Accessibility and the development in Portuguese off-cost regions

A spatial regression analysis

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During the last twenty years, the main road network of Portugal underwent a profound transformation, particularly important for the off-coast depressed region close to the Spanish borderline and with a very poor road network. The new, fast roads built there in the late 1980s and early 1990s completely changed the accessibility conditions. This makes off-coast Portugal a perfect setting for the analysis of a matter that deserves a deeper debate in planning literature i.e. the relationship between accessibility and spatial development. In previous research and for a group of 86 municipalities in this region, we found that accessibility contribution for development (how its increase affects population growth) is poor or null when confronted with population literacy levels, in an autoregressive spatial analysis environment. In the spatial models estimated, heterogeneity is still present, which might compromise the relation between the explanatory variables and the dependent variable over the complete dataset. Among other spatial regression analysis techniques, Spatial Regimes is able to account for this heterogeneity, by means of switching regression models. When different subsets in the data correspond to spatial clusters or regions with special characteristics, the Spatial Regimes specifications adds important information to this innovative application of spatial econometric analysis. The way accessibility affects local development changes substantially accordingly to the spatial scale undertake and this type of group wise estimation. These facts underline the importance of selective infrastructures policies within the national and regional context.

Keywords: Road infrastructure, accessibility, regional development, population, spatially autoregressive models, spatial regimes.

JEL Classification: C13, C21, C52, R58

1 Introduction

Road transport infrastructures are commonly associated with regional development issues. In fact, new and fast road transport infrastructures are a way to help people and goods to get closer and therefore considered as improvement inputs in regional economic dynamics.

During the last decades, there were great investments both in the United States and in Europe on new road infrastructures, mainly supported by the argument that these infrastructures are important tools in improving social and economic cohesion and have a key role in the minimization of developed problems in peripheral areas. In Europe, the policies and actions on this subject mainly relate with the consolidation of Trans-European Transport Networks (TEN-T*):*"*the European Union must aim to promote the development of Trans-European networks as a key element for the creation of the Internal Market and the reinforcement of Economic and Social Cohesion"* (European Commission, 2005, 2007).

The last decade's results showed much weaker than expected (and/or unexpected) impacts, especially when looking at regional development on a local basis. One of the central issues arising from these results relates with the fact that road infrastructures, due to its network nature, tend to redistribute development rather than improving it.

During the last twenty years, Portugal's main road network has undergone a profound transformation under policies and investments related to the TEN-T, which resulted in a substantial increase in the number of kilometres of main roads, in a decrease in travel time by road and consequently in an increase on accessibility. This transformation leads to high expectations, particularly in the traditionally less developed northern and central off-cost areas, above mentioned. However, these areas development does not match expectations, symptomatically reflected, for example, in the population decline. This is particularly notable when looking to the problem on a spatial disaggregation able to account for local effects, as it is the municipality.

As it is possible to carry out from a literature review focused on evaluation studies of new road infrastructures in regional development, there are not many examples of this type of studies, especially for the municipality level of spatial disaggregation. The great majority of the existing studies apply on a spatially aggregated basis, and uses methodologies and models such as Production Functions and Cost Benefit Analysis.

The recent developments in spatial econometrics, namely in spatial regression, bring new possibilities. Worldwide, spatial econometrics is growing in importance in the understanding of the spatial economic systems complexity, in all levels of geographic aggregation.

Following partially the work developed by Paez (2004), this paper present another example for this type of evaluation studies, accounting for local spatial distributed effects while testing for accessibility increase impacts in development, in a sufficiently detailed spatial disaggregation such as the municipality. It also adds important information about the local behavior of this relation, by means of a Spatial Regimes specification.

This paper structure is as follows. First, we developed a literature review on the models traditionally used to measure the relationship between investments in infrastructures and regional development and presenting the new alternatives (section 2). In section 3, we introduce the case study and in section 4 the econometric model used. Section 5 is devoted to the presentation and discussion of results. Finally, section 6 includes some conclusions and opens the field for discussion.

2 Literature review

This literature review presents a general historical background of the models most commonly used to approach the relationship between investments in infrastructures and regional development. Moreover, it focuses in specific studies of spatial local development impacts evaluation of transport infrastructures and presents some of the new approaches, applied in this study.

In the beginning of the new millennium, the complexity inherent to this relationship still lacks a considerable amount of focused explanation, concerning the wide range of possible approaches, combination between approaches and the different associated results.

There are several perspectives that imply transport potential (or observable) influence in regional development[1]. From Multiregional Input Output Analysis - where

[1] For an extensive classification on the type of models, see Rietveld and Bruinsma (1998).

transport enters as a business cost in the transferences between regions and sectors (using production functions), like in the work of Amano & Fujita (1970), Oosterhaven (1981) and Liew and Liew (1985) - to Cost Benefit Analysis - which results are usually integrated in wider regional development prospective such as Production Functions - several approaches apply.

This represents an enormous effort in terms of literature review, which we do not aim to develop were. Therefore, it remains our concern a literature review directly related (as much as possible) with econometric models built or adapted to study new (recently built) regional transport infrastructures impacts (measured through accessibility improvements) on local development (as a general background for the models used in this study).

2.1 Aggregated production functions

The 'Production Functions' models can be considered the closest methodological approach to the one developed in this paper. In fact, it is an econometric model that relates variables potentially able to induce regional development such as capital or labor to the ones that are able to measure regional development.

When used in the dynamics of national output/input incomes it usually gets the form:

$$Y = A * F(K, L) \quad (1)$$

It was only with Aschauer's (1989) work that this methodological approach started in a consolidated form. The work of Aschauer, developed for the national level, showed that public capital had a positive and significant effect on private output and total factor productivity, with an estimated elasticity of 0,39. Moreover indicates that the composition of this public capital is also relevant. The basic infrastructures such as those of transport, energy and water and sewer, are the ones that showed the closest relationship with productivity.

Accordingly, Ashauer pointed the following argument:

'*A higher level of highway capacity expands transportation services and raises the marginal product of private capital. This induces higher investment in physical capital and growing per capita incomes and output*'.

Up to now, the evaluation in Portugal used mainly these aggregated analysis approaches. This is the case of a study from Pereira & Andraz (2005), showing that new transport infrastructures positively affect the Portuguese economy global performance. These authors used the same approach as Aschauer, where private output is regressed on public capital and private outputs – employment and capital, for the national aggregate data. In this study, aggregate public investment holds an elasticity of 0,18 on output. When looking at road infrastructure such as highways, this elasticity drops to 0,024.

The positive results obtained with these aggregated models started to be looking through with caution during the nineties, due to different local economic behaviors observed in the presence of new transport infrastructure.

In fact Aschauer also pointed the need to further explore the results following a change in the scale of analysis (from country or big country regions, to small regions inside of it).

Mas et al (1996) stressed that the network features of infrastructures usually imply *spillover* effects, observed when the estimations for each individual region included the values of private output for the neighbour ones.

2.2 The inclusion of accessibility measures in production functions and other models

During the nineties, some authors developed a way to improve the inclusion of infrastructure on production functions. Peter Rietveld (1994) used aggregated accessibility measures (of gravity type) as a way to measure services of infrastructures supply in a production function framework:

$$V_r = g(K_r, L_r, IN_{rr'}) \quad (2)$$

where region *r* gross domestic product (V_r) depends on aggregate capital (K_r), aggregate labour (L_r) and depends also on $IN_{rr'}$ which measures services of infrastructures supply in region *r* as in other related regions. The term $IN_{rr'}$ includes one intraregional component (quality and capacity of the network) and one interregional component (measures such as aggregated accessibility indicators as a way to capture spatial spillovers effects, usually out from traditional production functions - how region *r* benefits from the infrastructure facilities in region *r'*).

The inclusion of accessibility also appeared in several integrated approaches. Jensen-Butler & Madsen (1999) referred to three different approaches: the production function approach, the transport cost approach and the accessibility approaches, and proposed a new integrated approach. With this approach, they were able to distinguish between distributive and generative effects of transport investment including both changes in transport costs (and therefore changes in accessibility) and models of regional and interregional structure. Applied to the Danish Great Belt Link (a road and rail connection between Denmark and Sweden) these model estimation results are similar to the findings of Vickerman (1987) or Button (1995) for the Channel Tunnel impacts evaluation study (between France and the UK). Also Bruinsma et al (1997), while analyzing several levels of impact of the A1 highway in the Netherlands, through a regression of potential factors influential in differential shift for the employment, found that the effects in total regional employment are minimum. Moreover, only inner region relocation effects appeared as significant and mainly for the most urbanized areas, with losses for other areas. Similar results appeared in Forslund & Johansson (1995), in another analysis of Channel Tunnel impacts.

At this point, it is important to stress that the calculation of an accessibility indicator (which is usually called 'accessibility approach') cannot be considered as an evaluation study about the impact of the infrastructures in development. In fact, it is possible to detect the increased regional disparities in terms of accessibility, and to speculate that those increased disparities will have effects on regional development, but they cannot effectively measure the impacts of accessibility on development.

2.3 The importance of the local approaches

A major question that arises is the importance of the geographical scale of analysis (the level of spatial disaggregation). In fact, one fundamental critic to the aggregated studies models is that it cannot identify the pattern of spillover effects and are not able to distinguish between distributive and generative effects.

Guild (2000), compared the results of these aggregated studies with more disaggregated geographical analysis. Among other examples, he compared the 0,39 output elasticity in Aschauer (1989) study, for the national level, with the modest 0,15 value obtained in Munnel (1990) for the state level, or the Duffy-Deno and Eberts (1989) 0,08 value for the metro level. Guild stressed that in the majority of empirical studies, impacts are largest at the national level, smaller at the regional level, and lowest at the municipal level, suggesting that the size and complexity off networks are important determinants of positive local impacts.

This is also the case of Berecheman et al (2006) work, using a production function and tested different forms[2] of it for state, county and municipality level, highlight the importance of a local approach.

Using a similar production function Boarnet (1998) concluded that the local (county) impacts have significance, the locations near the new roads benefit more, and the locations far from the new roads tend to lost output (within a redistribution induced by the new roads).

The local characteristics, as pre-conditions for development, are also major issues to account for in the models. As Holl (2004) pointed out (for a probability profit model at a county/municipality level), local characteristics guide the variable impact of an infrastructure corridor on the location decision of firms. This is the case of the existence of agglomeration economies, the type of activity sector, the existing markets dimension, the work force specialization and diversification and the concentration/dispersion of economic activity.

2.4 New approaches

As Coughlin pointed out in a recent editorial of a special issue in Annals in Regional Science (Coughlin et al, 2008) - devoted to the interaction between transportation investment and economic growth - different modeling approaches apply and no unique framework is defined for each specific case. The same type of concerns remains in Weisbord (2008).

Some recent developments give some insight on this subject like in Gkritza et al (2008), where models, of linear regression form, estimate the economic-development impacts of different types of highway construction projects, using data from Indiana, in the project development phase. With these models, the proximity of a highway, especially with good access to an airport or a port, proved to be determinant of economic development potential. These estimates can help a better-oriented policy

[2] A regular production function where transport enters as public capital, a lagged model where different time lags were introduced to test for delays in output response and a *spillover* model to test the hypothesis that highway investments made in one area have development impacts on neighbour areas and that these impacts become more pronounced as the geographical area gets smaller.

although they cannot be considering as a way to measure infrastructures impact in spatial development. Also in Pugh and Fairburn (2008), the application of econometric techniques guides the evaluation of the economic impact of a toll road in the UK development. The panel data approached used suggests that there are local development effects close to the road and that these effects diminish with travel time, using buffers of 5 minutes and 15 minutes.

None of these models includes explicitly the spatial location of the local geographical units in relation to others, in order to prove if a specific road or group of roads had impact in spatial development for the neighbor units, in a more detailed and enlarged analysis.

One possible innovation relies on a simplified approach taking spatial regression as a privileged tool, where variables selection and transformation is determinant, where accessibility takes a leading role as explanatory variable and where the network spatial effects is accounted for through the explicit incorporation of spatial effects in models.

One example is the spatial lag model:

$$Y = \rho \boldsymbol{W} Y + \boldsymbol{X}\beta + \varepsilon \qquad \textit{(spatial lag model)} \quad (3)$$

where $\boldsymbol{W}$ is a matrix of weights for the neighbour relations between spatial units.

Therefore, spatial regression techniques represent a new approach in a spatial framework, for the evaluation of transportation infrastructures impacts on spatial development.

This is the case of the work from Páez (2004), a spatial regression applied to study the influence of network accessibility in the spatial distribution of economic activity in Eastern Asia. The model takes the following form:

$$W_i = A_i + \sum_{k=1}^{K} x_{ik}\theta_k + \varepsilon_i \qquad (4)$$

where W_i is the weight of location (the major economic zones) and is measured in population or GDP, A_i is the accessibility of each location to the same type of economic activity, x_{ik} represent other explanatory variables and $\varepsilon_i$is a residual. The main results of this application showed that network accessibility is weakly influent in the distribution of economic activity, especially after adding other variables to the model.

Although direction of causality might be questionable, the absence of correlation gives a clear statistical indication of this weakness.

The present case study tests this conclusion using a local geographical unit of analysis (municipality - local approach) and a set of other variables related with development, in a similar spatial regression analysis framework.

3 The study area

3.1 Localization

The study area locates in the off-cost northern and centre areas of Portugal where there was a great increase in accessibility between 1991 and 2001. This off-coast region is near the borderline with Spain, it has 290 kilometres extension per 130 kilometres wide, and it is composed by 86 municipalities. It includes five capital districts, Bragança, Vila Real, Viseu, Guarda e Castelo Branco and the following NUT III PIS: Pinhal Interior Sul; PIN: Pinhal Interior Norte; SE: Serra da Estrela; D: Douro; ATM: Alto-Trás-os-Montes; BIN: Beira Interior Norte; BIS: Beira Interior Sul; CB: Cova da Beira; DL: Dão Lafões (see Figure 2). Portugal is a European country with about ten million inhabitants and it is located in the South West Europe (see Figure 1).

(Include here Figure 1)

(Include here Figure 2)

3.2 Population

The above referred municipalities observed a negative population growth rate of sixty percent (-6%), in average, for the same decade of new roads implementation. This population decrease is also noticeable through the observation of two maps corresponding to 1981-1991 and 1991-2001 population evolution using Portuguese population census data (see Figure 3). In the 1981-1991 decade, only the district capitals (Bragança, Vila Real, Viseu, Guarda, and Castelo Branco) showed a growth rate above average. The municipalities closed to the borderline with Spain showed the smaller growth rate. Looking at the 1991-2001 evolution, the panorama did not change deeply, although some differences appear. This is the case of two district capitals crossed by new roads, Viseu and Guarda, that increased population, with a growth value definitely above average. Other municipalities, some close to new roads, seemed to slow down population growth, going under initial levels of growth. In a way, there was a redistribution of population, with intensification on district capitals cities at expenses of a deeper decrease on municipalities close to the border, for example. This is noticeable through the polarization effect around the municipality of Viseu in opposition to Almeida, a municipality with a population growth above average before and with a growth bellow average after, both crossed by the same new road.

(Include here Figure 3)

In a first glance, it seems that the past behavior it terms of population growth does not influence recent evolution, although a redistribution of this growth occur after the implementation of new roads. Nevertheless, population growth during the 1980s (1981-1991) was tested as independent variable.

Moreover, population growth during the 1990s (1991-2001) is the dependent variable, substituting the more usual GDP variation. This choice will be explain in the next section.

3.3 GDP, population and other development variables

The gross product (GDP) variation rate is usually adequate to reflect regional development and is common in this type of study.

However, there is no information on this variable for the municipality level. For that reason, the population variation rate can act as a proxy for the GDP variation rate and represents a good alternative in the absence of good GDP data. In fact, comparing both variables for the period under study (1991-2001) and for the usual scale of NUT III, there is some positive correspondence between population growth and GDP growth (see Figure 4).

(Include here Figure 4)

This correspondence gets stronger if we consider only the NUT III regions included in study area (see Figure 5).

(Include here Figure 5)

In fact, looking at GDP evolution (between 1991 and 2001), it is possible to see that inside the study area only the NUT III Dão-Lafões is above average, with most of the NUT III inside the study area with more than one standard deviation below average (see Figure 6). Observing the 2006 values (which are not substantially different from the 2001 values) one can see that only Lisbon and Porto metropolitan areas, a few adjacent ones and Algarve are above average. All NUT III in the study area are below average (see Figure 6).

(Include here Figure 6)

These observations reinforce the opportunity in the use of population growth as a proxy for development for 1991-2001 period.

Other variables could be assessed to represent development (as dependent variables), such as purchase power and population migrations, but they proved to be not adequate and/or are not consistent with this study purposes. In the case of purchase power, it is not possible to guarantee that it easily relates with endogenous factors such as the way families use it in benefit of local development. In the case of migrations, Portuguese data is not consistent with reality (there is not enough data about emigration for other countries, for example) and therefore it is not wise to use it.

3.4 Accessibility and population

The evolution of accessibility conditions for the study area was analysed with detail, since the associated indicators represent the independent variables used to measure new infrastructures effects in terms of accessibility.

There are several ways to measure accessibility and therefore different types of indicators were calculated and integrated in a sensitive analysis.

The two main types are relative accessibility indicators and potential accessibility indicators.

Relative accessibility indicators have the general expression is as follows:

$$A_{ij} = t_{ij} \qquad (5)$$

where $j \in \{capitals\}$, $i \in \{municipalities\}$ and

$t_{ij} = minimum\ travel\ time\ by\ road\ between\ \ i\ and\ j.$

This is typically a measure for spatial separation between i and j i.e. between each municipality and each capital (destinations) considered. Four different types of capitals (destinations) were taking into account, resulting in four different types of measures for each municipality:

- time to the national capital (Lisboa);
- time to the regional capital (Porto for the north part and Coimbra for the south part of the study area);
- time to the district capital of each municipality; and
- time to the nearest local capital (nearest locality with a bureau that provides city councils with technical support services in civil engineering).

Using the values for 1991 (before) and 2001 (after), the variation rate for each municipality was calculate and used as an independent variable.

Regional accessibility indicators, representing a more integrated approach (namely daily accessibility and potential accessibility), are regarded as being the most suitable to capture the variability of impacts. In fact, they take into account both the different geographic units' socio-economic characteristics, and the different transport network infrastructures. The approaches using regional accessibility indicators were pulled-up with Keeble's seminal work (Keeble et al, 1982). Other authors such as Evers (1987), Rietveld (1989), Gutierrez & Urbano (1996), Vickerman (1995, 1999), Schurmann et al (1997) and Rietveld & Bruinsma (1998) also developed several studies on accessibility indicators, namely in potential accessibility.

The regional accessibility indicators have the following general expression:

$$A_i = \sum_j g(W_j)\, f(C_{ij}) \qquad (6)$$

In this expression, $g(W_j)$ is the utility function (the quality of what is accessible) and $f(C_{ij})$ is the impendence function.

Daily accessibility has the following general expression:

$$A_i = \sum_{j \in Z: t_{ij} \leq t_{max}} P_j \qquad (7)$$

In this expression P_j is population in destination$j$; Z represents the group of destinations according to a time limit $t_{máx}$ and $t_{máx}$ is alternatively 60 minutes or 90 minutes. These limits are according, in average, with the regional trip pattern in Portugal. The value t_{ii} is equal to one. Using the values for 1991 (before) and 2001 (after), the variation rate for each municipality was calculate and used as an independent variable.

Potential accessibility has the following general expression:

$$A_i = \sum_j \frac{P_j}{e^{0,05 t_{ij}}} \quad (8)$$

In this expression, P_j is the population and represents utility in destination j and t_{ij} is the minimum travel time by road between i and j. The value $\beta = 0,05$ we choose represents, in average, the way the demand for a trip decreases with the increase of travel time expected, in Portugal. As before, the value t_{ii} is equal to one. Using the values for 1991 (before) and 2001 (after), the variation rate for each municipality was calculate and used as an independent variable.

The use of accessibility indicators' variation rate (accessibility gains) as independent variable is easily justifiable because changes expected in the short run, commonly have an influence in what is happening now.

All these indicators calculation uses minimum 'travel time by road' matrices (one for the moment before and other for the moment after the new road improvement) and the municipalities' socio economic characteristics. These time matrices were built upon detailed road networks, connecting the 86 municipalities and a set of other cities used as potential destinations in the accessibility indicators calculations. These other destinations are some capital districts (in the coastal region) and other important Portuguese cities, close or important to the region under study. These networks correspond respectively to the before and to the after moments and the resulting time matrices have one hundred and forty one (141) nodes (see Figure 7).

(Include here Figure 7)

It was also previously tested the potential relation between growth in accessibility and population growth. Curiously, there was not found a strong correlation between the two evolutions, leading us to the mistrust of accessibility importance on the model chosen.

In fact and looking at the population evolution (rate of variation) on one side and on potential accessibility evolution (rate of variation) on the other, the regional pattern shows a few important differences, like some municipalities with a population evolution above average and accessibility evolution below, or the other way around (see Figure 8 and Figure 9).

(Include here Figure 8 and 9)

Moreover, we found a correlation coefficient of 0,23 while using rate of variation for both variables (population and accessibility), and a coefficient of 0,31 while using only the variation. This fact indicates that the initial situation (1991) in terms of both population and accessibility is weakly determinant on the evolution. Therefore, and looking for a more precise spatial pattern on the combined evolution[3] of population and accessibility, a new map with the summing variation on both population and potential accessibility was built. We noticed that the municipalities that are simultaneously close to district capitals, near the coastal area, and close to new roads, revealed an evolution between population and accessibility positive and significant.

(Include here Figure 10)

This combined evolution of population and accessibility helped us to define two different areas or clusters, further applied on the spatial econometric analysis, to test for the structural stability of this area (two different spatial regimes).

3.5 Human resources

The human resources in the beginning of the period of analysis (1991) - in the form of population levels of education - are the variables used to test for the accessibility indicators significance against regional development (population growth). This is because while gains in accessibility relate with investments in infrastructures the

[3] This value was obtained by summing the population variation in each municipality with the potential accessibility variation on each municipality (which is variation of the population reachable due to a decrease on travel time by road).

level of higher educated people relate with education policies under a more dynamic economy.

The four educational levels chosen are:

- Fourth level or less in 1991, called ‘Primary’
- Basic education (9th level) in 1991, called ‘Basic’
- High school education (12th level) in 1991, called ‘High school’
- University education (5 years) in 1991, called ‘University’

Although the simultaneous use of these four variables causes some problems in the analysis of regression (because they represent percentages of the same quantity), the regression analysis process followed accounts for the exclusion of multicollinearity, keeping the significant ones. Testing for the opportunity in the use of these variables, we developed a few previous tests.

Namely, we tested for the relation between University educational level in 1991 and population variation in 1991-2001 and the same relation but for the less than 9^{th} grade educational level.

We found out that most of the municipalities have 60% to 80% of population with less than 9^{th} grade. Above the level of 70%, the great majority have negative levels in population evolution. Considering the University educational level, all the municipalities with more than 3,5% of population with an university educational level have clear positive population evolutions. On the other hand, most of the municipalities have university level proportion between 1% and 2% and corresponding population evolutions below zero (see Figure 11 and Figure 12).

(Include here Figure 11 and 12)

4 The model

The model applied has the following general expression:

$$\Delta D = f(\Delta \boldsymbol{A}, \boldsymbol{X}, \varepsilon, \boldsymbol{W}\Delta D, \boldsymbol{W}'\varepsilon) \tag{9}$$

where ΔD means population growth (development) for the period 1991-2001, $\Delta\boldsymbol{A}$ means accessibility gains for the same period, $\boldsymbol{X}$ represents a matrix of added variables (including population levels of education), ε is the error term, $\boldsymbol{W}\Delta D$ is the spatial lag for the population growth and $\boldsymbol{W}'\varepsilon$ is the spatial error term.

The selection of this set of variables allows us to answer the question: what is more important for the population growth during a certain period?:

- the population initial levels of education (substantial levels of high educated people relate with a more dynamic local economy),
- the population growth in the past (the past tendency is the same now?), or
- the accessibility gains expected (public road infrastructures supply, easiness of access to markets and places).

The inclusion of space (alternatively spatial lag or spatial error term) as an explanatory factor, also allows us to verify whether the statistical significance of accessibility depends on the existence of spatial auto-correlation (i.e. significant spatial patterns). The methodology followed starts with the evaluation of classical regression results and searches for the opportunity of including a spatial specification (lag or error) in the models (Anselin, 1988; Anselin, 1992; Bailey & Gatrell, 1998 Florax et al, 2003, Arbia, 2006).

Among several models and specifications in spatial econometric methods, these two alternatives to the classic model adapt to the most part of spatial development situations at a regional scale.

(classic)
$$\Delta P = \beta\Delta\boldsymbol{A} + \gamma\boldsymbol{X} + \varepsilon \qquad (10)$$

(*spatial lag*)
$$\Delta P = \rho\boldsymbol{W}\Delta D + \beta\Delta\boldsymbol{A} + \gamma\boldsymbol{X} + \varepsilon \qquad (11)$$

(*spatial error*)
$$\Delta P = \beta\Delta\boldsymbol{A} + \gamma\boldsymbol{X} + (I - \lambda\boldsymbol{W})^{-1}\varepsilon \qquad (12)$$

We test these models in a previous research and present its results on the next chapter.

The presence of spatial heterogeneity on spatial error specifications from that research, lead us, in a first attempt, to test the structural stability of the data set.

In fact, the assumption of a fixed relation between the explanatory variables and the dependent variable that holds over the complete dataset might not correspond to reality. Instead, heterogeneity may be present, in the form of different intercepts and/or slopes in the regression equation for subsets of the data. This structural instability can be express in the form of switching regression models. When the different subsets in the data correspond to regions or spatial clusters, these switching regression specifications correspond to different Spatial Regimes (Anselin, 1988).

For example, for two regimes following the value of an indicator (dummy) variable d, the constant term and slope coefficients would take on two different sets of values, depending on the regime:

$$y_1 = \alpha_1 + X_1\beta_1 + \varepsilon_1 \quad (13)$$

$$y_2 = \alpha_2 + X_2\beta_2 + \varepsilon_2 \quad (14)$$

This method allows us to detect locally the significance of the relation between accessibility evolution and population evolution.

5 Results

5.1 Resume of previous research

In a first phase, a spatial regression analysis was done for both types of accessibility variables (relative and regional). Each one of these sub phases, comprehend two steps. In the first step, accessibility indicators significance is test using only population growth in the previous period as an independent control variable. In the second step, accessibility indicators significance is test using human resources and population growth in the previous period, as independent variables.

After this initial process, all the significant variables in previous analysis were included in a final model (except for the ones that inflate the multicollinearity number), using a spatial error specification in order to uphold the previous results (see table 1).

(Include here Table 1)

The final expression obtained is as follows.

$$\Delta P_{0-1} = -29{,}81 + 0{,}36\Delta A_{0-1}^{naccap} - 0{,}21\Delta A_{0-1}^{regcap} + 0{,}04\ \Delta A_{0-1}^{pot} + 1{,}24Eob_0\ + 3{,}09Esup_0\ + (\boldsymbol{I} - 0{,}42\boldsymbol{W})^{-1}\varepsilon \quad (15)$$

were ΔP_{0-1} is population growth between 1991 and 2001, ΔA_{0-1}^{rel1} is accessibility growth to national capital, ΔA_{0-1}^{rel2} is accessibility growth to regional capital, $0{,}04\ \Delta A_{0-1}^{reg3}$ is potential accessibility growth, $E_0^2$is basic level of education (9th grade) in the beginning of the period, E_0^4 is university level of education in the beginning of the period and $(\boldsymbol{I} - 0{,}42\boldsymbol{W})^{-1}\varepsilon$ is the error term, spatially auto-correlated.

The following interesting outcomes can be use as general conclusions. The only significant accessibility variables are the gain in accessibility to the national capital (Lisbon) ($0{,}36\Delta A_{0-1}^{naccap}$) and the gain in accessibility to the regional capital - although in the latter case with an inverse relation ($-0{,}21\Delta A_{0-1}^{regcap}$). None of the regional accessibility variables is significant, except ‘Potential’ accessibility ($0{,}04\ \Delta A_{0-1}^{pot}$), but when educational levels are included. Nevertheless, this variable drops its significance in spatial error specification. The ‘basic’ and the ‘university’ levels of education are the most significant ones, although with particular significance in the latter case ($3{,}09E_0^{sup}$).

In view of these results, it is wise to state that accessibility variables are weak explanatory factors in development (population growth) when considered isolated and get weaker when population levels of education are included. On the other hand, when these variables are included, the advice for the use of a spatial error specification also appeared (and the high and significant autocorrelation coefficient confirms it: 0,42).

The high autocorrelation term and the high level of significance for remaining heterocedasticity in the spatial error specification, indicate that this might be due to the existence of spatial regimes(different clusters or areas where the relation modeled observes different coefficients).

5.2 Spatial regimes

To test for the Spatial Regimes specification, two different regimes were considered. These regimes were built using a dummy variable designated as $Regi$, that results from a criteria applied to the summing of population variation and potential accessibility variation, (in each municipality)[4]:

$$Regi = \begin{cases} 1 \Leftarrow (P_1 - P_0) + (APOT_1 - APOT_0) \geq 15000 \\ 2 \Leftarrow (P_1 - P_0) + (APOT_1 - APOT_0) < 15000 \end{cases} \quad (16)$$

According to this variable, two different spatial regimes can be considered, dividing the study area in two, and resulting in switched regression as follows:

Regime 1

$$(\Delta P_{0-1})_1 = -\alpha_1 + \beta_{11}\left(\Delta A_{0-1}^{naccap}\right)_1 + \beta_{12}\left(\Delta A_{0-1}^{regcap}\right)_1 + \beta_{13}\left(\Delta A_{0-1}^{pot}\right)_1 + \beta_{14}\left(Eob_0\right)_1 + \beta_{15}\left(Esup_0\right)_1 + \varepsilon_1 \quad (17)$$

Regime 2

$$(\Delta P_{0-1})_2 = -\alpha_2 + \beta_{21}\left(\Delta A_{0-1}^{naccap}\right)_2 + \beta_{22}\left(\Delta A_{0-1}^{regcap}\right)_2 + \beta_{03}\left(\Delta A_{0-1}^{pot}\right)_2 + \beta_{24}\left(Eob_0\right)_2 + \beta_{25}\left(Esup_0\right)_2 + \varepsilon_0 \quad (18)$$

These two regimes correspond respectively to an area simultaneously closed to the cost, to district capitals and to new roads, from north to south (*Regime 1*) and to the remaining area (*Regime 2*), with 50 and 36 municipalities (see Figure 13). A mentioned in a previous note this divides the study area sensitively by half in a West - East division.

(Include here figure 13)

Running the resulting heterokedastic error model, it is possible to notice that R2 is not substantially different but slightly better (0, 59 against the previous 0, 54) and that the information criteria (Log Likelihood, Akaike and Schwarz) are not substantially different (better in Log Likelihood and Akaike but worse in Schwarz).

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[4] The use of 15000 value is case sensitive. In further analysis other limits should be tested. For now, this choice was determined by the fact that this value divides the study area into two similar areas, in a clear West-East division and shows the influence of some new roads.

Looking at variables significance, in *Regime 1* all variables are significant except the variation rate of potential accessibility, as it happens in spatial error specification for expression (15). In *Regime 2,* none of the variables is significant except the university educational level.

In *Regime 1*, the accessibility to the national capital growth holds a significant but negative relation with population growth.

The test for the structural stability for two regimes, is implemented for all variables jointly and for each separately (Chow-Wald test). This is a test on the null hypothesis that the coefficients are the same for the two-regimes. In the present case, it is possible to reject the null hypothesis, with the value of 14, 47 being extreme for 3 degrees of freedom. This is to say, the differences between coefficients in the two regimes is statistically significant. In the test for individual coefficients, it is noticeable the fact that only accessibility growth to national capital and to regional capital, have statistically significant differences between the two regimes. In order words, the relation between each of these two types of accessibility and population growth is different in each of the regimes defined by variable *Regi*.

In the diagnosis for spatial dependence, there is no indication that the proper analysis of the effects of spatial regimes should include a spatial lag or a spatial error in the model. This means that the indication for spatial error dependence, in the first phase of the analysis, was probably related with the existence of spatial regimes. With the use of this switched regression model the indication for this dependence no longer exists.

As a general conclusion of the application of spatial regimes specification, it is possible to say that there are statistically significant differences for the relation indicated in expression (15), at least for two different geographical areas inside the study area.

6 Conclusion

In the results of this application study, we verified that the contribution of accessibility to regional development, measured in population growth, is poor or inexistent.

First, the general idea that new roads have a strong effect in regional development when looking at it on an aggregated level, gets diffused when looking at that effect on a local level. This conclusion has becoming increasingly present in the scientific literature devoted to study the relation between accessibility and regional development. For this case study and first considering a study area composed by 86 municipalities -which is a small area compared to the more usual European NUTIII – it was statistically robust to stand that the only type of accessibility growth that was positively influent on population growth was the accessibility to the national capital. The growth in accessibility for the regional capital was negatively influent in population growth and the regional accessibility of the gravity type was weakly significant but loosing that significance when estimating a spatial error model.

Secondly, the fact that the final spatial error model estimated still holds a significant amount of heterocedasticity yet to be absorbed indicates that some spatial processes were still occurring and are not included in the model. This apparent structural instability could probably indicate that it is not possible to hold the modeled relationship over the complete study area. Therefore, and using a previous geographical analysis on the relation between population growth and accessibility growth, two different subsets of municipalities were built. These two groups form a Spatial Regimes specification, for a switching regression method. Surprisingly, but accordingly to the previous geographical analysis above mentioned, there is a statistically significant difference in the relation between accessibility growth and population growth with the two different areas or regimes.

First and for both regimes, potential accessibility growth is not significant.

Secondly, the growth in accessibility to the capital influences negatively population growth for the sub-area corresponding to *regime 1* (more closed to the coast and closed to the main roads that guide the traffic for the capital), with statistical significance (the same does not happened in *regime 2*).

Thirdly, the accessibility growth to the regional capital is significant and positively influent in population growth in this area, but not in *regime 2*. This is opposite to what happened in the analysis for the complete study area.

The proportion of the population with a university degree, have a positive and significant impact on population growth for both regimes.

The proportion of the population with basic education is only significant in *regime 1*.

From a regional development perspective, we can state that it is more important to have highly educated people now, than to built for substantial gains in accessibility in the future, in order to predict population growth (and consequently development), as we previously stood for.

Accessibility revealed to be not significant or much less significant that might be initially expected.

The further analysis should turn on into other geographically detailed analysis, like the consideration of a spatial regimes specification dividing the study area into North and South, or spatial regimes defined by the relative importance of different urban centers.

Other spatial models and other variables should also be considered in order to capture more of the regional relationship between accessibility and development and to make this methodology completely able to replicate in other case studies.

This approach is innovative in the type of spatial disaggregation, in the type of variables used and in the comparisons made.

It is also the first Portuguese study testing for the recent huge gains in accessibility impacts in the off-coast Portuguese regions development and underlines the importance of selective infrastructures policies within the national and regional context.

The test on the spatial regime specification also indicates its importance in analyzing different local behaviors in the relation between accessibility growth and population growth.

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Figure 1 - The study area location

Figure 2 - The study area (in green)

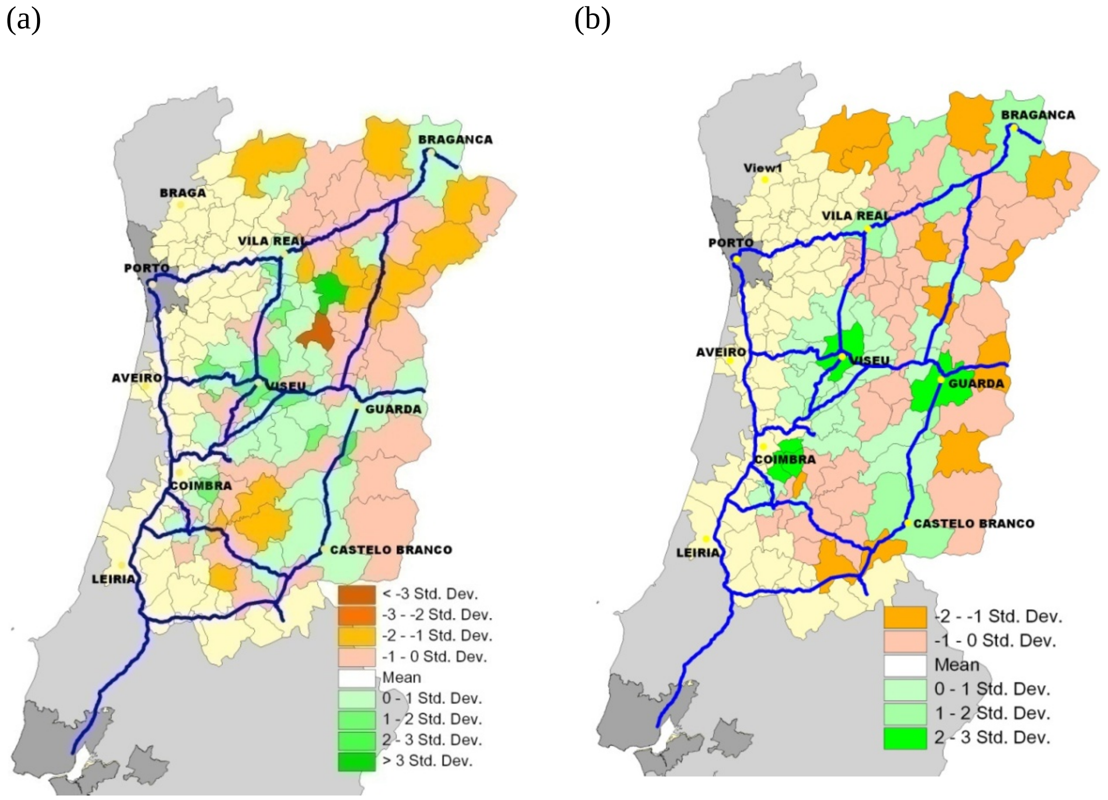

Figure 3 - Population growth in the period 1981-1991 (a) and in the period 1991-2001 (b)

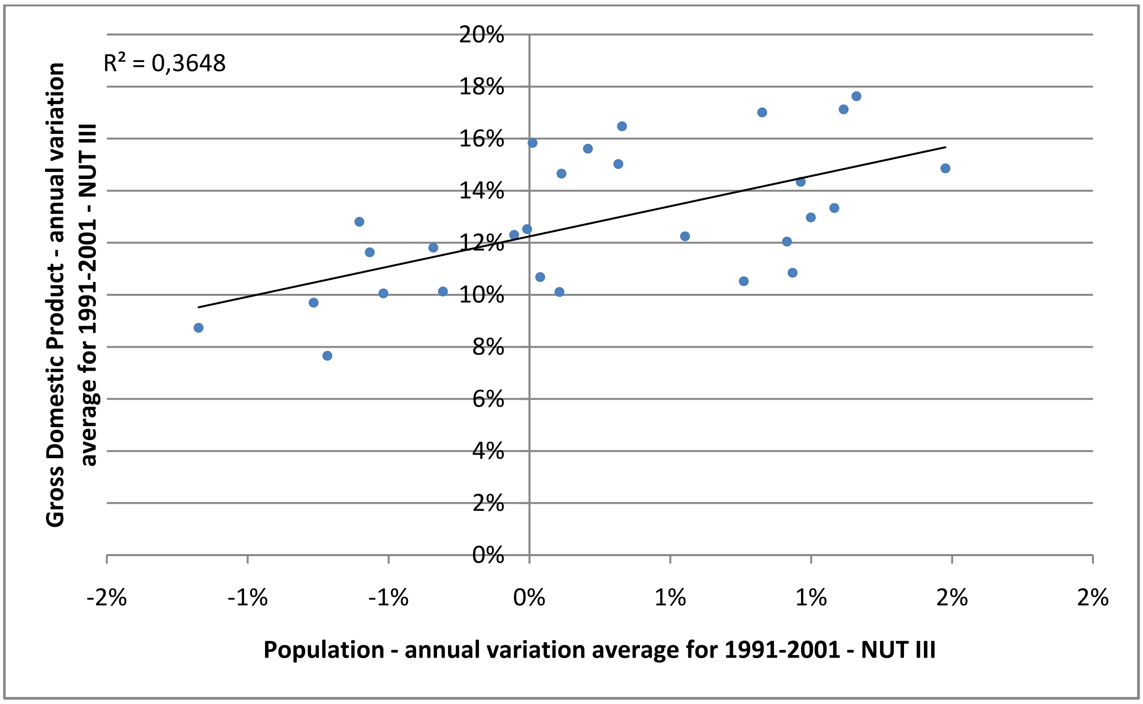

Figure 4 – Population variation rate versus GDP variation rate in NUTIII Portuguese regions

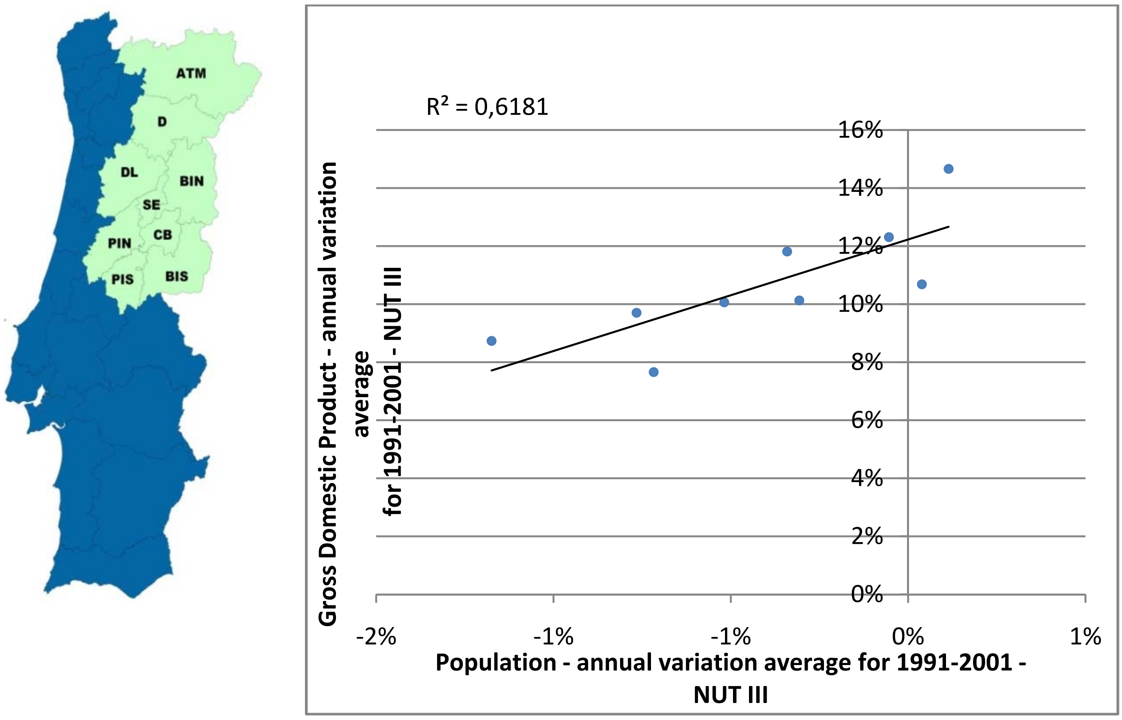

Figure 5 - Population variation rate versus GDP variation rate in the NUTIII included in the study area

(a) (b)

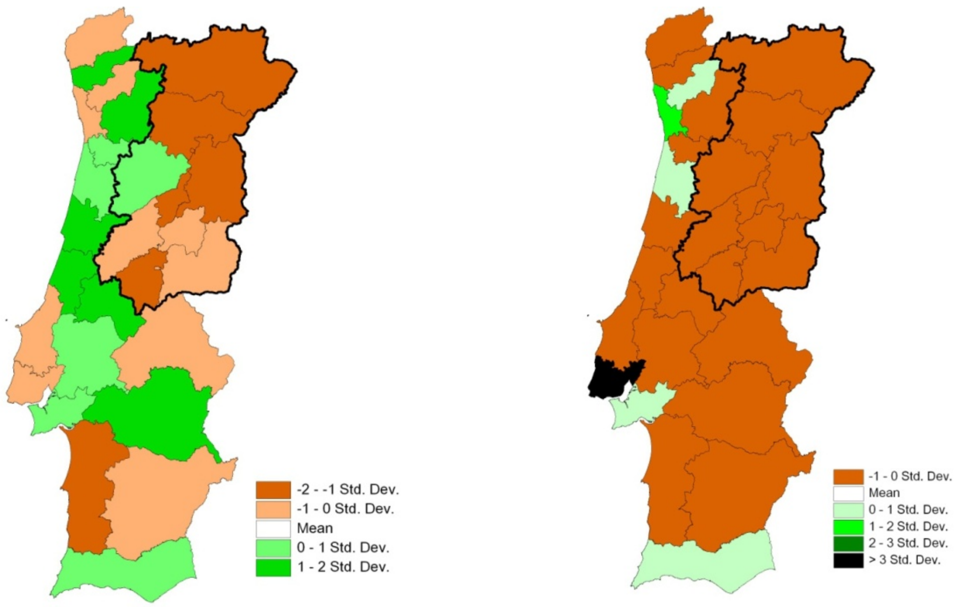

Figure 6 – Gross domestic product evolution between 1991-2001 and gross domestic product in 2006

(a) (b)

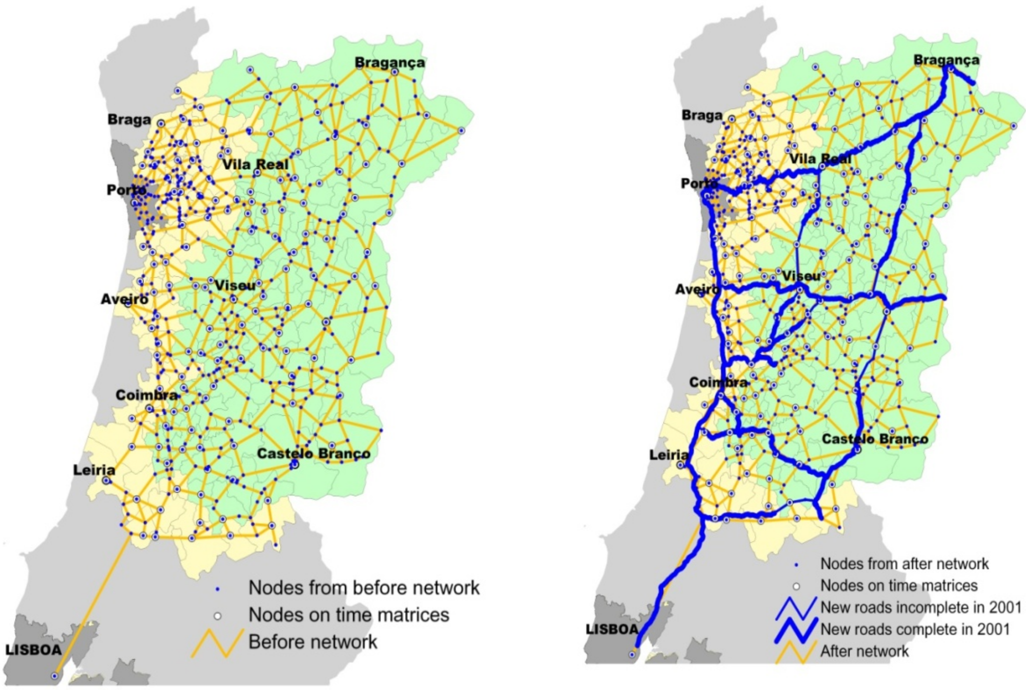

Figure 7 – The study area road network ‘before’ (a) and ‘after’ (b) the new road improvements

(a) (b)

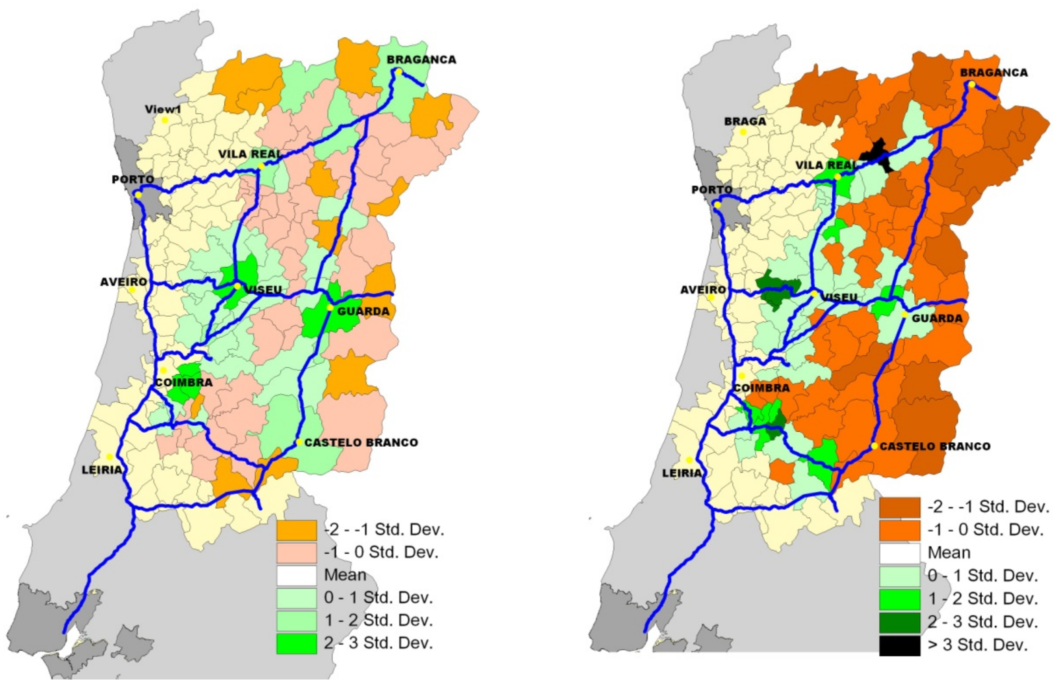

Figure 8 – Population (a) and Potential Accessibility (b) evolutions between 1991 and 2001

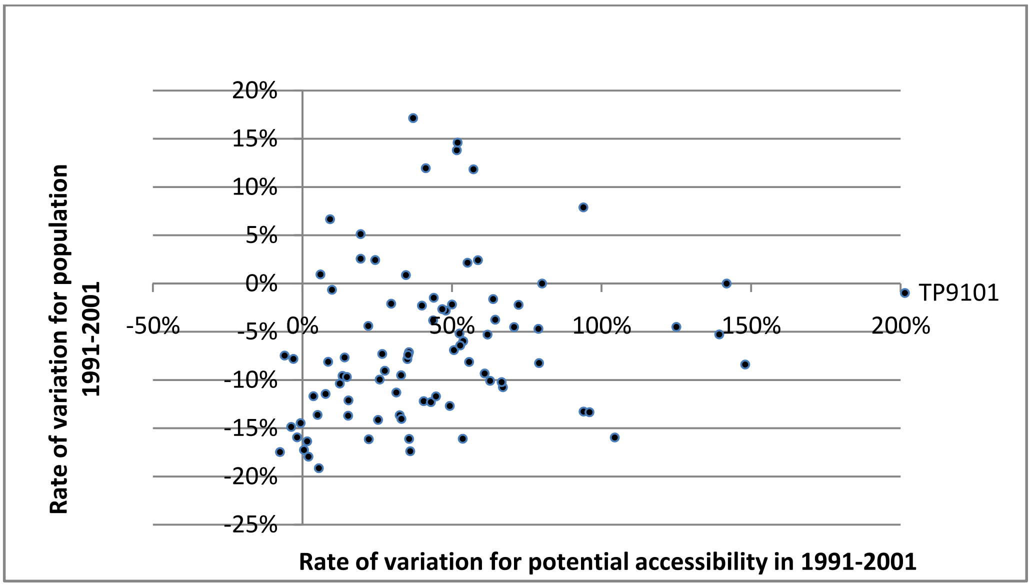

Figure 9 – Population (a) and Potential Accessibility (b) evolutions between 1991 and 2001

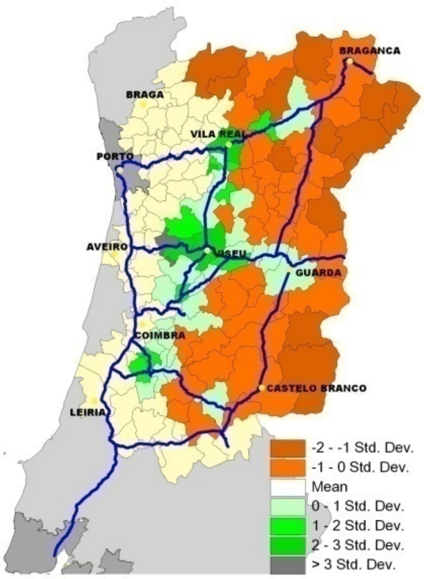

Figure 10 – Population (a) and Potential Accessibility (b) combined evolutions between 1991 and 2001

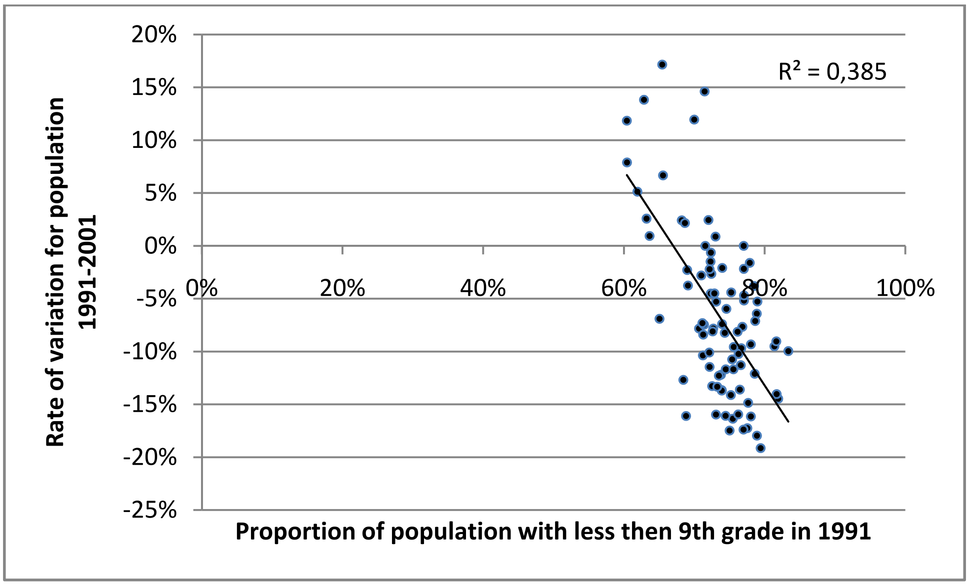

Figure 11 – Relation between less educated people in 1991 and the population evolution between 1991-2001

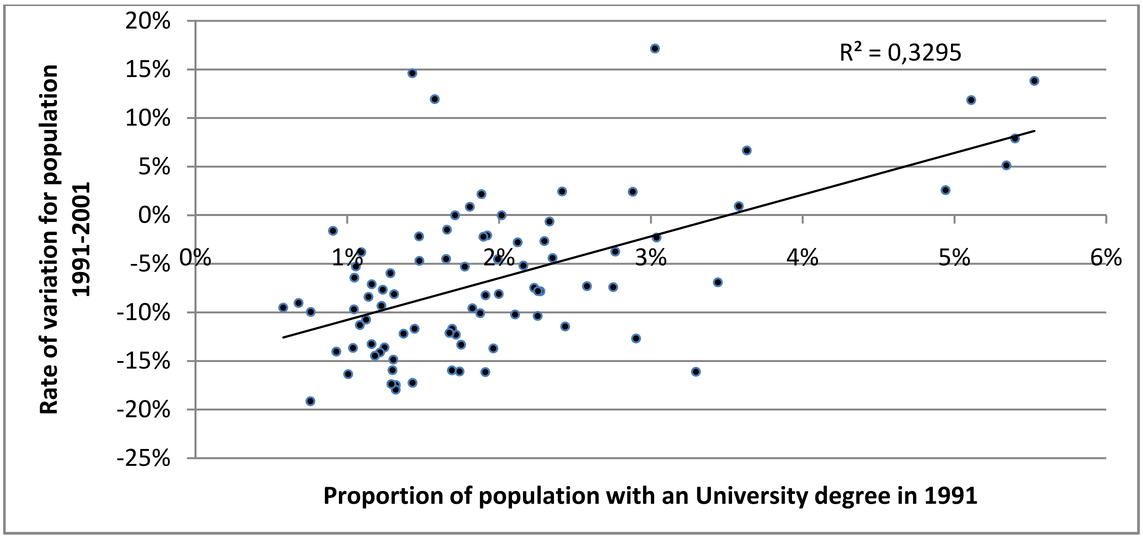

Figure 12 – Relation between people with a university degree in 1991 and thepopulation evolution 1991-2001

Figure 13 – Spatial regimes considered

Statistics	Classic Regression			Spatial Error Regression		
	COEFF	**SD**	**t-value**	**COEFF**	**SD**	**z-value**
R2	0,54			0,59		
R2aj	0,51					
Constante	-29,08	5,10	-5,70	-29,81	5,61	-5,31
ΔA_{0-1}^{rel1}(National capital)	0,36	0,13	2,70	0,36	0,17	2,16
ΔA_{0-1}^{rel2}(Regional “)	-0,29	0,07	-4,19	-0,21	0,08	-2,72
ΔA_{0-1}^{reg3} (Potential accessibility)	0,05	0,02	2,09	0,04	0,03	1,49
E_0^2(Basic education)	1,33	0,66	2,01	1,24	0,65	1,91
E_0^4 (University “)	2,98	1,01	2,94	3,09	0,95	3,24
λ				0,42	0,13	3,29
Log Likelihood	-266,89			-263,48		
Akaike	545,79			538,96		
Schwarz	560,51			553,69		
Multicoliniarity	27,34					
Jarque-Bera (normality)	3,29					
Breuch-Pagan (heterocedasticity)	31,83					
Koenker-Basset (heterocedasticity)	24,49					
White (heterocedasticity)	38,15					
Moran’s I	0,18					
Normalized Moran’s I (Z)	3,23					
Lag Lagrange Multiplier	4,60					
Lag Lagrange Multiplier (robust)	0,16					
Error Lagrange Multiplier	6,18					
Error Lagrange Multiplier (robust)	1,74					
Breuch-Pagan				31,47		
Likelihood Ratio				6,83		

Figure 14 - Accessibility and human resources versus development – comparing the classic and the spatial error regression

HETEROSKEDASTIC ERROR MODEL (GROUPWISE)				
R2	0,5984			
Log Likelihood	-259,732			
Akaike	543,463			
Schwarz	572,915			
VARIABLE	**COEFF**	**SD**	**z-value**	**Prob**
CONST_0	-18,55	6,81	-2,73	0,01
ΔA_{0-1}^{rel1}(National capital)_0	-0,02	0,18	-0,11	0,92
ΔA_{0-1}^{rel2}(Regional “)_0	0,11	0,09	1,20	0,23
ΔA_{0-1}^{reg3} (Potential accessibility)_0	0,03	0,05	0,55	0,58
E_0^2(Basic education)_0	-0,05	1,00	-0,05	0,96
E_0^4 (University “)_0	5,18	1,67	3,10	0,00
CONST_1	-34,22	7,58	-4,52	0,00
ΔA_{0-1}^{rel1}(National capital)_1	-0,60	0,21	-2,88	0,00
ΔA_{0-1}^{rel2}(Regional “)_1	0,42	0,11	3,85	0,00
ΔA_{0-1}^{reg3} (Potential accessibility)_1	0,04	0,03	1,04	0,30
E_0^2(Basic education)_1	1,65	0,81	2,05	0,04
E_0^4 (University “)_1	2,35	1,15	2,05	0,04
REGI_0	18,70	4,41	4,24	0,00
REGI_1	29,95	5,99	5,00	0,00
REGRESSION DIAGNOSTICS				
TEST ON STRUCTURAL INSTABILITY FOR 2 REGIMES DEFINED BY REGI				
TEST	**DF**	**VALUE**	**PROB**	
Chow - Wald	6	14,47	0,02	
STABILITY OF INDIVIDUAL COEFFICIENTS				
CONST_0	1	2,37	0,12	
ΔA_{0-1}^{rel1}(National capital)_0	1	4,48	0,03	
ΔA_{0-1}^{rel2}(Regional “)_0	1	5,10	0,02	
ΔA_{0-1}^{reg3} (Potential accessibility)_0	1	0,01	0,92	
E_0^2(Basic education)_0	1	1,77	0,18	
E_0^4 (University “)_0	1	1,96	0,16	
TESTS ON HETEROSKEDASTICITY				
Wald test	1	2,29	0,13	
LR test	1	2,24	0,13	
DIAGNOSTICS FOR SPATIAL DEPENDENCE				
Lagrange Multiplier (error)	1	1,85	0,17	
Lagrange Multiplier (lag)	1	1,33	0,25	

Figure 15 – Heteroskedastic error model (Spatial regimes) results