Physical and Human Capital and Brazilian Regional Growth: A Spatial Econometric Approach for the Period 1970-2010

Ricardo Carvalho de Andrade Lima - PIMES (UFPE)
Raul da Mota Silveira Neto – PIMES (UFPE)

Resumo
O objetivo do trabalho é identificar os determinantes do crescimento econômico e analisar a dinâmica de renda considerando um painel para o período de 1970-2010 com 522 microrregiões brasileiras. Para tal, a pesquisa estima os parâmetros de um *Spatial Durbin Model* (SDM) com efeitos-fixos derivado diretamente de uma expansão do modelo teórico de Mankiw-Romer-Weil (MRW) que, além de considerar explicitamente o capital físico e humano, incorpora dependência espacial com respeito à tecnologia. Para mensurar o impacto das variáveis sobre o crescimento regional, são calculados os impactos diretos e indiretos (*spillovers*). Além de indicarem forte dependência espacial entre as taxas de crescimento das microrregiões brasileiras, os resultados também indicam que tanto o investimento em capital físico, quanto o investimento em capital humano importam não só para o crescimento da própria economia, mas também para o crescimento de economias vizinhas.

Palavras-Chave: Crescimento Econômico, *Spillovers* Espaciais, Painel Espacial, Convergência de renda.

Abstract
The aim of this paper is to identify the determinants of economic growth and analyse the dynamics of income using a panel of 522 Brazilian micro-regions for period 1970-2010. Based on the spatial extension of the Mankiw-Romer-Weil (MRW) model and explicitly considering both physical and human capital, the parameters of a Spatial Durbin Model (SDM) with fixed-effects are estimated. The direct and indirect impacts (spillovers) of the determinants of regional growth are then calculated. The results not only indicate strong spatial dependence among Brazilian micro-regions, but also that investments in physical and human capital are important for the growth of the economy and those of neighbouring economies.

Keywords: Economic growth, Spatial Spillovers, Spatial Panel, Income convergence.

Código JEL: R11, R15.

Área Anpec: 10 – Economia Regional e Urbana.

Physical and Human Capital and Brazilian Regional Growth: A Spatial Econometric Approach for the Period 1970-2010

1. Introduction

With its large continental area and diverse regional environment conditions, Brazil faces significant and persistent regional income disparities (AZZONI, 2001; SHAKAR and SHAH, 2003; BAER, 2001; VELEZ *et al*., 2004). These circumstances are the result of its colonial economic history, when export-based activities were based on local natural resources, poor transportation networks among the country's regions, and the concentration of industrialisation in Brazil's Southeast region during the twentieth century (CANO 1985; BAER 2001). The lack of education investment and the high degree of closure of its economy during most of the twentieth century, on one hand, and agglomeration forces, on the other, have contributed to maintain the historical regional distribution of activities (SILVEIRA NETO and MENEZES, 2008; ÖZYURT and DAUMAL, 2013).

This characteristic is widely and clearly illustrated by the conditions in the Northeast (the poorest) and Southeast (the wealthiest) macro regions of the country, the two most populous regions of Brazil. The Northeast and Southeast regions represented 34,7% and 44,6% of the Brazilian population and 17% and 63% of Brazilian GDP (Gross Domestic Product) in 1939, respectively; this regional inequality persisted for the remainder of the twentieth century, while 28,1% and 46% of the Brazilian population was located in the Northeast and Southeast regions and the shares of GDP in these regions were 12,4% and 58,3% in 2000, respectively (AZZONI, 2001). Throughout the period for which macro regional data are available (from 1939 on), the per capita GDP of the Northeast was never greater than half that at the national level, and the Northeast exhibited poverty levels more than twice those registered for the Southeast region **(**ROCHA, 2003**;** SILVEIRA NETO, 2005).

Understandably, this situation has motivated regional policies that, historically, have primarily focused on increasing physical capital by attracting manufacturing activities to less-developed regions (CANO, 1980; BAER, 2001). The results of these politics appear mixed, resembling those of the European Structural Funds (MARTIN, 1999; HUSRT and VANHOUDT, 2000; PUGA, 2002). For example, FERREIRA (2004) suggests that these traditional regional policies providing capital subsidies for Brazil's Northeast did not reduce regional disparities. CARVALHO *et al*. (2005), however, noted that these policies had positive effects in attracting manufacturing to Brazil's poorest regions, a result also obtained by MANOEL *et al.* (2009). Moreover, the Brazilian experience in evaluating "place-based" regional policies provides an example of the classical problem of the absence of a strong counterfactual; in other words, it is impossible to know what the economic and social conditions in the poorest regions would have been in the absence of the traditional policies intended to augment the stock of regional capital by attracting manufacturing. As in the European experience (DURANTON and MONASTITIOTIS, 2002; OVERMAN and PUGA, 2002), these mixed results for Brazil have motivated a debate on potentially more effective "spatially blind" policies specifically focused on improving the Brazilian population's education level, which would have a greater influence on the poorest regions (SILVEIRA NETO and MENEZES, 2008).

In the Brazilian case, the argument for improving the regional education level is based both on evidence obtained from micro data regression analysis estimating the impact of schooling on regional labour income (SILVEIRA NETO and MENEZES, 2008; DUARTE *et al*., 2004) and growth regressions using aggregate variables to estimate the impact of schooling variables on the regional level of GDP per capita or growth (AZZONI *et al.* 2000, FERREIRA 2000, SILVEIRA NETO and AZZONI 2006, RESENDE 2011, CRAVO *et al*. 2014). The former approach suffers from an inability to adequately distinguish supply and demand factors that simultaneously affect a region's level of labour income. Thus, apart from the potential problem of reverse causality, when considering income levels, it is possible that the effect of education captures some degree of the effect of the presence of capital. The growth regression evidence features a similar problem; without exception, due to the failure to employ a regional physical capital measure, the available evidence only considers the effect of schooling on regional per capita GDP and clearly does not generate a robust measure of the importance of education to regional growth.

In addition, apart from the issue of adequately considering the influence of both human and physical capital on Brazilian regional GDP growth, the evidence concerning the impact of these factors obtained from growth regressions devotes little consideration to the presence of spatial dependence in the variables that lead to positive bias in the estimates (ANSELIN, 1988). As recently highlighted by ARBIA and PIRAS (2005), FINGLETON and LÓPEZ-BAZO (2006) and ELHORST *et al*. (2010), in the case of European regions, and REY and MONTOURIO (1999), for U.S. states, the dynamics of growth in geographic units are highly associated with the dynamics of their spatial neighbours, and to correctly estimate the influence of the determinants of growth, this spatial dependence must be explicitly considered in the econometric model.

The works of MAGALHÃES *et al*. (2005), SILVEIRA NETO and AZZONI (2006), RESENDE (2011) and ÖZYURT and DAUMAL (2013) are among the few exceptions that address spatial dependence in regional growth regressions on the Brazilian case, and these works confirm the importance of explicitly accounting for spatial dependence. None of these works on the Brazilian regions, however, simultaneously employ spatial panel data and adequately interpret the estimated effects of the variables on regional per capita GDP or income growth. Specifically, RESENDE *et al.* (2012) and CRAVO *et al.* (2014) were the first to employ a spatial panel data approach to measure the impact of schooling on regional income growth in Brazil, but the authors fail to simultaneously consider the influence of physical capital, and because they do not consider the role of regional spillovers, they also fail to correctly measure the effect of the human capital variable on growth of regional per capita Income. ÖZYURT and DAUMAL (2013), however, while correctly interpreting the influence of the variables (including human capital and the degree of regional openness) on regional per capita GDP, only consider cross-sectional data and a very brief period of analysis (2004-2007). These characteristics make their estimates of the importance of human capital much less reliable.

Given the above context, the contribution of this paper is twofold. By considering a new and 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 panel data for the period 1970-2010. This allows us to more precisely control for the influence of time-invariant factors that are potentially associated with each type of capital. Previously, no information on the relative importance of these types of capital was available for the Brazilian regions. Second, to account for spatial dependence and based on the argument advanced by ERTUR and KOCH (2007) regarding the spatial dependence of growth rates, we consider an empirical spatial panel econometric model (*Durbin Model*) that allows us to measure the spatial spillovers potentially arising from regional growth and the regional levels of both physical and human capital utilisation. This methodology not only makes it possible to obtain unbiased estimates 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 effects of the variables. In conjunction, these considerations enable a much more precise understanding of the roles that physical and human capital play in Brazilian regional income dynamics.

The main results of the paper indicate that strong, positive spatial dependence was present in the per capita income dynamics of Brazilian micro-regions between 1970 and 2010 and both human and physical capital are important in understanding the dynamics of Brazilian regional per capita income in this period. By calculating the direct and indirect effects of the two types of capital, we also show that the spatial dependence implies that the estimated coefficients 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 employed, the two types of capital have very similar effects on Brazilian regional growth.

The remainder of this paper is organised into four additional sections. In the next section, we present a review of the empirical literature on regional economic growth and human and physical capital in Brazil. In the section three, we present the data and methodology employed in the paper. The results and discussion are presented in section four, and the final remarks are provided in section five.

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

The works of FERREIRA (2000) and AZZONI (2001) can be considered pioneering contributions on the determinants of regional growth in Brazil based on regressions with specifications derived from the traditional neo-classical growth model. Both investigations indicated that the process of income convergence among Brazilian states is sensitive to the period of analysis and the set of variables included in the regressions. However, in addition to considering cross-sectional data, which do not allow the researcher to consider the influence of the heterogeneity among the states' economies on their growth trajectories, these two articles present two further limitations: they did not consider the spatial dependence of the states' growth rate trajectories or use a measure of or proxy for the rate of savings or investment in physical capital.

Following the pioneering paper by REY and MOUNTOURI (1999), which estimated spatial growth regressions and identified the presence of positive spatial dependence among the economic growth rates of U.S. states, MAGALHÃES *et al.* (2005) and SILVEIRA NETO and AZZONI (2005), considering a cross section of Brazilian states, incorporated spatial dependence in the growth regressions and also identified positive spatial dependence among the growth rates. In a similar vein, DE VREYER and SPIELVOGEL (2009), considering a cross section of Brazilian municipalities, also showed that that the growth rates of neighbouring economies and their initial levels of GDP per capita are important variables in explaining the income dynamics of a particular economy. RESENDE (2011) analyses Brazilian regional growth at multiple geographic scales for the period 1991-2000 and demonstrates that, regardless of the geographic scale considered, a high-quality infrastructure and high levels of educational 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 the level of GDP per capita in Brazilian micro-regions. The results reveal that while openness to the international market is beneficial for a given micro-region, it ultimately has negative effects on neighbouring 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 that of neighbouring economies. In other words, they found evidence of positive human capital spillovers.

These empirical results on Brazilian regional growth appear consistent with a recent theoretical extension of the neoclassical model proposed by LÓPEZ-BAZO *et al*. (2004) and ERTUR and KOCH (2007). In this context of economic dependence and based on the evidence obtained by KELLER (2002) that technological diffusion decreases in the 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 human capital version (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 investments in physical and human capital) and those of neighbouring economies are important in explaining regional economic growth. In other words, ERTUR and KOCH (2007) highlight physical and human capital spillovers as important variables for explaining the growth of a particular economy.

However, by only considering cross-sectional data on Brazilian geographic units, neither of these studies on the Brazilian regional experience accounted for the influence of the heterogeneity among regional economies on their growth trajectory or GDP, nor did they include any measure of the influence of physical capital on income growth or the income level. As noted by ISLAM (1995), an appropriate means of accounting for heterogeneity in the production function of each economy is to estimate the growth regressions using panel models, which consider the fixed and specific characteristics of each region (regional effects). From a methodological perspective, the estimation of panel models allows to the researcher to distinguish the effects of the variables included in the model (such as investments in physical and human capital) from the effects of unobservable characteristics (such as technology, geography and institutional quality) and reduces omitted variable bias from temporally fixed variables, which represent potential sources of endogeneity. In the case of Brazil's regions, these specific regional effects appear 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 growth rates among regions.

NAKABASHI and SALVATO (2007) and CRAVO (2012) addressed the first of these concerns by considering panel data on Brazilian regions. NAKABASHI and SALVATO (2007) examined the role of human capital and CRAVO (2012) examined the role of entrepreneurship on regional economic growth and, respectively, obtained evidence that human capital and entrepreneurship are important for regional growth. However, despite their use of more appropriate strategies to address economic heterogeneity (regional fixed effects), these studies ignored the possibility of spatial dependence among the growth rates and their determinants and, again, did not consider any measure of physical capital affecting Brazilian regional growth.

Following the works of ARBIA and PIRAS (2005) and ELHORST *et al.* (2010), which employ a spatial panel approach to study European regional growth, only RESENDE *et al.* (2012) and CRAVO *et al.* (2014) applied this methodology to the Brazilian case. RESENDE *et al*. (2012) demonstrated, for Brazilian municipalities, micro-regions and meso-regions, the existence of positive spatial dependence among the income growth rates of regional spatial units even after accounting for regional fixed effects. Utilizing a panel of 508 micro-regions for the period 1980-2004, CRAVO et al. (2014) demonstrated that the activity of small and medium-sized enterprises (SMEs) are important to explain economic growth and can generate spatial spillovers. Additionally, for the micro-regions, both the studies found no evidence of a relationship between human capital spillovers and regional economic growth.

However, the work of RESENDE *et al*. (2012) and CRAVO *et al.* (2014) nevertheless presents two important limitations. The first is that the role of physical capital is entirely neglected. This limitation hampers the theoretical consistency of the paper's empirical results, as theory indicates that investments in both physical capital and its potential spillovers are important in explaining regional economic growth (ERTUR and KOCH, 2007). Note that on one hand, from an econometric perspective, this limitation can bias the parameters of growth equations; on the other hand, from a regional policy perspective, this limitation prevents determining the influence that physical capital has on regional growth. The second limitation is that the articles presents an inaccurate interpretation of the parameters estimated using the spatial models. As LESAGE and FISCHER (2008) demonstrated, when considering growth models that explicitly incorporate the influence of the growth of neighbouring economies, it is necessary to calculate the direct and indirect impacts to determine the true effect of a marginal change in the independent variable and make inferences regarding the sign, magnitude and significance of the explanatory variables. As FISCHER (2011) showed, (inaccurately) interpreting the parameters estimated using spatial models as one would for models that fail to consider the spatial dimension (typical regressions) can be very costly: the conclusions and implications of the empirical model can be meaningfully affected.

Thus, this paper aims to contribute to the debate on Brazilian regional economic growth by directly addressing these limitations. Specifically, to study Brazilian regional growth from 1970 to 2010, we explicitly consider the roles of both human and physical capital in a spatial panel model that allows us to control for both spatial dependence and unobservable, time-invariant factors. This approach permits us to obtain more reliable parameter estimates from the theoretical model. Additionally, the accurate interpretation of the spatial parameters in this work allows us to generate more reliable evidence regarding the importance of both types of capital (physical and human) and their potential spatial spillovers.

3. Theory, Methodology and Data

3.1 Theory and specification of the empirical model

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

We begin with the Cobb-Douglas production function proposed by ERTUR and KOCH (2007), which takes the traditional specification:

$$y_{it} = A_{it} k_{it}^{\alpha} h_{it}^{\beta} \tag{1}$$

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:

$$A_{it} = \Omega_t h_{it}^{\omega} k_{it}^{\phi} \prod_{J \neq i}^{N} A_{jt}^{\rho w_{ij}} \tag{2}$$

Where Ω_t is the total amount of technology created in the world, available for any region, and grows at an exogenous rate, such 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 exhibit a higher level of technology, akin to 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 indicates the technological interdependence among economies, and hence, the technical progress in a particular region depends positively on the technology levels in 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 region "i" and region "j". These terms are assumed to be non-stochastic, non-negative and finite. It is assumed that $0 \leq w_{ij} \leq 1$ and, incorporating empirical evidence obtained by KELLER (2002) that technological diffusion between two distinct regions decreases in geographic distance; it is supposed that the closer region "i" is to region "j", the greater the w_{ij}. Thus, economies more proximate to economy "i" will have a more substantial influence (in terms of technological diffusion).

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

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

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 neighbouring regions, and β_s (s = 0, 1, 2, 3, 4), θ_s (s = 1, 2, 3, 4) and η are combinations of model parameters. It is interesting to note that if $\rho = \omega = \phi = 0$, technology in region "i" only relies on the exogenous term, and hence equation (3) becomes the traditional convergence equation in MANKIW *et al*. (1992).

As can be observed from equation (3), the growth rate of the economy "i" depends positively of the level of investment in human and physical capital and negatively of the rate of population growth and the economy's initial income level, as indicated in the model developed by MANKIW *et al.* (1992). However, given the assumed interactions expressed in equation (2), economic growth now also depends positively on the investments in physical and human capital and the rate of output growth in neighbouring regions and negatively of the rate of population growth and initial income levels of neighbouring regions.

From an empirical perspective, there are two important issues concerning equation (3). First, as argued by MANKIW *et al.* (1992), the term Ω_t can represent the degree of technology and the endowments of resources, institutions and climate and hence may differ between economies. As this variable is not observable, it is captured by the error term ($\eta\Omega_t = \varepsilon_{it}$) of the 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 necessary, but this type of assumption appears overly strong. For example, it is unconvincing to argue that the level of capital investment in an economy is not related to its institutional quality. As argued by ISLAM (1995), an appropriate solution to this problem is to employ panel models and consider the existence of a regional effect (μ_i) in the unobserved 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 $s = 1, \dots, 4$, of this spatial extended model. Note that due to spatial interactions that imply feedbacks arising from changes in production factors and technology, we place the initial income, growth rate, human capital and physical capital variables of neighbouring economies on the right side of equation (3). Therefore, the marginal effects of the changes in variables representing regional growth rates are no longer given by the estimated β_s but by a combination of parameters involving β_s, θ_s and ρ. To clarify this point, we rewrite equation (3) in matrix form and explicitly consider the panel structure of our data by incorporating a regional effect (μ) in the unobserved term:

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

Where y is a vector $nt \times 1$ of observations of the per capita income growth rate of "n" regions for "t" periods of time, X is a matrix of explanatory variables (initial income level, investments 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 an identity matrix, $t \times t$, I_n is an 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 the 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 the dependent and explanatory variables and is known in the spatial econometrics literature as the Spatial Durbin Model (SDM).

It is assumed that each element μ_i of vector μ is an unobserved individual characteristic of a particular region "i", which is constant over time and 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 the institutions in a particular region. Institutions are a classic example of a feature that is fairly independent of time, is not observed and is related to the characteristics observed and included in the model. By considering the regional effects, we will reduce omitted variable bias and, consequently, obtain 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 per capita GDP growth in these regions will differ due to the inclusion of the parameter μ_i. Therefore, the use of panel models allows for the existence of heterogeneous production functions. Moreover, BALTALGI (2005) argues that panel data exhibit greater variability, a lower degree of collinearity among variables and provide more efficient estimators.

Thus, spatial panel models enable us to simultaneously control for spatial dependence and unobserved fixed effects, which are potential sources of endogeneity (ARBIA and PIRAS, 2005). Therefore, by using this methodology, we can verify the existence of spatial spillovers arising from physical and human capital and analyse income dynamics with non-biased and consistent estimators. The traditional (and strong) assumptions of closed economies and homogenous production functions imposed in cross-sectional studies of growth are relaxed. With the objective of estimating equation (4), we follow ELHORST (2003) suggestion of transforming the variables (achieved by subtracting the average time for each observation in cross-section) to eliminate the fixed-effects. As suggested by LESAGE and PACE (2009) and ELHORST (2003), the parameter $\hat{\rho}$ can be obtained through a concentrated[1] likelihood function and then substituted into a likelihood function to obtain the values of θ, β and σ_ε^2.

As argued above, due to the spatial dynamic incorporated into equation (3), a marginal change in the explanatory variable for region "i" can affect both the income growth of region "i" and that of all other regions, $j \neq i$, for $j = 1, \ldots., N$. To interpret the parameters obtained from an SDM, consider the reduced form of equation (4):

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

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

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

The resulting expression is a matrix of dimension $nt \times nt$. The elements of the main diagonal of matrix (6) reflect the effects of a change in y_i in response to variations in the explanatory variables for the same region, x_{ir}, these own-partial derivatives are known as the direct impact[2]. The elements off of the diagonal of matrix (6) reflect the effects of a change in y_i in response to variations in the explanatory variables for different regions, x_{jr}, $j \neq i$. These cross-partial derivatives are known as indirect impacts or spillover 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 on and off of the main diagonal of matrix (6), respectively.

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

[2] These direct impacts include *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 an additional change in the variable. y_i.

3.2 Data and spatial matrices

To estimate the parameters of the model specification in equation (4), it is necessary to determine adequate measures of GDP per capita, investments in physical and human capital and the population growth rate. To do so, we employed official data from Brazilian Demographic Census for the years 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. Brazilian micro-regions serve as the spatial scale[3] of the analysis. The micro-regions are formed by a group of adjacent municipalities and were defined according to similar characteristics regarding the agricultural, mining and industrial production structures of the municipalities, and social factors are also taken into consideration (MAGNAGO, 1995). An alternative would be to select larger geographical units (states or meso-regions); however, in addition to reducing the number of available observations, states and meso-regions include localities that differ substantially in economic characteristics, rendering the regional growth analysis less accurate.

When analysing Brazil, we face the problem of the creation of new municipalities[4], and as the micro-regions are sets of adjacent municipalities, these are also subject to change with respect to their geographical extent. To solve this issue, we adopted the approach proposed by RESENDE *et al.* (2012); specifically, the micro-regions analysed were constructed by aggregating data obtained from minimum comparable areas[5] (MCAs), which generated a sample of 522 micro-regions with constant borders over time.

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

To verify the accuracy of this last variable as a measure of physical capital, BARROS *et al*. (2013) calculated its correlation with other measures of physical capital, which are only available for more aggregated geographic units: gross fixed capital (available at the national level) and industrial electricity consumption (available at the state level). Table 1 reports the correlation coefficients between the stock of residential capital and each of other measures of physical capital. As can be observed from table 1, residential capital is highly correlated with all other measures of physical capital. As argued by BARROS *et al.* (2013), as the marginal product

---

[3] 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.

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

[5] The minimum comparable areas (MCAs) are municipalities that have a consistent boundary over the period 1970-2010 (Reis et al. 2005)

of capital tends to be the same in different segments, the expectation is that regions with a larger stock of residential physical capital are identical, in this respect, to those with a larger stock of non-residential fixed capital.

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

Variables	Correlation Coefficient
Gross fixed capital – Non-residential 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 gross fixed capital (Non-residential building, Machinery and equipment and total), the coefficient was calculated using national information from 1970 to 2000; for industrial electricity consumption, the coefficient was calculated using state-level information.

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

Regarding the spatial weight matrices used to capture the spatial relationships between neighbouring economies, we initially employed the more traditional normalised *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 the estimates and inferences obtained from spatial regressions are not affected by the choice of a particular structure for the matrix. These authors demonstrate that when the model is interpreted appropriately (considering the direct and indirect impacts), the results relevant to estimation and inference do not vary significantly. We adopt a more flexible approach and, as robustness checks, also consider the *4th nearest neighbours matrix* (W2) and *8th nearest neighbours matrix* (W3). These matrices account for the fact that regions with greater geographical proximity will receive a higher weight, which is consistent with the hypothesis of KELLER (2002) that the greater the geographical proximity between two regions, the greater the interdependence (in technology) between them.

4. Results

4.1 Descriptive Statistics and Model Estimation

In this section, we present evidence concerning the influence of both physical and human capital in Brazilian regional growth using an empirical spatial panel model that explicitly accounts for the characteristics of neighbouring regions (ERTUR and KOCH, 2007). From the Brazilian Demographic Census for the years 1970, 1980, 1991, 2000, and 2010, it is possible to construct four time periods with respect to variations in per capita income. The time periods and average values of the variables considered in the regressions are displayed in table 2 below.

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 for the years 1970, 1980, 1991, 2000, and 2010. SD corresponds to the standard deviation. Income growth refers to annualised per capita income variation and Income refers to initial level of the log per capita income values of the micro-regions; Human capital and Physical capital correspond to the logarithm of the initial values of the respective variable; Popul. growth refers to annualised relative variation in the population of the micro-region.

From the figures in table 2, we note higher growth in per capita income during the periods 1970-1980 and 2000-2010 than during the other two periods. The weaker income growth during the periods 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 the human capital variable (*average years of schooling of the population over 25 years old*) and the physical capital proxy (*stock of residential capital*) exhibited positive growth between the periods. Regarding population growth, we note that it exhibited a monotonic decrease.

Table 3 presents the parameter estimates from equation (4), the spatial Durbin model with fixed effects. The explanatory variables are in logarithms and, to eliminate endogeneity resulting from simultaneity, we use the explanatory variables at their initial values (t), while the growth in per capita income (dependent variable) is given between time (t) and (t +1). Table 3 also reports the t-values associated with each parameter. To obtain consistent estimators for the variance parameters of the spatial models, we apply the bias correction proposed by LEE and YU (2010). Column 1 presents the results when estimating the empirical model without considering space or 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 physical capital, $\alpha = \phi = 0$ and Column 4 reports the results of the complete version of the model (without any restrictions).

Regarding the non-spatial models (columns (1) and (2)), we note that the variables considered take the signs predicted by the theoretical model. Moreover, the inclusion of physical capital as an explanatory variable improves the fit of the model (as indicated by the adjusted R^2), a result that reinforces that our measure of physical capital (residential capital) is an appropriate proxy. Additionally, the inclusion of investment in physical capital also reduces the importance of human capital (as indicated by the reduction of the human capital coefficient), increases the speed of convergence of the economy and provides a better control to investigate the role of population growth in regional growth. These results indicate that omitting physical variable reduces not only the theoretical consistency of the empirical model but also generates substantial bias in the estimators[6].

Table 3 – Determinants of Brazilian regional growth - Panel estimate - Dependent variable is the growth in 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)
Region fixed effects	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes
R^2	0.51	0.62	-	-
Adjusted R^2	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 estimates. The variables W Per capita Inc., W Human capital, W Physical capital and W Popul. growth correspond to lagged spatial variables for initial per capita income, human capital, physical capital and population growth, respectively. "**" and "*" indicate statistical significance at the 1% and 5% levels, respectively. The non-spatial models were estimated using a *within* estimator, and the spatial models were estimated by maximum likelihood.

Columns (3) and (4) report the results of the SDM with fixed effects; the estimations were obtained using the *Queen* matrix, which, according with the measures of goodness of fit (log-likelihood and the Akaike Criterion and Scharz Criterion), provides the best fit of the spatial

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

matrices considered (4th and 8th nearest neighbours). As can be observed, the spatial model that includes physical capital investment (column (4)) exhibits better fit to the data. Thus, all subsequent analyses will be based on this model, the full version of the model proposed by ERTUR and KOCH (2007), equation (4), using the *Queen* matrix.

First, we observe that the spatial dependence parameter (ρ) is large and statistically significant, indicating that the higher (lower) the growth rate(s) of neighbouring micro-regions, the higher (lower) the growth rate of a particular micro-region. These findings demonstrate that Brazilian micro-regions cannot be treated as independent economies and the location of an economy is important in defining its growth trajectory. From an econometric perspective, ignoring this type of spatial dependence would generate omitted variable bias and lead to inconsistent estimators.

As emphasised in the previous section, the presence of spatial dependence throughout the dependent variable, which implies spatial feedback effects arising from variation in the determinants of micro-region growth, the estimated of coefficients do not represent the marginal effects of the explanatory variables on the dependent variables. Thus, 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 estimated coefficients in table 3 for calculating the equation (6). The estimated impacts are presented[7] 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 estimates. The figures in the table are obtained using matrix W1 (*Queen*). The standard deviations and *z* values are obtained by simulation, assuming a normal distribution; "**" and "*" indicate statistical significance at the 1% and 5% levels, respectively.

From Table 4, we can observe that the coefficients of all variables take the signs predicted by the theoretical model developed by ERTUR and KOCH (2007). It is noteworthy that the indirect impacts are statistically significant, indicating that the characteristics of neighbouring economies (per capita income and investments in human and physical capital) are important in explaining the process of economic growth in a particular economy. These spatial spillovers represent further evidence of the importance of correctly interpreting the estimated regression

[7] Impacts were estimated with the W2 and W3 matrix. The results were robust to any type of matrix used, a result in line with the study by LESAGE and PACE (2010).

coefficients[8]. Notably, the indirect impacts are greater in magnitude than the direct impacts, which is feasible, as argued by LESAGE and FISCHER (2008). As the average indirect impact is calculated as a change in the explanatory variables for *all neighbours* on the dependent variable for region "i", it is entirely plausible that this would be greater than the direct impact, provided that 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 indicates that wealthier economies with wealthier neighbours tend to have lower future growth rates, an indication that the hypothesis of conditional convergence holds. Specifically, a 1% increase in an economy's per capita income in the initial period leads to a 0.037 percentage point reduction in its growth rate, while a 1% increase in the initial incomes of all neighbouring regions leads to a reduction of 0.101 percentage points. While such negative spillovers may appear contradictory, they are a natural consequence of the process of convergence: economies with high income levels tend to have low rates of economic growth, and due to positive spatial dependence, these economies generate negative effects on the growth of surrounding regions.

Table 4 reports that human and physical capital generate positive spillover effects (as the indirect impacts are positive and statistically significant). Thus, micro-regions having neighbours with high rates of investment in physical and human capital ultimately benefit. In the light of the theoretical model developed in section 3, higher levels of physical and human capital investment generate a larger stock of technology (learning-by-doing*)* for a given economy. Due to the technological interdependence described by ERTUR and KOCH (2007), see equation (2), these additional technology stocks in a given region flow into neighbouring regions, causing higher rates of economic growth for the latter regions. With respect to the magnitudes of the direct and indirect impacts, one standard deviation increases in human and physical capital investment in an economy generate similar variations in growth, while the latter exhibits a slightly larger impact[9]. Regarding investments in neighbouring economies, physical capital is relatively more beneficial for the surrounding economies[10]. A possible explanation for this is that physical capital is related to infrastructure that, unlike human capital, is often non-excludable and non-rivalrous and hence benefits neighbouring economies to a greater extent. Thus, these results indicate that investments in physical capital contribute more significantly to economic growth in a given micro-region and in neighbouring micro-regions.

Finally, Table 4 also indicates that the direct impact of population growth is negative and statistically significant, a result consistent with theoretical growth models. However, the indirect

---

[8] 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 from human capital and an absence of spillovers from physical capital, which are widely divergent conclusions.

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

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

impact of population growth is not significant, indicating that increased rates of population growth in neighbouring economies does not affect an economy's rate of economic growth, i.e., there are no spatial spillovers.

4.2 Region fixed effects

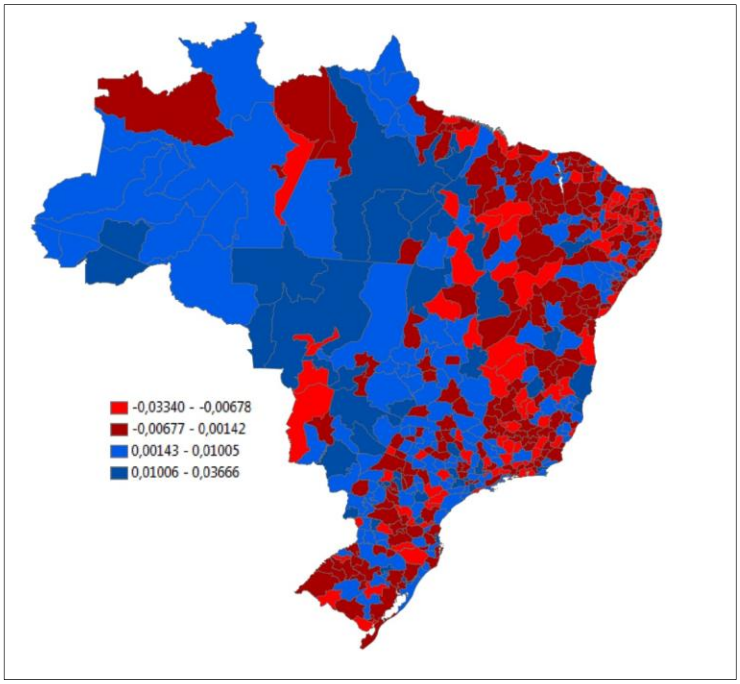
Using the estimated model parameters, it is possible to derive the micro-regions' fixed effects. These effects represent time-invariant characteristics of the localities that affect their economic growth during the period 1970-2010. Although it is not possible here to precisely determine what these effects capture (the factors range from geographic to persistent institutional characteristics), this evidence can reveal the consistency of known, time-invariant favourable and unfavourable characteristics of Brazilian localities as determinants of economic performance or suggest unknown spatial regularities that affect the growth of the localities. To obtain each Brazilian micro region's fixed effect, we use the parameters estimated in the econometric model (vector β,θ and the spatial coefficient ρ) and the data in following equation:

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

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

The results are depicted in figure 1 below. There are at least two pieces of evidence that should be highlighted. First, the fixed effects estimates indicate more favourable conditions for the micro regions located in North and, primarily, Mid-West regions of Brazil. More specifically, confirming the visual inspection, we find that 69.0% of the micro regions located in Mid-West and 61.0% of the micro regions located in Brazil's North macro region exhibit fixed effects in the two most favourable categories of the figure. However, there is also a clearly negative finding: only approximately 27% of micro regions located in Brazil's Northeast macro region exhibit fixed effects in these two most favourable categories. Second, we also note that the magnitude of these fixed effects is far from negligible. According to the estimative, the effects on economic growth range between -3,34% and 3,66%, and the latter value is approximately equivalent to a effect of one standard deviation increase in the human capital variable.

Figure 1 –Fixed effects of Brazilian micro-regions



Source: Author's estimates. The estimates are obtained using the parameter estimates obtained from model (4) and reported in table 3.

Clearly, we cannot be certain regarding the explanation of these results, but we note that they are consistent with one of most notable economic facts concerning Brazilian regional growth between 1970 and 2010: the above-average performance of most micro-regions in the Brazilian Mid-West (its micro region grew more rapidly than the national average). As these micro regions exhibit greater dependence on the products of agricultural export sector that require land as a production input, the quality of which is not explicitly considered in our estimates, than this characteristic of Brazilian regional growth appears to be captured by micro-regional fixed effects. Furthermore, in relation to northeast macro-region, these effects could also reflect the worst geographic conditions associated with the semi-arid climate of most micro-regions there.

5. Conclusions

The high and persistent levels of regional income inequality in Brazil have motivated various types of policies to attenuate this regional disequilibrium. Traditionally, these policies have been based on improving the physical capital stock of poorer regions by directing public investment to such regions and granting manufacturing capital subsides. More recently, federal policies rely on different types of spatially blind policies such as social programmes in the form of cash transfers and, primarily, expanded schooling. Although these two types of policies have focused on different targets, both are intended to increase the per capita income of Brazil's poorest regions. This work is the first to provide evidence of the effects of both physical and human capital on Brazilian regional per capita income growth during the period 1970-2010 using a panel data approach that explicitly allows for the possibility of spatial spillovers arising from the levels of physical capital and human capital.

In addition to controlling for the influence of (unobserved) regional fixed effects on regional economic growth, the empirical approach adopted allows us to assess the influence of variables associated with neighbouring regions on the per capita income growth of a given region and provides precise measures of the influence of human capital and physical capital on economic growth that account for the potential spatial interdependence among Brazilian micro-regions. Furthermore, these measures allow us to identify spatial spillovers arising from specific regional variables. The results indicate that both physical and human capital are important in explaining micro-regional economic growth during the period 1970-2010 and, at least for the variables we used to capture the influence of these factors, the magnitudes of the effects of these two factors are similar. However, the evidence also shows very strong spatial dependence among the economic growth of Brazilian micro-regions, and hence, the effects of human and physical capital derive not only from a unit's own levels of investment in these two types of capital but also, and importantly, the influence of neighbouring micro-regions' investments. In other words, there were significant spatial spillovers associated with investments in both physical and human capital that substantially and positively affect the economic growth of Brazilian micro-regions. Thus, in Brazilian regional growth, the micro-regions tend to benefit from their neighbours' greater investments in human and physical capital and not only from their own investment.

The approach employed was able to provide a measure of the impacts of these types of capital that not only considered the micro-regions' own investments but also the effects of the investments of neighbouring micro-regions. We also note that the estimated micro-regional fixed effects are quantitatively important in explaining the economic growth of Brazilian micro-regions, meaning that time-invariant characteristics are also important in understanding the economic performance of these micro-regions. Furthermore, the identified values of these fixed effects are consistent with the omitted fixed factors represented by the quality of land and expanded agricultural production of the micro-regions located in the Brazilian Mid-West, on the one hand, and by the less favourable geographic conditions of most Brazilian micro-regions located in the Northeast, on the other.

References

ANSELIN, L. (1988) *Spatial Econometrics: Methods and Models*. Kluwer Academic Publisher, Dordrecht.

ARBIA, G., PIRAS, G. (2005) Convergence in per-capita GDP across eu-nut2 regions using panel data models extended to spatial autocorrelation effects. *Working Paper REAL*, 05-T-3, Urbana Champaign.

AZZONI, C. (2001) Economic growth and regional economic inequality in Brazil. *The Annals of Regional Science* 35, 133–152.

AZZONI, C., MENEZES, N., MENEZES, T., SILVEIRA NETO, R. (2000) Geography and income convergence among Brazilian states. Inter-American Development Bank, Research Network Working Papers, R–395.

BALTAGI, B. (2005) *Econometric Analysis of Panel Data*. Chichester, UK: Wiley.

BAER, W. (2001) *The Brazilian Economy*, 5th Edition, Praeger.

BARROS, G., NAKABASHI, L., SAMPAIO, A. (2013) Determinantes do Capital Físico: o papel do Capital Humano e da Qualidade Institucional. In: Encontro Nacional de Economia – ANPEC, Foz do Iguaçu.

CANO, W. (1985) A Questão Regional no Brasil. *Pensamiento Iberoamericano* 7.

CARVALHO, A., LALL, S., TIMMINS, C. (2005) Regional Subsidies and Industrial Prospects of Lagging Regions, Working Paper No. 3843. World Bank Policy Research.

CRAVO, T. (2010) SMEs and economic growth in the Brazilian micro-regions. *Papers in Regional Science* 89, 711–734.

CRAVO, T., BECKER, B., GOURLAY, A. (2014) Regional Growth and SMEs in Brazil: A Spatial Panel Approach. *Regional Studies 48*. 1–22.

DE VREYER, P., SPIELVOGEL, G. (2009) Spatial externalities between Brazilian municipios and their neighbours. In: Klasens, Nowak-Lehmann F (eds) *Poverty, inequality, and policy in Latin America*. MIT Press, Cambridge, MA.

DUARTE, J., FERREIRA, P., SALVATO, M. (2003). Regional or Education Disparities? A Counterfactual Exercise. *Ensaios Econômicos* 532. 1-29.

DURANTON, G., MONASTIRIOTIS, V. (2002). "Mind the Gaps: The Evolution of Regional Inequalities in the U.K. 1982–1997," *Journal of Regional Science* 42, 219–256.

ELHORST, P. (2003) Specification and Estimation of Spatial Panel Data Models. *International Regional Sciences Review* 26, 244-268.

ELHORST, P. PIRAS G., ARBIA G. (2010) Growth and convergence in a multi-regional model with space-time dynamics. *Geographical Analysis* 42, 338–355.

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

FERREIRA, A. (2000) Convergence in Brazil: Recent trends and long-run prospects. *Applied Economics* 32, 479-489.

FERREIRA, P. (2004). Regional Policy in Brazil: A Review. World Bank commissioned paper. Available at www.fgv.br/professor/ferreira/RegionalPolicyFerreira.pdf. Last accessed: march 24, 2014.

FINGLETON, B., LÓPEZ-BAZO, E. (2006) Empirical growth models with spatial effects. *Papers in Regional Science* 85, 177-198.

FISCHER, M. (2011) A spatial Mankiw–Romer–Weil model: theory and evidence. *Annals of Regional Science* 47, 419-436.

HURST, C., THISSE, J., VANHOUDT, P. (2000). What Diagnosis for Europe's Ailing Regions? *EIB Papers* 5, 9–30.

IPEADATA. Dados Regionais (Available at : http://www. ipeadata.gov.br).

ISLAM, N. (1995). Growth empirics: A Panel data approach. *Quarterly Journal of Economics* 110, 1127-1170.

KELLER, W. (2002) Geographic localization of international technology diffusion. *American Economic Review* 92,120–142.

LEE, L., YU, J. (2010) Some recent developments in spatial panel data models. *Regional Science and Urban Economics* 40. 255–271.

LESAGE, J., FISCHER, M. (2008) Spatial growth regressions: Model specification, estimation and interpretation. *Spatial Economic Analysis* 3. 275-304.

LESAGE, J., PACE, R. (2009) *Introduction to spatial econometrics*. Taylor and Francis, Boca Raton, FL.

LESAGE, J. P., PACE, R. (2010) The Biggest Myth in Spatial Econometrics. Available at SSRN: http://ssrn.com/abstract=1725503.

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

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

MAGALHÃES, A., HEWINGS, G., AZZONI, C. (2005). Spatial dependence and regional convergence in Brazil. *Investigaciones Regionales* 6, 5–20.
MAGNAGO, A. (1995) A divisão regional brasileira – uma revisão bibliográfica. *Revista Brasileira de Geografia* 4, 65-92.
MANKIW, G., ROMER, D., WEIL, N. (1992) A Contribution to the empirics of economic growth. *Quarterly Journal of Economics* 107, 407-37.
MANOEL, A., RESENDE, SILVEIRA-NETO, R. (2009) Eficácia do Gasto Público: Uma Avaliação do FNE, FNO e FCO. *Estudos Econômicos* 39, 89–125.
MENEZES, T., SILVEIRA-NETO, R., AZZONI, C. (2012) Demography and evolution of regional inequality. *The Annals of Regional Science* 49,643-655.
MARTIN, P. (1999). Are European Regional Policies Delivering? *EIB Papers* 4, 10–23.
MILLO, G., PIRAS, G. (2012) splm: Spatial Panel Data Models in R. *Journal of Statistical Software* 47, 1–38.
NAKABASHI, L., SALVATO, MA. (2007) Human capital quality in the Brazilian states. *Revista Economia* 8, 211–222.
OVERMAN, H., PUGA. (2002) Unemployment Clusters Across Europe's Regions and Countries, *Economic Policy* 17, 115–147.
ÖZYURT, S., DAUMAL, M. (2013) Trade openness and regional income spillovers in Brazil: A spatial econometric approach. *Papers in Regional Science* 92, 198-215.
PUGA, D. (2002) European Regional Policy in Light of Recent Location Theories, *Journal of Economic Geography* 2, 373–406.
REIS J., TAFNER P., PIMENTEL M., MEDINA M., MAGALHAES K., REIFF O., SERRA R. (2005) *O PIB dos municípios brasileiros: metodologia e estimativas, 1970-96*. IPEA Discussion Paper, n. 1064, Brasília.
REY, S., MONTOURI, B. (1999) U.S. regional income convergence: A spatial econometric perspective. *Regional Studies* 33, 143-156.
RESENDE, G. (2011) Multiple dimensions of regional economic growth: The Brazilian case, 1991-2000. *Papers in Regional Science* 90, 629-662.
RESENDE, G., CARVALHO, A., SAKOWSKI, P. (2012) Evaluating Multiple Spatial Dimensions of Economic Growth in Brazil using Spatial Panel Data Models, 1970-2000. In: Encontro Nacional de Economia, Porto de Galinhas.
ROCHA, S. (2003) Pobreza no Nordeste: a década de 1990 vista de perto, *Revista Econômica do Nordeste,* 34 , 7-41.
ROMER, P. (1986) Increasing returns and long run growth. *Journal of Political Economy* 94. 1002–1037.
SILVEIRA NETO, R. (2005) Quão Pró-Pobre tem sido o Crescimento Econômico no Nordeste? Evidências para o Período 1991-2000. *Revista Econômica do Nordeste* 36, 483-507.
SILVEIRA NETO, R., AZZONI, C. (2006) Location and regional income disparity dynamics: the Brazilian case. *Papers in Regional Science* 85, 600-613.
SILVEIRA NETO, R., MENEZES, T. (2008) Preferência Revelada e Arbitragem Espacial: Determinando um Ranking de Qualidade de Vida para as Regiões Metropolitanas Brasileiras. *Revista Brasileira de Economia* 62, 361-380.
SOLOW, R. (1956) A contribution to the theory of economic growth. *Quarterly Journal of Economics* 70, 65-94.
SHANKAR, R., SHAH, A. (2003) Bridging the economic divide within nations: a scorecard on the performance of regional development policies in reducing regional income disparities, *World Development* 31, 1421–1441.