to the potential spatial interdependence among the Brazilian micro-regions. Furthermore, these measures allow us to identify spatial spillovers arising from specific regional variables.

The set of results indicates that both physical capital and human capital matter in explaining micro-regional economic growth during the period 1970-2010 and, at least for the variables we used for capturing the influence of these factors, the magnitude of the influence of these two factors are similar. But the set of evidence also shows very strong spatial dependence among the economic growth of Brazilian micro-regions and so that the influence of human capital and physical capital derives not only from own levels of investment in these two kinds of capital, but also and importantly come from the influence of neighbors micro-regions investments. In other words, there were significant spatial spillovers associated to the investment in both physical capital and human capital that substantively and positively affect the economic growth of Brazilian micro-regions. Thus, in Brazilian regional growth, the micro-regions tend to benefice from the higher levels of investment in human capital and physical capital of their neighbors micro-regions and not only from their own investment. The approach we used could provide a measure of the impacts of these capitals that considered not only the micro-regions own investment, but also the impact of investments of their neighbors micro-regions.

We also note that the estimated micro-regional fixed effects are quantitatively important for explaining economic growth of Brazilian micro-regions, which means that time invariant characteristics for understanding economic performance of these micro-regions. Furthermore, the identified values of these fixed effects are consistent with the omitted fixed factos represented by the quality of land and the agriculture expansions of the micro-regions located in Brazilian Mid-West, on one hand, and by the less favorable geographic conditions of most of Brazilian micro-regions located in Northeast, on the other.

Over all, the set of results provide not only empirical support for the importance of the investment in both physical and human capital to regional growth in Brazilian, but also makes clear that the benefits of these investments tend to spillover to neighbor regions. This last result is important because the micro-regions should not necessarily compete with its neighbors for attraction of manufacturing investment and highlights the importance of the coordination of federal government in the process.

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Appendix A: Impact estimates with W2 and W3 matrix

Table A.1 – Direct and Indirect impacts with W2 matrix

	Direct	Indirect	Total
Per capita income	-0,041**	-0,105**	-0,146**
	(-16,706)	(-8,617)	(-10,759)
Human capital	0,026**	0,062**	0,088**
	(12,774)	(5,129)	(6,543)
Physical capital	0,017**	0,052**	0,070**
	(5,668)	(4,14)	(4,601)
Popul. Growth	-0,101**	-0,376	-0,477
	(-2,639)	(-1,769)	(-1,958)

Source: Author's estimative. The numbers of ythe table are obtained using the matrix W2 (*4th nearest neighbors*). The standardized deviations and *z* values are obtained by simulation, assuming normal distribution "**" and "*" indicate statistical significance at, respectively, 1% and 5%.

Table A.2 – Direct and Indirect impacts with W3 matrix

	Direct	Indirect	Total
Per capita income	-0,030**	-0,106**	-0,137**
	(-12,530)	(-4,830)	(-5,87)
Human capital	0,020**	0,077**	0,098**
	(10,520)	(3,550)	(4,281)
Physical capital	0,008*	0,032*	0,041**
	(2,490)	(1,980)	(2,120)
Popul. Growth	-0,077*	-0,385	-0,462
	(-2,21)	(-1,062)	(-1,194)

Source: Author's estimative. The numbers of ythe table are obtained using the matrix W3 (*8th nearest neighbors*). The standardized deviations and *z* values are obtained by simulation, assuming normal distribution "**" and "*" indicate statistical significance at, respectively, 1% and 5%.

Notes

[i] For details about the estimation, see ELHORST (2003) or MILLO and PIRAS (2012).

[ii] These direct impacts include the *feedback effects*: a change in x_{ir} causes not only an effect on y_i but also an effect on y_j which in turn causes a second change in the variable y_i.

[iii] The Brazil can be divided into political-administrative regions: 27 states and 5.570 municipalities or functional regions: 5 macro-regions, 137 meso-regions and 558 micro-regions.

[iv] For example, the number of municipalities increased from 3.920 in 1970 to 5.570 in 2013.

[v] The minimum comparable areas (MCAs) are municipalities that have a constant boundary in the time period 1970-2010 (Reis et al. 2005)

[vi] These conclusions are also valid when we consider the spatial models (column (3) and (4)).

[vii] The estimates of impacts for W2 and W3 matrix can be found in Appendix 1. The results were robust to any type of matrix used, a result in line with the study by LESAGE and PACE (2010).

[viii] If we interpret the coefficients based on the estimation of the SDM (column 4 of Table 2), we could conclude that there are negative spillovers of human capital and absence of spillovers for physical capital, a widely divergent conclusions.

[ix] The one-unit increase in the standard deviation of the logarithm of physical capital (0.63 in 2000) raises the growth of the economy in 0.0082 percentage points, while a one unit increase in the standard deviation of the logarithm of human capital (0.32 in 2000) elevates in 0.0079 percentage points.

[x] An increase of one unit of standard deviation of the logarithm of physical capital of neighboring economies $j \neq i$ (0.55 in 2000) raises the growth rate of the economy i in 0.029 percentage points, while a one-unit increase in the standard deviation of the logarithm of human capital of neighboring $j \neq i$ (0.27 in 2000) increases the growth rate of economy i in 0.014 percentage points.