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EMPIRICAL APPROACH TO THE USE OF DIAGNOSTIC TECHNOLOGY. A SPATIAL ANALYSIS BY AUTONOMOUS COMMUNITIES

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Abstract

Background and Objective: In health, there is concern about people's access to high-tech diagnostic (HTD), because the existence of such technology does not guarantee equity and access for all the people of the same territory. Therefore, the aim of this study is twofold: analyzing whether the use of HTD is similar throughout the Spanish territory and second, showing how spatial analysis is a suitable technique to work inequalities in health.

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Keywords and phrases: medical technologies, spatial analysis, health and population, autonomy variability.

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Methods: We conduct a spatial analysis which seeks to study HTD in the autonomous communities (ACs), taking into account various Spanish groups and variables: population over 65 years, immigrant population, per capita income and private health coverage.

Results: We show that there is variability of behaviour in the use of HTD in the 17 ACs that make up the Spanish territory, taking into account some of the groups analyzed.

Conclusions: As for the population of the elderly, it cannot be said that the ACs with the highest percentage present the greatest expenditure in diagnostic tests for HTD. As regards the immigrant population, only the per capita number of studies with hemodialysis machines shows a positive relationship with this group. Regarding the relationship between per capita income and the number of studies on HTD per AC, no statistically significant relationship between both variables was found. Finally, it cannot be said that the autonomous communities with a higher proportion of the population with private health coverage perform fewer HTD tests in public health.

1. Introduction

There exists concern about the access of the population, from any territory, to medical high-tech diagnostic. A wide range of literature, both national and international, shows the territorial inequalities in the different healthcare dimensions and of course, in diagnostic technology [11 and 13]. It is inferred from this review that an effective diagnostic technology does not guarantee equity or the access of all the people from one territory, and it is confirmed that the people who need medical assistance the most are the ones who frequently are least likely to get it (Inverse Assistance Law).

In Europe, some studies show variability in the use of different diagnostic tests inside the same territory [2, 4, 18 and 19], where a 2005 [17], paper showing the existence of significant differences in the use of cardiovascular diagnostic technology between regions of the United Kingdom outstands.

In Spain, this territorial inequality has been studied in the use of diagnostic technology for cardiovascular disease and it has been concluded that the variability between the communities is fundamentally explained by regional richness and not by the load of sickness. Other papers analyze the use of medical technologies by looking for significant relationships with the volume of population, bearing in mind social variables and establishing relationships between population ageing, the use of hospital services and health expenditure. In this sense, other authors [5] offer a detailed description of the factors that influence the variation of the medical practice, where the inaccuracy of the data outstands, as do sociodemographic factors, the balance between offer and the available resources, as well as its financing. Moreover, they prove the importance of aspects derived from the direct provider, the uncertainty of doctors with respect to technologies or the very ignorance of some of the therapies, while they present some evidence on the relationships between these factors and the confusions to which they can lead when analyzing the added statistical data.

Other studies [6, 10 and 12] analyze the effects of ageing on health expenditure and highlight how this variable affects healthcare and, therefore, the behaviour of diagnostic technology. More specifically, in Catalonia, the Agència d'Avaluació de Tecnologia i Recerca Mèdiques [3], (Agency of Evaluation of Medical Technology and Research) analyzes the demand for public health bearing in mind the relationship with the immigrant population community, concluding the existence of a positive relationship between them. Then, the present work seeks to prove the existence of behaviour variability in the use of medical high technology in the 17 Autonomous Communities (ACs) which make up the State of Spain by means of the spatial analysis technique.

This technique is one of the recently appeared modalities of empirical analysis, and it is scarcely spread in certain spheres of the scientific community. Based on statistical and mathematical methods, using maps, geographic information systems (G.I.S.) and several simulation tools, spatial analysis shows structures and recurring spatial organization ways that summarize, for example, the centre-periphery models, the gravitatory interaction fields, prioritized urban weaves, the several types of nets or territories, etc.

The advantages of this technique are being profited by other disciplines in addition to Geography (research field where it has been most used), such as Spatial Econometry (or regional science), History, Agronomy, Archaelogy and Environmental Sciences, among others.

Consequently, as has been mentioned, the aim of this work is twofold on the one hand, showing how spatial analysis is an adequate technique to work in the health sector, and on the other hand, trying to identify significant relationships between the number of tests and the existence of links to a specific community or to per capita income levels in the different ACs. Apparently, there exist, in this sense, positive correlations of the number of High-tech Diagnostic (HTD) tests with the percentage of local population over 65 years, and with the percentage of immigrant population. Likewise, a positive correlation between the HTD value and the Per Capita Income has been suggested, although this relationship has never been analyzed while controlling the effect of private healthcare. Our expectation is that the correlation between both variables (HTD and Per Capita Income) will be negative, as is shown by the effect of private health coverage, since the higher the Per Capita Income, the more people turn to private healthcare and the less to public health, thus, reducing the value of HTD [9 and 20].

2. Method

Analyzed variables

For each of the ACs, the numbers of diagnostic tests in High-tech Diagnostic variables were registered as criterium or endogenous variable and the percentage of population over 65 years, the percentage of immigrant population, the per capita income of each AC and private health coverage, as predicting or exogenous variables. The aforementioned variables were registered for all the ACs for the 1999-2004 period [1], focusing on the latter year as a comparative reference point. The two main sources of information in obtaining these data have been the Instituto Nacional de Estadística (National Statistics Institute) and the Ministerio de Sanidad *y* Consum (Ministry of Health and Consumer Affairs).

In the case of the HTD variable, the number of tests conducted in any of the seven HTD types that the Spanish Ministry of Health and Consumer Affairs has catalogued as such in its last report on health expenditure has been considered [15]. Computerized Axial Tomography (CAT), Nuclear Magnetic Resonance Imaging (NMRI), Renal Lithiotripsy (RL), Linear Accelerators (LA), Hemodialysis machines (HM), Mammography systems (MM) and Hemodynamics rooms (HD). Aiming to correct the absolute value of these data, they have been adjusted to the per capita value of each AC in order to solve the difference in population sizes. Some of the predicting variables have been made operative by means of percentages (population over 65 years, immigrant population and private health coverage), leaving aside the Per Capita Income direct value since it had already been corrected.

Data analysis: spatial analysis

Spatial statistics comprises every analysis with a spatial dimension, whether this dimension refers to the very statistical tool, to the object of analysis or to the variables used as a descriptor of the object itself. It measures by giving values to the phenomena of interest in the framework of a geographical formulation. On the one hand, initially, it helps to characterize the attributes of the objects under study, and, on the other, at the end, it intervenes in order to characterize spatial forms, describe the nature and intensity of the relationships, qualify similarities, etc. When studying the variability of a particular phenomenon depending on other factors, statistical models are used (multiple regression, variance analysis, covariance analysis, logarithmic model, etc.), according to the nature of the endogenous variable and the exogenous variables. There are different levels of space integration in the statistical treatments, depending on the methods used and the attributes chosen to characterize the objects under study.

Distance estimates are one of the fundamental bases of statistical techniques, which, together with probability models, account for the inferential and statistical decision logic, whether it is in the Fisherian or the Bayesian orbit. In 1963, Matheron [14], relates these estimates for the first time with what is now called *spatial analysis*, thus, generating concepts such as semivariograms or Kriging methodology, among others. In the last twenty years, the use of this technique has extended to different scientific fields.

In the present paper, spatial analysis has been conducted in two phases: an exploratory phase and a confirmatory one. The first one intends to evaluate whether endogenous and exogenous variables follow any specific behaviour pattern and, to accomplish that, graphic tools such as the quantile map or the box map have been used (they allow exploration of the observed distribution of every variable). In addition, the possible existence of statistically significant spatial autocorrelation has been explored. To accomplish that, Moran's I standardized statistic has been used, obtained from simulating "*k*" samples from the original data. Such procedure is based on obtaining the aforementioned statistic in each of the "*k*" samples, thus, deriving its standard error and proceeding to its statistical signifying ("leave-one-out" sampling model), which, in this case, has been set at $k = 999$ simulations. Standardising this statistic responds to the need of setting its variability rule in order to make its interpretation easier, as is usually done in the various correlation coefficients. Its usefulness resides in determining the distance between each measured subject (in our case, each AC) and establishing a standardized distance matrix that allows evaluation of the possible proximities (similarities) between A.C. To conclude this first phase of exploratory analysis and once the behaviour diagrams have been analyzed at a global variable level, it is necessary to detect whether there exists some specific behaviour of these variables locally, since it may happen that a variable shows a random distribution globally but one or some observations present spatial autocorrelation diagrams locally. In order to analyze this phenomenon, one of the four usual tools is used, specifically, the Cluster Map, which detects statistically significant local behaviour.

Once the variables specified in the model have been explored, predicting spatial dependence problems, we move on to the second and last phase of the spatial analysis methodology. The goal of this second phase is to estimate the model by ordinary least squares (OLS) in order to analyze whether the exogenous variables proposed predict the endogenous variable's behaviour and to detect whether the specified model is valid or it is necessary to discard it in favour of another which comprises spatial dependence. All the statistical analyses described here have been carried out with the GEODA computer software, which provides the results both at a statistical level and in a graphic environment, which makes it possible to enrich the results obtained after computing the contrasts (as mentioned before, the box map, an extension of the quartile map together with the upper and lower extreme values). A detailed presentation of the statistical structure of the technique at hand can be obtained by reading several authors experts on the subject [1, 7, 8 and 16]. In few words, in a set of observed data (*s*) defined in an E^n Euclidian *n*-dimensional space, so that $s \in E^n$ and where an $s \in D,$ random vector is potential of reference of $Z(s),$ where *D* is a subset of $E^n,$ it is supposed that

$$\operatorname{var}(Z(s_1) - Z(s_2)) = 2\gamma(s_1 - s_2), \quad \text{for all } s_1, s_2 \in D. \tag{2.1}$$

That is to say, the variability observed between distances between pairs of values belongs to a domain of modelizable data. In order to transfer this expression to a semivariogram system with Cartesian coordinates (more easily interpretable), the following expression is used after analyzing the heterogeneity problems:

$$\gamma(d) = \frac{1}{2}\sum_{j=1}^{n-1}(C_i - C_j)^2, \tag{2.2}$$

where $\gamma(d)$ is the semivariogram value at *d* distance and C_i is the value at each of the Cartesian axes. The main global spatial association statistic is Moran's *I*. Its calculation expression is defined by

$$I = \frac{N}{S_0} \cdot \frac{\sum_{ij}^{N} W_{ij}(X_i - \overline{X})(X_j - \overline{X})}{S_{i1}^{N}(X_i - \overline{X})^2} \quad i \neq j, \tag{2.3}$$

where X_i is the value of the X variable in the *i* region, $\overline{X}$ is the observed mean of the *X* variable, W_{ij} are the weighting weights that integrate the *W* matrix, *N* is the sample size and finally, $\sum_i \sum_j W_{ij}$. Locally (that is, without establishing spatial distances), this very statistic takes the following formulation:

$$I_i = \frac{Z_i}{\sum_i Z_i^2 \Big/ N} \sum_{j \in J_i} W_{ij} Z_j, \tag{2.4}$$

where Z_i is the value corresponding to the *i* region of the standardized variable and J_i is the set of regions next to *i*. Taking all this information as a starting point, the technique is based on regression models and parameter estimation (OLS), taking into account the possible spatial autocorrelation problems of serial dependence. Complementarily, and for those contrasts that resulted statistically significant, the "*r*" effect size was obtained, estimated by means of Cohen's $(r = I/n - 1)$ statistic which, in case of being over .80, would indicate a very high intensity effect.

3. Results

From the analysis of the respective maps, it is inferred that the number of per capita HTD tests of the seven types analyzed shows positive spatial dependence, because of the clear similar value association in the territory. With the results obtained from the box maps of the variables, it can be claimed that the majority shows a similar behaviour at a general level. In some cases, certain autonomous communities outstand because they behave as extreme values in the upper tail (specifically in the hemodialysis-machines and mammography-systems variables in Valencia) and as extreme values in the lower tail (specifically in the hemodynamics-rooms variable in La Rioja).

As for the exogenous variables, that is, the percentages of third age population, immigrant population, population covered by private healthcare and per capita income, it is worth noting that, as it happened when interpreting the quantile map of the endogenous variables, their behaviour is very similar. Intuitively, it seems that all the exogenous variables show positive spatial dependence. Only in the percentage of population with private health coverage do three autonomous communities show an atypical behaviour (Catalonia, Madrid and the Balearic Islands are special extreme values in the upper tail, that is, they show higher values than their neighbours).

Analogously to the previous step, the existence of spatial autocorrelation is analyzed both for endogenous and exogenous variables. In most of them, it can be concluded that there exists positive spatial autocorrelation. Catalonia is further away from the behaviour of the other ACs as regards the average number of all the per capita HTD studies. Table 1 shows the comparison-summary conducted by means of the results of the 999 random permutations. Therefore, it is possible to conclude in a statistically reliable way whether there exists spatial autocorrelation or not, and in case it does, to interpret its sense (positive or negative).

Table 1. Result summary with Moran's I value, its signification, effect size and interpretative summary

Endogenous and exogenous variables	Moran's I statistic with its signification value	Effect size (r_i)	Interpretation
Mean of all the studies	–0,0356(p = .554)	r = .08	No significant effect.
Computerized Axial Tomography	0,0482(p = .224)	r = .32	A slight tendency to signification with a low effect.
Nuclear Magnetic Resonance Imaging	–0,0874(p = .433)	r = .11	No significant effect.
Renal Lithiotrpsy	–0,2087(p = .165)	r = .42	A slight tendency to signification with a low effect.
Linear Accelerators	–0,0552(p = .540)	r = .28	No significant effect.
Hemodialysis Machines	0,0934(p = .159)	r = .41	A slight tendency to signification with a low effect.

Mammography Systems	$-0{,}0141(p = .626)$	$r = .22$	No significant effect.
Hemodynamics Rooms	$-0{,}0459(p = .545)$	$r = .31$	No significant effect.
Percentage of third age population	$0{,}4712(p = .003)^{**}$	$r = .84$	Highly intense effect where it is shown that the percentage of third age population is significant to explain the spatial distribution of HTD.
Percentage of immigrant population	$0{,}3278(p = .0160)^{*}$	$r = .76$	Highly intense effect where it is shown that the percentage of immigrant population is significant to explain the spatial distribution of HTD.
Per Capita Income	$0{,}4348(p = .003)^{**}$	$r = .89$	Highly intense effect where it is shown that the per capita income is significant to explain the spatial distribution of HTD.
Percentage of population with private health coverage	$0{,}0957(p = .144)$	$r = .48$	Tendency to signification that might lead to think that the percentage of private health coverage influences the spatial distribution of HTD.

(∗) Signification $p < .05$ (∗∗) Signification $p < .01$

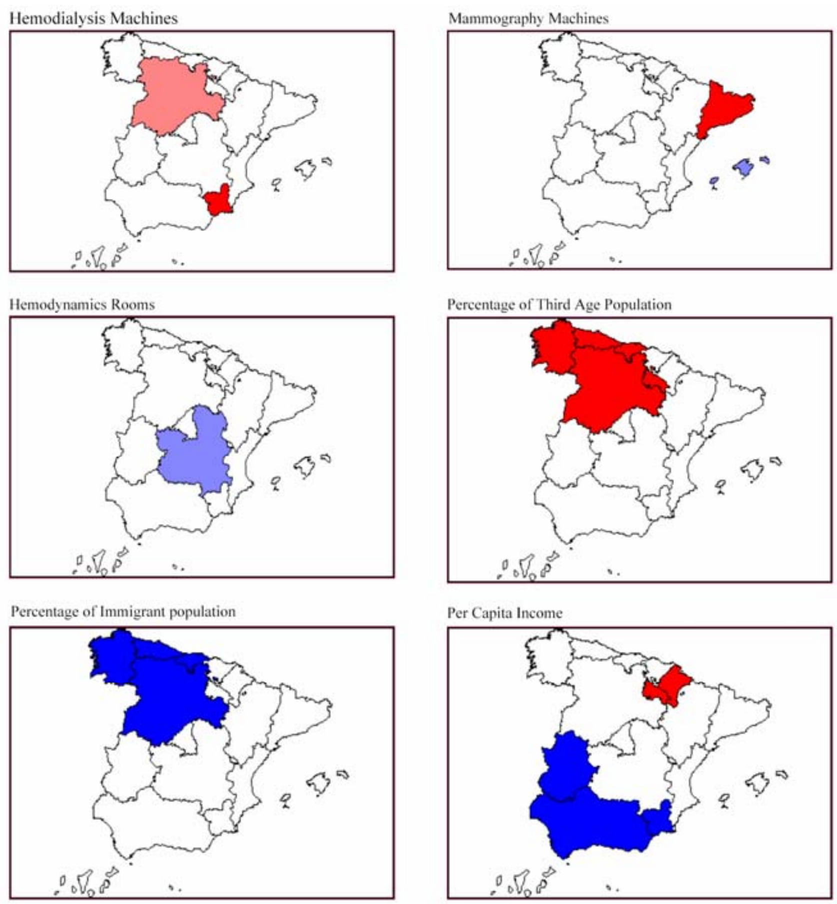
Taking the information in Table 1 as a starting point, some considerations can be extracted in relation to the spatial dependence the analyzed variables present. None of the endogenous variables present spatial autocorrelation, that is, all of them adjust to a random model and, therefore, without spatial dependence. In the case of exogenous variables, all of them-except the percentage of population with private healthcare-present statistically significant positive spatial autocorrelation. It is inferred from this that the percentage of population with private health coverage presents a random spatial distribution diagram. It is important to point out that the only statistically significant contrasts were linked to the effect of the percentage of third age population, $I_{Moran} = 0{,}4712(p = .003)$, the percentage of immigrant population, $I_{Moran} = 0{,}3278(p = .0160)$, and finally the statistic corresponding to the Per Capita Income, $I_{Moran} = 0{,}4348(p = .003)$, whose effect sizes between $r = .76$ and $r = .89$ showed the great impact that those variables have on the HTD spatial distribution. Complementarily, it is worth noting that, although the Private-Health-Coverage variable showed no statistically significant effect, it did show a tendency that is worth pointing out: $I_{Moran} = 0{,}0957(p = .144)$ with an effect size of $r = .48.$ With these data, it is not possible to claim a stable and forceful effect, but it is possible to point out a certain upward tendency in the role of private healthcare in this clinical multivariant layout.

Lastly, to conclude this first phase of the exploratory analysis, we analyzed the Cluster Maps where the following variables present no behaviour pattern that outstands locally in a significant way: Computerized Axial Tomography, Nuclear Magnetic Resonance Imaging, Renal Lithiotripsy and Linear Accelerators.

As regards the endogenous variable corresponding to the number of studies of per capita Hemodialysis machines, it is worth noting that, unlike other cases, Murcia is an autonomous community with a spatial cluster local behaviour, i.e., Murcia and its neighbours concentrate values significantly higher than it would be expected were the variable equitatively distributed in space. In addition, the autonomous community of Castile and León presents a local behaviour of spatial extreme value with respect to its neighbours.

In the case of the number of mammography studies, some ACs also present values worth highlighting. Specifically, the Balearic Islands present a spatial outlier behaviour of low values, while Catalonia is a spatial cluster of high values, where it and its neighbours concentrate significantly high values with respect to the other communities. As regards the number of per capita Hemodynamics room studies, it is worth mentioning that the community of Castile-La Mancha presents a spatial outlier behaviour of low values with respect to its neighbours.

It is also interesting to analyze the behaviour of the different exogenous variables formulated in this study. In the percentage-of-third-age variable, it is worth noting that there exist various spatial clusters with high values, which are the autonomous communities of Galicia, Asturias, Cantabria, Castile and León and La Rioja. Unlike the previous exogenous variable, the local behaviour of the percentage of immigrant population is characterized by the fact that Galicia, Asturias, Cantabria, Castile and León and La Rioja are spatial clusters of low values. In the case of the per capita income, Navarre and La Rioja are spatial clusters with high values, and the autonomous communities of Extremadura, Andalusia and Murcia present the opposite behaviour, i.e., they are spatial clusters of low values. Finally, in the case of the percentage-of-population-with-private-health-coverage exogenous variable, no autonomous community outstands for having a local behaviour different from their neighbours. These conclusions extracted locally from the significant behaviour of some variables can be analyzed graphically in Figure 1, which summarizes some of the most relevant statistical results.



White: Not significant. **Red:** Delimitation of high signification with high signification. **Dark blue**: Delimitation of low signification with low signification. Light blue: Delimitation of low signification with high signification. Pink: Delimitation of high signification with low signification.

Figure 1. Descriptive maps of the local behaviour of the variables that have shown significant effects in relation the neighbouring autonomous communities in relation to the use of high-tech diagnostic in the State of Spain.

From this initial analysis of the variables specified in the model (both endogenous and exogenous), it is worth nothing-globally and locally-both the percentage of third age population and of immigrant population as well as the per capita income, which all present spatial dependence. This is also true of the hemodialysis machines, the mammography systems and the hemodynamics rooms only locally. Therefore, it can be asserted that the aforementioned variables can cause problems in the model's parameter estimation (OLS) and it will be the confirmatory analysis that will detect whether it is necessary to estimate by means of a different model which comprises the effects of spatial dependence.

The confirmatory analysis has focused specifically on the exogenous variables that showed some kind of spatial dependence in the first exploratory phase. More specifically, then, we will study the adjustment of the regression parameters for the exogenous variables of hemodialysis machines, mammography systems and hemodynamics rooms.

For the Computerized-Axial-Tomography, Nuclear-Magnetic-Resonance-Imaging, Renal-Lithiotripsy and Linear-Accelerator endogenous variables, since there has been no evidence of any kind of spatial dependence, OLS regression parameter estimation will yield an adjusted valid model, but which will have no empirical interest, given the aforementioned absence of spatial dependence on any of the exogenous variables treated. It is worth highlighting that, as has been proved, the number of studies with mammography systems and hemodynamics rooms can be OLS-estimated without a problem. Therefore, the only thing left to consider is the number of studies carried out with hemodialysis machines.

From the obtained data, some relevant comments can be extracted. As for the adjustment, the percentage of variation explained by the model is 36.13% $(R^2 = 0.3613)$. Therefore, it could be said that the prediction capability of the endogenous variable supplied by the exogenous variables is not high (moderate-low intensity). In relation to the model's explicative variables, it is worth noting that only one of the four ones proposed is significant. Specifically, the percentage of immigrant population presents a positive relation to the number of studies per inhabitant with hemodialysis machines in 2004. Were the immigrant population to double, the number of studies per inhabitant with hemodialysis machines would increase, according to our data, in 58 studies per inhabitant. In order to contrast the heteroscedasticity in the model's errors (different variability in the parameter error estimation), Breusch-Pagan's test resulted non-significant $(BP = 6.34;\ df = 4;$

$p = .17)$, and therefore, it is assumed that the error term variance is constant. For the analysis of the possible existence of spatial dependence in the model, Moran's I value also resulted non-significant $(I = -0.48;\ p = .62)$, which entails the absence of spatial dependence. Finally, the values of the different Lagrange multipliers resulted likewise non-significant $(p_{values}$ between .15 to .44$)$, which means a sufficient adjustment to the proposed model's original data and, therefore, the implicit validation of each parameter's OLS-estimated values.

4. Conclusions

Once all the endogenous and exogenous variables of the formulated model have completely been studied as regards spatial dependence, the model's parameters have been estimated and, therefore, the highest determination coefficient has been selected, we can conclude the following aspects.

Globally, no endogenous variable presents spatial dependence behaviour, i.e., what happens in one autonomous community is not influenced by what happens in the neighbouring communities.

By assessing the local results, only three types of HTD studies present specific behaviour at that level. Hemodialysis machines: the community of Murcia presents a spatial cluster behaviour, that is, Murcia and its neighbours concentrate significantly higher values than would be expected if the variable were distributed equitatively in space. The autonomous community of Castile and León presents a spatial outlier behaviour (extreme value) as a high value with respect to its neighbours. Mammography systems: the Balearic Islands present a spatial outlier behaviour of low values, while Catalonia is a spatial cluster of high values, where that community and its neighbours concentrate significantly high values with respect to the other communities. Hemodynamics rooms: the community of Castile-La Mancha presents a spatial outlier behaviour of low values with respect to its neighbours.

If we bear in mind the percentage of third age population, it may not be affirmed that the autonomous communities with a higher percentage present higher expenditure in HTD tests. Likewise, only the number of per capita studies with Hemodialysis machines is a diagnostic test that is positively related to the percentage of immigrant population in each autonomous community. Therefore, the higher percentage of immigrant population in a specific autonomous community does not necessarily imply more HTD tests, as can be inferred from the analysis conducted.

With respect to the relationship between the per capita income and the number of per capita HTD studies per autonomous community, it can be asserted that, according to our data, there is no statistically significant relationship between both variables. As regards the relationship between the number of HTD studies and the percentage of population with private health coverage, it is worth noting that there is no significant relationship between both variables. That is to say, it may not be claimed that the autonomous communities with a higher percentage of population with private health coverage conduct fewer HTD tests in public health.

5. Limitations of the Study

The main limitation of the present study comes from the number of observations, since it has only 19, which correspond to the 17 autonomous communities plus the territories of Ceuta and Melilla. Both the spatial statistical analysis and the linear regressions need a higher number of observations for its correct application, and maybe part of the statistical nonsignifications derive from the reduced number of observations. Therefore, a future line of work should be based on conducting this type of analysis and health phenomenon with smaller geographical units (for instance, provinces), in order to obtain a much more detailed map of the use of diagnostic resources.

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