Determining the Effects of Central-Peripheral interactions on the Distribution of Human Activity in Space*

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Natural advantages determine where agglomerations emerge. Also, efficiency and economies of scale determine how many agglomerations subsist and how they interact, forming complex urban hierarchies. Moreover, physical characteristics influence the way humans divide land into irregular parcels we call administrative regions. If, on one hand, initial location advantages are responsible for defining where the main urban nodes will grow and subsist because of lock-in effects, central-peripheral relations play a decisive role in defining the distribution of activity in space. This paper explores the importance of location in relation to the main centripetal nodes. A central-peripheral model is used to explain the distribution of hospital emergency services in Mainland Portugal. Also, urban growth dynamics is included in order to analyse how this variable conditions public investment in healthcare. It is shown that in a recent re-organisation of emergency services, territorial equity also played an important role in explaining spatial patterns in healthcare provision.

*This research is funded by the FCT - Fundação para a Ciência e Tecnologia (Grant SFRH/BPD/66012/2009).

1 Introduction

Human interactions depend on the emergence and growth of agglomerations. The resulting urban nodes form complex networks organised in hierarchies, in which the position of each node depend on the functional distributions of economic and administrative centres. Cities represent the centre of gravity, whose size and dynamism depend on the centripetal forces or agglomeration economies which allow an urban node to subsist. Initial advantages or first order advantages ((Krugman 1991, Ellison and Glaeser 1997 and 1999) which determine the birth of a city normally condition future investment rounds (Krugman 1993, Norton 1999). As cities grow, intricate hierarchies emerge; certain market locations become dominant, and peripheral regions emerge; in fact, although dominant locations concentrate most activity, most territory is peripheral in relation to some higher-order node.

Central-periphery dynamics have different consequences at different geographical scales and functional attributes. Locally, distinct rents/income levels have long been identified as a function of physical distance to a given location/point - typically representing the Central Business District, in a single-node region (Lösch 1954, Hagget 1969, McCann 2001). At the supranational level, the same push-pull dynamics creates larger centres, hence larger peripheries. This fact and the consequent need to create instruments to promote territorial cohesion was recognised in Post-War Europe with the creation, in the early Seventies, of the first major financial instrument in the sphere of regional policy and cohesion, the European Regional Development Fund (ERDF).

Different geographical scales imply different morphology and spatial distributions of human activity; yet, the underlying principles are the same. The factor which determines the number of nodes in relation to a specific social function is the necessary scale for this spatial distribution to be efficient, and scale, in economic terms, determines the catchment-area of each node. Different functions result in different hierarchies, because activity organises itself according to functional levels. The European Integration process is a good example: economic dynamics at a global level and the Common Market with the free flow of tradable goods, services and capital result in the emergence of new convergence clubs (Quah 2007, Crescenzi 2009). These clubs are a consequence (and later a reason) for activity to reorganise itself according to these new functional needs, and also according to efficiency maximising principles.

Long-term growth and decline of cities is determined by a complex number of centripetal and centrifugal forces, which have long been typified in Economics and Geography (McCann 2001). Agglomeration economies, which range from internal returns to scale (related to single firms) to externalities which are simply a result of broader supply of services inherent to dynamic urban nodes, condition urban growth. Planning policies and market forces together interfere with the spatial morphology of a city or metropolitan region. Planning interferes not only in terms of land-use restrictions but also in terms of investment in infrastructures, which range from transportation to education and health.

In relation to central planning in the field of Health Policy, there is a dichotomous relation between supply and demand. If on one hand, investment and the spatial reorganisation of activities should follow geographical trends in terms of demography, on the other, the location, or the absence of local supply of healthcare increases the peripheral nature of rural areas.

In the present study, the study-area, mainland Portugal, with its 89 thousand squared kilometers, represents only 2% of the European Union territory. Yet, it is characterised by a strong physical diversity which leads to different forms of land-use and exploitation and also to distinct forms of spatial agglomeration. This results in densely populated areas in the North and sparse occupation patterns in the South. The North/South divide, which has a natural border in the Tagus river, is the traditional macro-characteristic of the country (Ferrão 2002). In modern times, the mainland/interior divide became also a marked feature of the portuguese mainland. This happened for three reasons: on one hand, transport technology favoured an increase of interactions between large urban nodes; second, the Atlantic coast, with its main ports, represented a strong centripetal force pulling activity to coastal urban nodes; third, industrial development in the second half of the 20^{th} favoured locations between the two metropolitan regions of Lisbon and Oporto. Figure 1 represents the study area.

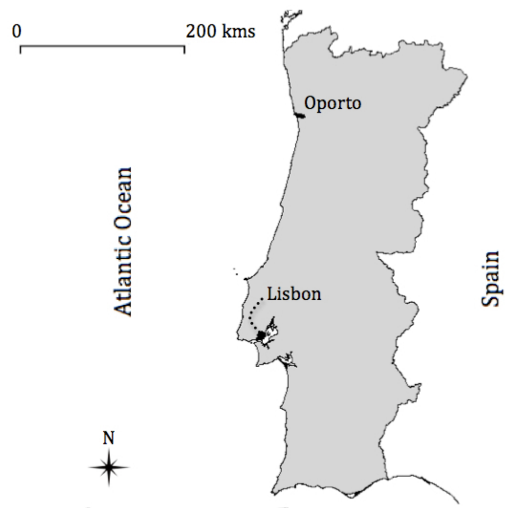


Figure 1: Study-area: Continental Portugal

Being peripheral within a territory marked by a strong and generalised polarisation of human activity along the coast, as in the case of Mainland Portugal means, in a first instance, to be located far away from the coastline. However, first order advantages, together with historical determinism in what initial hierarchies is concerned, caused an agglomeration of administrative functions in a small set of urban nodes. Moreover, since these small set of locations are not distributed homogeneously along the Atlantic coast (because of the scale necessary for them to be efficient), distance in relation to these small set of cities became very important.

The rest of the present paper is organised as follows: section 2 contains a set of methodological notes which explain how the theme of the study will be analysed. After the description of the variables considered and the tools used for their computation, a detailed description of the three sets of data is put forward together with a brief exploratory analysis concerning each. It will start with the definition, computation and analysis of distance measures, of great importance to the construction of a peripherality index; this will be followed by a exploration of urban trends during the Nineties in Mainland Portugal; finally, healthcare provision data, focused on the (re-)distribution of emergency services, will be presented. Section 3 discusses the models to be estimated and presents the results. Section 4 concludes.

2 Methodology and exploratory analys

The central-periphery definition, which is in the core of the present study, is supported by the measurement of two key variables: first, time-distances to two metropolitan areas and to the coastline, and second, resident population (Rodrigues 2010). While the latter is obtained from the 2001 Census, the former is computed using a Geographic Information System (GIS). The use of GIS as a modelling framework to measure time-distances to pre-defined targets became a common methodology particularly because of advances in computer hardware in the recent past ((Julião 1998, Rodrigues 2001, 2005, 2010, Rodrigues etal. 2008). In this study, accessibility to Lisbon and Oporto is measured as a function of the time it takes to move, using private transportation, from any location in the study-area to the nearest destination. A *raster* model is used, which divides the study-area into a regular grid of 50 by 50 meter cells, where the value of each cell is equal to the time it takes to cross it (cell crossing time), which itself is a function of road-network typology, census tracts classification (urban/rural) and the first order hydrographic network. Whilst road network and census tracts classification directly condition travelling speeds, hydrography is used as partial obstacles in order to take into account physical terrain differences; this is based on two factors: first, movement along a sinuous network is slower than over a flat landscape;

second, density of an hydrographical network is positively correlated to terrain irregularity.

As mentioned above, one objective of the present article is to understand the relation between the core-periphery framework and urban growth. In order to measure urban growth, the general census has a number of useful variables which quantify, for each census tract, the number of new buildings according to predefined time-periods. This allows the construction of simple, yet robust indexes of urban dynamics. These measures allow an accurate understanding of spatial patterns observed in the study-area.

The second variable (or group of variables) which will be analysed together with peripherality is that which classifies the availability of health emergency services. According to a 2008 Law-Decree, the Urgency-Emergency services in Continental Portugal were reorganised in order the cover more efficiently the whole territory (Rodrigues etal. 2008). It is assumed that supply of healthcare responds to demographic trends; hence, a functional relation will be tested which conditions the spatial distribution of emergency services to peripherality and urban growth.

The individual exploratory analysis of the three steps of variables aid to understand existent patterns in terms of: (i) the central-peripheral dichotomy in Continental Portugal, (ii) existing urban hierarchies and their dynamics and (iii) the distribution of essential public health services.

2.1 Central-periphery dichotomy

The task of calculating time-distances between any given pair of locations requires solving the exercise of minimising the total cost of traveling between these locations. This modelling exercise, in order to consider the continuous nature of space, involves also the creation of a theoretical surface, a cost surface which, given a set of assumptions, simulate the portion of the real world being studied. Within this cost surface, in which the cost of traveling (cell crossing time) is expressed in minutes, time-distances are calculated between a set of origins (which can be the whole surface and a set of pre-defined destinations). The assumptions mentioned can be divided in two groups: first, those which assume an homogenous traveling cost (i.e. for any direction chosen, speed is constant), considering in this case isotropic theoretical surfaces; second, those which take into account different variables, creating in this case anysotropic theoretical surfaces.

When using an anysotropic surface, the use of variables which cause crossing costs to differ along a particular study area allows the calculation of the total crossing-time between any given locations. The exercise of calculating crossing-times between all the study area and a number of chosen destinations result in the creation of accessibility surfaces, where the value of each cell/location represents the minimum time it takes to travel to the nearest destination. Figure 3 represents the accessibility surfaces in respect to the coastline (a) and to Lisbon and Oporto (b). Time-distances were calculated only for census tracts classified as urban; Rodrigues (2010) demonstrates that, for this study area, differences between this methodology and one which calculates distances from every location in the study-area are not significant.

After calculating the accessibility surfaces, time-distances to the nearest target were aggregated allowing the computation of a set of statistics for each of the 278 local councils of Mainland Portugal. Figure 3 represents average time-distances from each local council to the nearest destination, in descending order. The common convex shape of the line indicates the existence of a number of ultra-peripheral regions within the study-area.

2.2 Urban structure

In relation to the concentration of urban functions around Lisbon and Oporto, figure 4 (a) shows evidence of such pattern; it represents population density for each local council: It is clear that there is a densely populated corridor along the

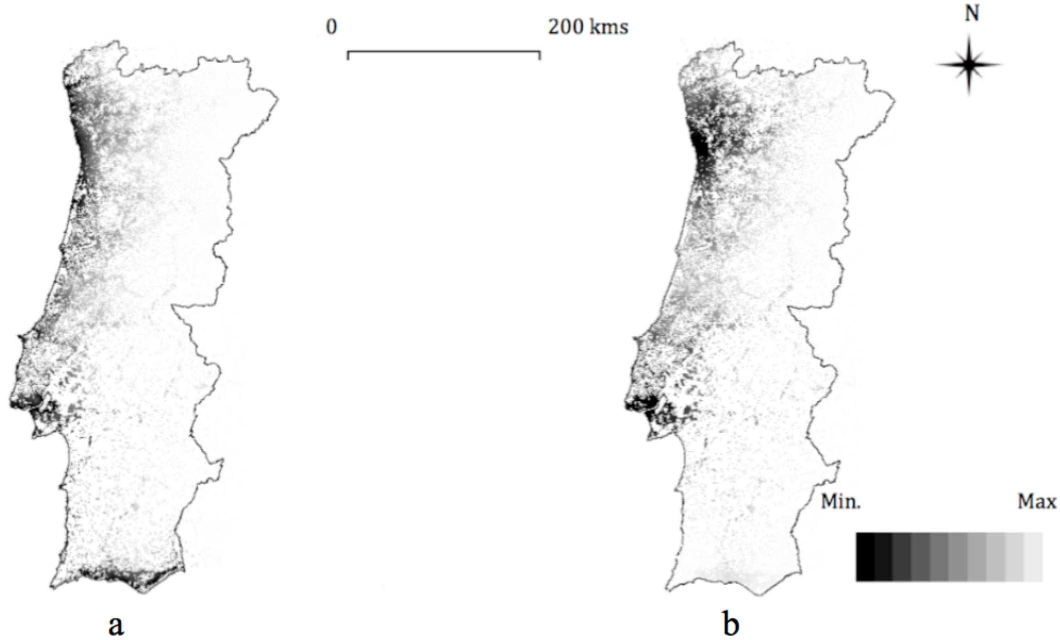


Figure 2: Coastal and metropolitan accesibility (time-distances)

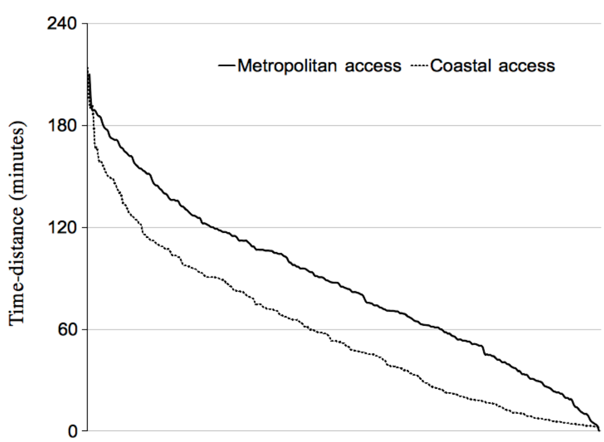
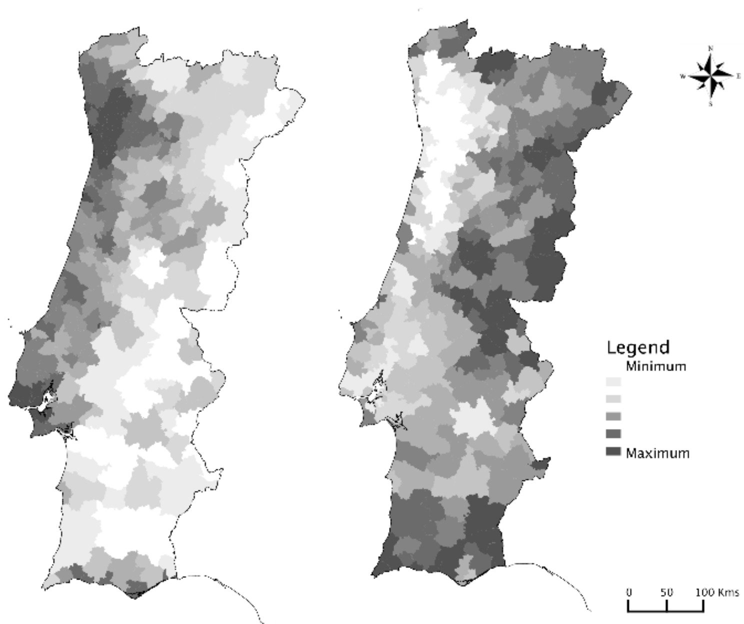


Figure 3: Coastal and metropolitan accesibility (time-distances)

coast, which starts in the northern border of the country and stops in the Lisbon metropolitan area. On the other hand, figure 4 (b) shows the spatial distribution of the ratio between the number of buildings and resident population. The spatial pattern is the inverse to that of population density. It is an indication of two phenomena: first, it results from a massive movement throughout the past decades from rural peripheral areas to Lisbon and Oporto. This trend was mostly noted since the 1960's when there was large public and private industrial investment along coastal areas, with high demand for blue-collar labour. The second factor which is somewhat related to the first is the existence of second-homes, owned by individuals or families who moved to the two emerging metropolitan areas.



a b

Figure 4: Population density (a), number of buildings per resident population (b)

With the objective of studying urban growth, census data from the 1990's was used. More important than analysing the gross number of buildings, an urban dynamics' index ($Udyn$) was constructed at the local council level, which is the ratio of new buildings erected in the Nineties ($b^{>90}$) and the number of existing ones (B). Formally, for each i local council:

$$Udyn_i = \frac{b_i^{>90}}{B_i} \tag{1}$$

In order to better understand the existing patterns of the index, a spatial lagged version of the variable was created, using a standardised contiguity spatial weights matrix W, where each element w_{ij} represent whether spatial units i or j are contiguous or not. Formally, the spatial lag of $Udyn$ is equal to:

$$Udyn_i^{lag} = \sum_{j=1}^{k} w_{ij} \cdot Udyn_j \quad , \tag{2}$$

for the set of k neighbours of i.

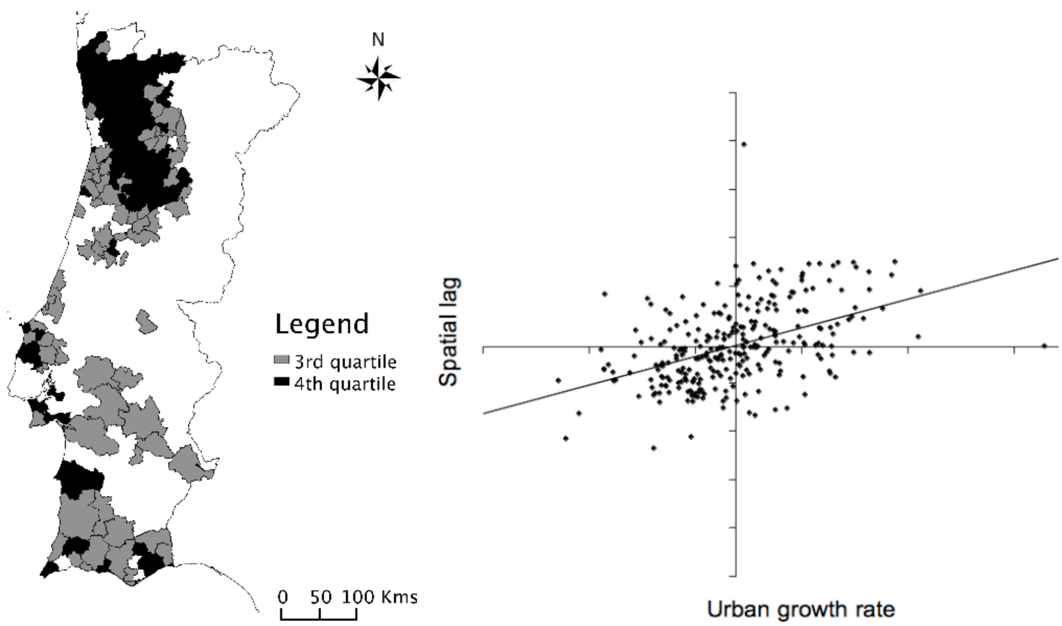


Figure 5: Urban dynamics' index

Figure 5 highlights those local councils whose value of the $Udyn$ belong to the third and fourth quartile. Some very interesting facts stand-out: first, the Lisbon and Oporto local councils (and some of its surroundings) did not register any significant construction. These already densely built areas expanded outwards. Second, following what was just said, construction patterns around the urban cores of the country is quite distinct; in the north, around Oporto, there is a cluster which registered intense activity in terms of new construction. This area, which is considered the main industrial hub of the country (Rodrigues 2001), continued to register the highest growth rates. On the other hand, around Lisbon, construction was registered mainly along new and existing motorways; one which connects the capital city to the Eastern border of of the country, the A6, and the second, an upgraded motorway which follows north, near the coastline (A8). The final fact to note is that in the south and near the western coast connecting Lisbon to the Algarve (The most southern region of the country), there were also high rates of construction in relation to existing values. This is mainly related to continuous growth of the tourist sector.

2.3 Health services

In relation to the spatial distribution of the emergency services, the need for equity and efficiency are both important and help shape the supply of healthcare along the country (Santana 2005, Rodrigues etal. 2008). Figure 3 shows the distribution of emergency services according to the local council division of the territory of interest. From a total of 278 local councils, 84 have some type of emergency service open 24 hours a day.

Although the distribution of supply of healthcare should guarantee territorial equity, it is expected that there is a concentration along the most populated and/or more dynamic nodes. This hypothesis will be formalised and tested in the following section.

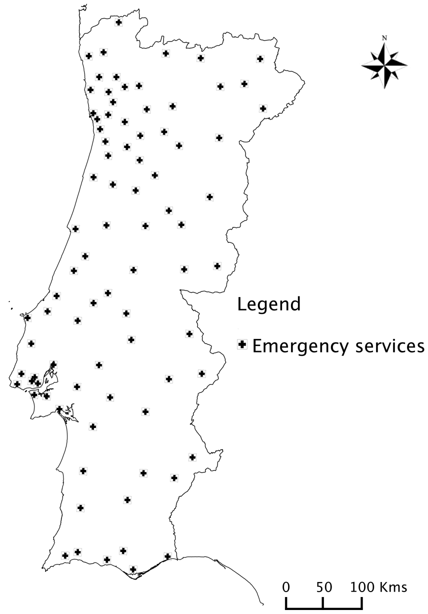


Figure 6: Distribution of Emergency services

3 Model

Following the exploratory analysis of the variables of interest, it is important to study a number of causal relations, in order to test the importance of peripherality on the spatial distribution of activity. As mentioned above, peripherality is understood as a compound measure of aggregate time-distances to sets of pre-defined targets and resident population. The index built is based on the concept of economic potential (Harris 1954). It relates a mass variable and distance between neighbours. The intention of including a mass variable is that it is thought that the magnitude of a compact spatial unit increases the centripetal forces which cause greater attraction of social-economic activity. Formally, economic potential (P) may be expressed as:

$$P = g(\cdot) \sum_{j=1}^{m} d_{ij}^{-\alpha} \, , \tag{3}$$

where $g(\cdot)$ represents the mass function and α the friction caused by irregularity in the spatial surface; it is the consequence of anisotropy of the spatial-area, which is taken into account in the GIS methodology used to calculate time-distances. In the present study, an empirical value for the friction coefficient α was calculated *a priori* thought the estimation of the zipf type power law (Zipf 1949). In the field of Regional Science this relation became known as the Rank-Size-Rule (Beckman 1958), and it relates the size of a region and its rank-position in a pre-ordered urban hierarchy raised to a friction coefficient. Whilst the theoretical value of the power coefficient is equal to -1, deviations from this value are considered informative and help to interpret and understand the existing distribution of a number of urban nodes over a spatial surface.

It is assumed that, in the long-run, the distribution of population activity is negatively related to distances. Hence, it makes sense to assume that Harris' concept of economic potential (equation 1), when calculated for a set of uni-nodal regions, approximates the Zipf Law. Instead of the rank variable, we use distance (d) computed using the GIS model. Hence, the estimation of the log-linear version of the functional relation $m = f(d)$ may be interpreted as a rank-size rule estimation. For the two accessibility surfaces used, the estimated friction coefficient $\hat{\alpha}$ is equal to -0.55 when considering time-distances to the coastal area and -0.95 when considering distances to Lisbon or Oporto. These estimated coefficients are themselves informative. First, a value greater than -1 may be interpret as corresponding to a set of urban nodes where dominance of a small number of regions is not as high as expected. On the other hand, a value smaller than -1 means greater disparities between larger and smaller urban nodes. The results obtained help to conclude that population distribution in Continental Portugal depends more on distances to the two existing metropolitan areas than to the coastal areas in general. This interpretation will be important in subsequent analysis when relating accessibility and the distribution of health services and urban growth.

The compound measure of accessibility used is a standardised index which varies from zero to 100 and uses estimated friction coefficients in order to calibrate the relation between population distribution and distances. Formally, *Compound Peripherality* (CP) is equal to:

$$CP = 100 * \frac{Pop_i}{d_{ij}^{\alpha}} / Max(\frac{Pop_i}{d_{ij}^{\alpha}}) \quad , \tag{4}$$

where Pop represents resident population and represents the mass of each urban node.

The distribution of public services is assumed to follow the existing structure of urban hierarchies as well as observed trends in urban dynamics. In order to test this principle, a model is constructed which attempts to explain the distribution of emergency services as a function of peripherality and urban growth. The dependent variable (E) is dichotomous and is set to one when there is at least one emergency hospital service open 24 a day within a local council. The functional relation takes the form:

$$E = f(CP, Udyn) \tag{5}$$

The second hypothesis to be tested is whether urban growth depended on peripherality, including the spatial lag as a regressor in order to test for autocorrelation in the series; formally:

$$Udyn = f(CP, Udyn^{lag}) \tag{6}$$

In relation to the first model, because of the binary nature of the dependent variable, a logistic specification was adopted. Both regressors were rescaled dividing each observation minus its mean by two times the its standard deviation, as proposed by Andrew Gelman (2008). Table 1 shows the results of the estimations using Generalized Linear Model (GLM) techinques. The first specification served to understand whether the distribution of emergency services followed the distribution of the peripherality index which included distances measured in relation to the metropolitan areas CP^m or that which include distances to the coastline CP^c. Model results show that the estimated coefficients are both positive, which indicates that the most central a local council is, the greater is the probability of having or being near an emergency service. Yet, only the estimated coefficient associated with coastal peripherality is significant. If we consider that there is a strong concentration of population near Lisbon and Oporto, these results show that territorial equity is taken into account in the spatial provision of healthcare.

$E = f(CP^m, CP^c)$			
	Estimated coef.	z value	Probability
$Constant$	-0.7815	-4.959	<0.000
CP^m	4.7828	0.679	0.4972
CP^c	6.5948	2.437	0.0148
$E = f(CP^c, Udyn^{lag}, Udyn)$			
	Estimated coef.	z value	Probability
$Constant$	-1.883	-2.162	0.03065
CP^c	7.33	3.289	0.00101
$Udyn$	-3.53	-1.362	0.17321
$Udyn^{lag}$	7.864	1.93	0.05357
$Udyn = f(CP^c, Udyn^{lag})$			
	Estimated coef.	z value	Probability
$Constant$	0.2371935	71.428	<0.000
CP^c	-0.107171	-3.274	0.0012
$Udyn^{lag}$	0.0011559	8.488	<0.000

Table 1: Estimation results

The second specification included as regressor coastal peripherality and the urban dynamics index (including the spatial lag of $Udyn$). Both estimated coefficients related to urban growth are not significant at the 95% significance level. Yet, the probability associated with the estimated coefficient of $Udyn^{lag}$ (0.05357) indicate clear significance at the 90% level, which show that urban dynamics have indeed some influence in the spatial organisation of healthcare. The greater significance of the spatial lag variable in comparison to $Udyn$ shows that the measurement of the growth of urban clusters whose limits fall beyond the local council administrative level, is a more adequate variable; It prevented, in this case, wrong conclusions which would be due to the inadequacy in the level of spatial aggregation of census data.

Finally, the second model was estimated, in order to infer whether peripherality has an influence on urban growth trends. The negative significant estimated coefficient associated with CP^c indicate that growth is moving away from the central regions. Yet, as mentioned above, the exploratory analysis indicate that urban growth is concentrated along new or upgraded road network links which connect Lisbon to the East and North, and in local councils located in the vicinity of the Oporto metropolitan region, increasing in fact, its functional limits (figure 5).

4 Concluding Remarks

Recent demographic and urban spatial trends are highly dependent on historical conditions which determined the location of settlements which are presently important urban centres. In Mainland Portugal, location near the two metropolitan areas of Lisbon and Oporto and near the coastline are still, as ever before, key variables when one tries to understand long-term territorial dynamics. This article intended to explore to what extent central-periphery relations still play an important role in the allocation of health services, more specifically, hospital emergency units. It showed that territorial equity and cohesion also plays an important part in what seems to be an attempt by government authorities to promote equity along an heterogeneous territory. Urban growth also show clear spatial patterns which also condition the allocation of resources. The methodology adopted also highlighted the importance of spatial exploratory techniques in the study of social phenomena when there is strong evidence of clear geographical patterns.

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