Spatial analysis of the impact of transport accessibility on regional performance: a study for Europe

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Abstract

Several works have addressed the impact of transport accessibility on regional development. Nevertheless, it is not consensual that new levels of accessibility lead to the improvement of regional development. This article proposes a methodological approach to assess whether significant relationship exist between these two variables. The methodology uses Data Envelopment Analysis to evaluate regional performance and spatial statistics methods (local bivariate relationships) to evaluate type of the relationship between accessibility and performance for each region, and its significance. The approach was applied to 186 NUTS that cover 19 European countries, extending previous works which focus on global results, in the sense that only one (usually large) area is considered. Results indicate that approximately half the regions have a significant relationship between transport accessibility and regional performance. Logit regression analyses show that central regions are more likely to exhibit significance, as well as regions with high (low) levels of performance surrounded by regions with high (low) levels of accessibility, hinting at a synergy between the two variables. An important policy implication is that regions of high performance surrounded by regions of low accessibility may benefit from investments in the transport infrastructure.

1. Introduction

Transport infrastructure investment has long played a key role in regional policies (Rokicki and Stępniak, 2018), leading to a natural debate about its influence on the development of the regions benefiting from it. The usual rationale is that new levels of accessibility can attract more people and businesses, thus improving regional development (European Commission, 2020). However, research carried out on the subject over the last decades does not always validate this reasoning. Existing studies may yield aligning results, but they also reveal different, sometimes contradicting conclusions depending on regional context, methods, and economic dependent variable. Although this variety makes up for a rich dataset of case studies, each example has its own specificities, making it difficult to understand under what conditions the above-mentioned rationale applies, and to what degree. Considering that the European Union (EU) budget has been undergoing many changes and that the allocation of public funds is under increased public scrutiny, the importance of deepening the understanding of the relationship between transport and regional development is rising in this economic region. Being able to better predict where, and how, transport investment is likely to generate economic and social plus-values is of paramount importance and the long-term objective of the transport/development discussion. This article contributes to the topic by proposing a methodology to assess whether significant relationships exist between transport accessibility and regional performance on economic zones consisting of administrative subdivisions, i.e., regions, with performance being understood in the sense of a region's efficiency in transforming inputs onto outputs. The methodology uses Data Envelopment Analysis (DEA) to evaluate efficiency and, resorting to spatial statistics methods, indicates for each region the significance and type of the relationship between accessibility and performance. The methodology evaluates regional performance considering two outputs in the DEA: an economic one, GDP, and, to incorporate the social dimension, a social well-being index. The evaluation procedure then considers the resources available to that region as inputs, more specifically capital stock per employee and active population rate. By combining DEA with spatial statistical techniques, it is possible to make a finer analysis and identify, within a global area, regions where a relationship between accessibility and regional performance may, or may not, be present. The use of performance as dependent variable in the transport accessibility/ regional development debate is relatively new. To best of the authors' knowledge, it has only been briefly explored in the literature, mostly in very specific contexts, making it important to consider more global applications, a gap this research now fills. Mahmoudi et al. (2020) further recommend focusing on performance assessment in transport systems, aiming at finding solutions to improve it in environmental, economic, and social sustainability contexts. Also, when confronted with other dependent variables, performance may shed light on how all these variables interrelate and thus contribute to a better predictive power of economic models.

This article is organized as follows. In section 2 a literature review is carried out and this researched is contextualized. Section 3 presents the proposed methodology. In section 4 the methodology is applied to a case study of 186 European NUTS2 regions, for which results are derived, implications are discussed. Section 5 concludes and provides pointers for future research. Limitations of this research are also presented in that section.

2. Literature review

This debate on the transport accessibility/regional development has many facets, and one of the most important insights is the above-mentioned fact that the relation between transport infrastructure and economic variables, such as productivity or growth, is not always positively correlated. Early work by Aschauer (1989) and Munnell (1992) found positive effects between highway capital stock and productivity, a conclusion that was soon after questioned by Holtz-Eakin and Schwartz (1995) who found no such effect between transport infrastructure stock and productivity. According to Boarnet (1996) and Sloboda and Yao (2008), depending on the perspective and the data, it is possible to identify not only positive but also negative effects of transport infrastructure investment on the GDP output. Button (1998) has found a positive relationship between GDP per capita and transport infrastructure investment, but that author underlines the importance of taking into account the difference between countries with high and low GDP, thus advancing a first explanation for the discrepancies. Vickerman (2008), in search for complementary explanations, emphasized that the impact of transport infrastructure depends on the territories' characteristics. According to this author, there are countries where transportation is not the factor impeding development, so additional investment on transport infrastructure is unlikely generate economic benefits. More recently, Crescenzi and Giua (2020) have concluded that the amount of investment may not be as relevant as issues such the models of implementation of the transport investment projects. In what concerns economic growth as dependent variable, Elburz et al. (2017) demonstrated that studies focused on the USA are more likely to conclude that transport infrastructure investments have a negative impact on regional growth, while studies focused on Europe tend to conclude the opposite. However, even within Europe itself differences exist. Pereira and Roca-Sagalés (2003) concluded that transport infrastructure has a positive effect on Spanish economic growth, while Álvarez et al. (2016) found no evidence of that effect. This led Elburz et al. (2017) to conclude in their meta-study that there is no literature consensus on whether a relationship exists between transport infrastructure and regional productivity or growth.

On the methodological side, research is usually based on econometric approaches such as the production function (Aschauer, 1989; Munell, 1992; Holtz-Eakin and Schwartz, 1995; Boarnet, 1996; Allroggen and Malina, 2014; Rokicki and Stępniak 2018); spatial regression models (Gutiérrez et al., 2010; Arbués et al., 2015; Álvarez et al., 2016); two-stage least squares models (Brueckner, 2003; Percoco, 2010; Hong et al., 2011); and computable general equilibrium (Bröcker, 2004; Chen et al., 2016). One feature in common among these works is that the dependent variable is usually GDP or an employment-related variable, which is explained by a group of independent variables which include transport-related ones. Most of these works present global results, in the sense that only one (usually large) area is considered, making it difficult to identify specific regions of that area where transport may impact productivity or employment more significantly. Moreover, the focus put on economic variables neglects other types of variables. This may prove to be a limitation; as regional dynamic is often too complex to be described by one aggregator variable alone. Variables such as e.g., the social dimension of development, have been underlined by Stiglitz et al. (2009) as an important consideration, which was integrated into the Europe 2020 Strategy (European Commission, 2009).

Another distinction that can be made is between the transport infrastructure itself and the service this infrastructure provides to the economy, i.e., accessibility, or the potential to engage in activities distributed across space and of interaction among regions (Hansen, 1959;

Geurs and Van Wee, 2004; Pot et al., 2021), a less debated topic. Among the few works that have addressed accessibility specifically, Martín et al. (2004) studied the impact of a new high-speed train Madrid-Barcelona-French border on the daily accessibility and the economy. Those authors have found that relative accessibility of each city depends on the partial accessibility indicator used but, for all indicators, results show that the new line increases regional accessibility disparities. Martín et al. (2004) concludes that accessibility is just a means to an end (economic development) and suggests that the accessibility indexes proposed could be used to obtain some explicative or predictive power over variables such GDP. More recently, Rokicki and Stępniak (2018) studied the relationship between accessibility improvement and regional economic growth in Poland, having found a positive relationship between accessibility and regional employment, but none between accessibility and labor productivity.

One final limitation is that most studies consider only one specific transport mode. Authors such as Rokicki and Stępniak (2018) and Condeço-Melhorado et al. (2011) focused on road infrastructure, whereas Vickerman (2018) and Cavallaro et al. (2020) dealt with rail infrastructure, and Scotti et al. (2012) and Allroggen and Malina (2014) explored air transport. Arbués et al. (2015) demonstrated the relevance of considering several modes of transport, having discovered that in the case of Spain provinces road infrastructure has a positive effect on the regional economy, but no evidence was found that the remaining modes produce similar impacts, thus proving that what holds for one mode does not necessarily extrapolate to other modes.

Summing up, the literature review shows that it is far from consensual whether transport infrastructure has a positive and significant impact on regional development, and to what degree. The fact that transport infrastructure impacts depend on regional characteristics (Sloboda and Yao, 2008), and because it is desirable to go beyond production functions to study this impact, this article proposes a novel methodological approach to the transport/development debate. The methodology is demonstrated in a case study of a large economic zone, namely 186 European NUTS 2 regions, located in 19 countries and encompassing countries located in Central Europe (e.g., Germany, Netherlands) as well as countries located in Southern Europe (e.g., Portugal, Spain). Along with the methodological novelty, to best of the authors' knowledge this research is also the first study on the relationship between transport and regional development over such a large area.

In light of the above, this research intends to answer three questions:

Q1. Is there a significant relationship between transport accessibility and regional performance in the 186 European NUTS 2 regions?

Q2. If so, in what regions can it be found, and of what kind is that relationship?

Q3. Are there any factors that may predict the existence (or not) of a significant relationship between transport accessibility and regional performance?

The answers to those questions may contribute to a better understanding of the impact of transport investments on regional performance, in particular whether a positive effect can be expected, thus assisting in designing strategies and plan interventions, taking into account the specificities of each region.

3. Methodology

The methodology proposed to study the relationship between transport accessibility and regional performance has three stages. The first stage evaluates performance by assessing the efficiency of regions in using capital stock and human resources capacities to promote regional development using a DEA approach. The second stage analyses the relationship between the accessibility by three different modes of transport (road, rail, and air) and regional performance, considering how that region is influenced by its neighbouring regions. This was done using local bivariate relationship analyses. The outcome of the methodology is, for each region, an indication of whether that region exhibits a significant relationship between accessibility and performance, and of what kind. The third stage is focused on the identification of the predictive factors of the Moran significance. Figure 1 summarizes the methodological approach.

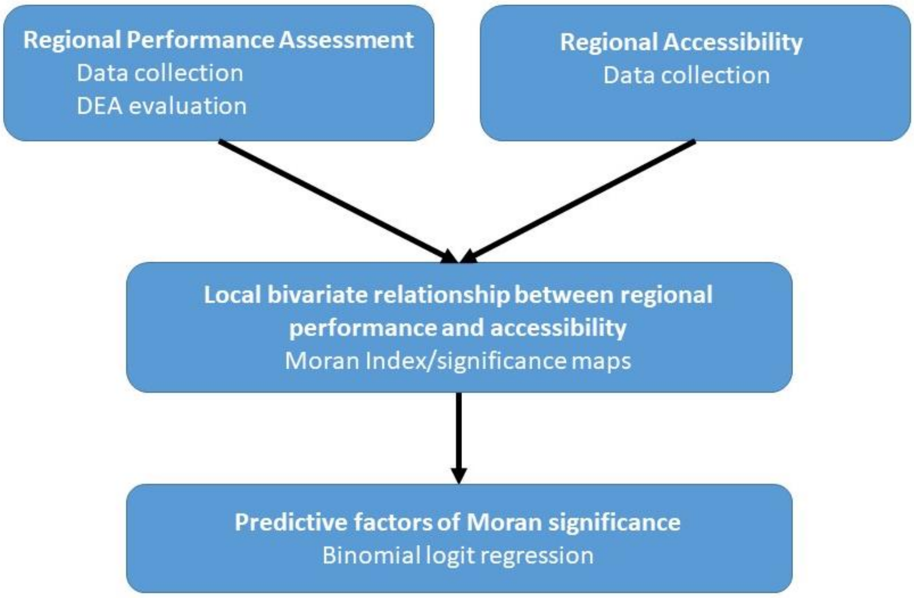

Figure 1. Methodological scheme.

3.1. DEA evaluation of regional performance

DEA is a non-parametric method designed to estimate relative efficiency of an economic activity, with efficiency defined as the capacity of each decision-making unit (DMU) to convert inputs into outputs. DEA has been applied to multiple activities, such as banks (Luo, 2003; Kao and Liu, 2014; Kaffash and Marra, 2017), hospitals (Banker et al., 1986; Nayar and Ozcan, 2008; Mujasi et al., 2016), airports (Gillen and Lall, 1997; Adler and Berechman, 2001; Örkcü et al., 2016); road network (Shen et al., 2012; Álvarez and Blásquez, 2014; Nikolaou and Dimitriou, 2018), and rail (Cantos and Maudos, 2001; Yu and Lin, 2008; Link, 2019).

DEA works by grouping the DMUs into two sets: efficient and inefficient units. The efficient DMUs define the Pareto frontier, a reference of efficiency which is achieved by at least one DMU. The way distance to the Pareto frontier is defined, which is a measure of DMU inefficiency, depends on the evaluation system of the chosen DEA model. Given the heterogeneity usually observed when several regions are considered in the analysis, the weighted additive DEA model with variable returns to scale and output orientation was chosen (Charnes et al., 1985). In the notation of Cooper et al. (2007) this model yields, for each DMU *o* under consideration, the following linear programming problem, whose outcome is the efficiency score for that DMU:

$$\text{ADD}_o \qquad \max_{\boldsymbol{\lambda},\boldsymbol{s}^-,\boldsymbol{s}^+} z = \boldsymbol{es}^- + \boldsymbol{es}^+ \tag{1}$$

$$\text{Subject to} \qquad \begin{aligned} X\boldsymbol{\lambda} + \boldsymbol{s}^- &= x_o \\ Y\boldsymbol{\lambda} - \boldsymbol{s}^+ &= y_o \\ \boldsymbol{e\lambda} &= 1 \\ \boldsymbol{\lambda}, \boldsymbol{s}^-, \boldsymbol{s}^+ &\geq 0 \end{aligned} \tag{2}$$

where

$\boldsymbol{s}^-, \boldsymbol{s}^+$: vectors of (respectively) input/output slack distances to the Pareto front (input excesses and output shortfalls).

$\boldsymbol{e}$: unit row vector.

X, Y: matrices of input/output scores for all the DMUs.

x_o, y_o: vectors of input/output scores for the DMU *o*.

$\boldsymbol{\lambda}$: a semipositive vector of weights of the DMUs' peers.

In this research, regions are the DMUs and the efficiency score is the region's performance. Inputs are the regions' resources, namely capital stock per employee and active population rate, and outputs the economic performance, measured by GDP per capita (from the household income perspective; Eurostat, 2021), and a social component, the Regional Well-being Index (OECD, 2018). See Figure 2.

In additive DEA the input/output slacks in the objective function can further be weighted. The most common choice is equal weights of 1 for both $\boldsymbol{s}^-, \boldsymbol{s}^+$. Output orientation equates to weight zero for $\boldsymbol{s}^-$. For this case the outcome of the DEA procedure is an efficiency score for DMU *o* which is the sum of the $\boldsymbol{s}^+$ slacks. Output orientation was chosen because in general it is not desirable, or even feasible, to reduce capital stock or active population rate to achieve efficiency.

The choice of inputs and outputs was motivated as follows. For the inputs, the KLEMS approach (Jäger, 2016) was used, which takes capital stock and active population as inputs to assess productivity. The capital stock of a particular asset is the sum of all past investments considering the loss in productive efficiency and the retirements that have happened since it was first acquired (Timmer and Szirmai, 2000; Jäger, 2016). The active population rate is used as a labour input proxy. Concerning the output variables, the proposed approach goes beyond

KLEMS, which considers only economic output (GDP per capita), and adds the Regional Well-being Index, an index developed by the OECD (2018) based on eleven well-being dimensions related to quality of life and material conditions, thus materializing the considerations of Stiglitz et al. (2009) who underlined the social dimension of development.

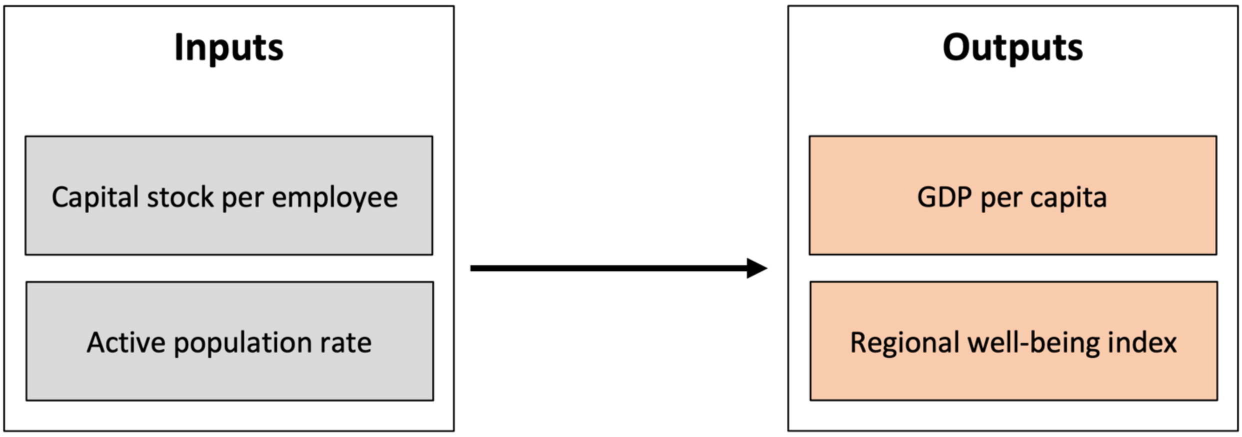

Figure 2. DEA model variables

3.2. Regional performance and transport accessibility – local bivariate relationship

A local bivariate relationship (LBR) is a type of multivariate spatial correlation between one variable at one location and a different variable at its neighbouring locations (Anselin and Rey, 2014). In this research the correlation is between regional performance and transport accessibility at the neighbouring locations. The index chosen to express the LBR was the bivariate Moran's I, defined by (Anselin et al., 2002):

$$I_i = cx_i \sum_j w_{ij} \, y_j \tag{3}$$

where

I_i: local bivariate relationship value for region i.

c: a scaling factor.

x_i: standardized score of regional performance of region i.

y_j: standardized accessibility score of region j, neighbour to i. The summation j runs over all neighbours of i and is sometimes called 'spatial lag' of y_j.

w_{ij}: spatial weights matrix elements, 1 if regions i and j are neighbours via edge or vertex (queen contiguity), else 0.

Moran's I tests for statistical significance vs. the null hypothesis of spatial randomness. Values of local Moran's I oscillate between 1 (strong correlation), 0 (spatial randomness), and -1 (strong anti-correlation). Figure 3 presents a Moran diagram, a visual representation of the spatial association between each observation and their neighbours (Salima and Bellefon, 2018), this is an exemplative diagram from a real case study. Moran's I values were obtained from the GeoDa software.

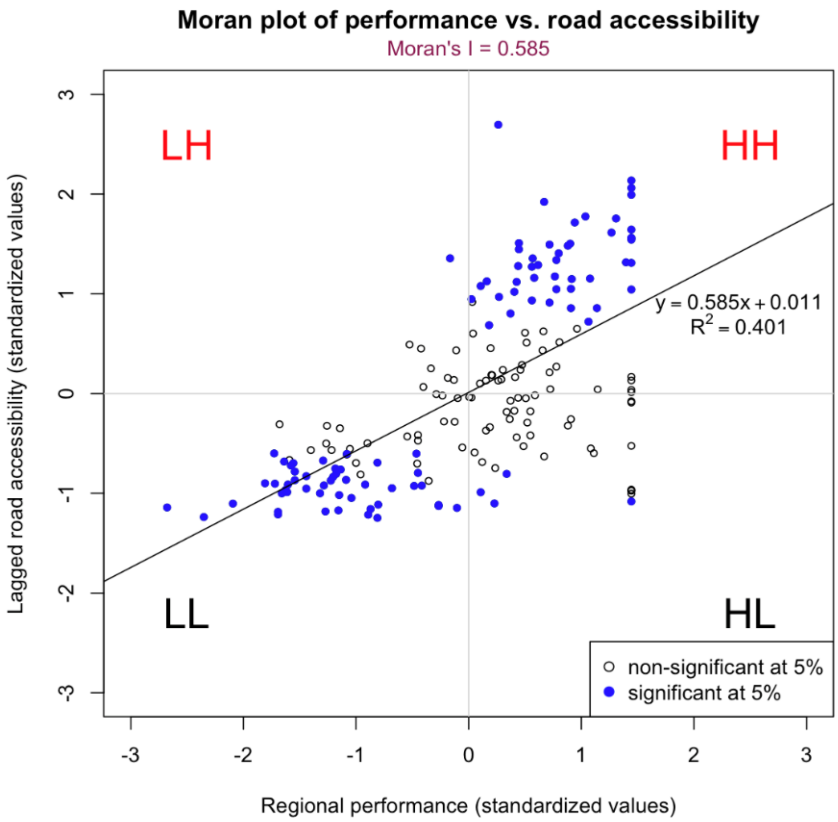

Figure 3. Moran's diagram for regional performance vs. road accessibility.

Each dot represents a region. A linear trendline was also added. The Moran diagram can be interpreted as follows: if the regions were randomly distributed in the diagram, no accessibility/performance relationship would exist among them. However, if the diagram exhibits clustering, this is an indicator that sets of contiguous regions exist with a significant accessibility/performance relationship, which in turn indicates a synergy between the two variables.

The diagram is divided into four quadrants of regional performance and road accessibility, with standardized axes. Figure 3 shows most dots fall into the HH or LL quadrants, which is why these quadrants are usually called clusters, even though they are not clusters in mathematical sense (e.g., k-means clusters). Regions in the high-high (HH) [low-low (LL)] clusters have performance and neighbouring accessibility values above [below] case study average. Regions in the high-low (HL) or low-high (LH) quadrants are called outlier regions and typically have complex performance/accessibility relationships. Regardless of what quadrant a region belongs to, its accessibility/performance relation may, or not, be statistically significant. A global Moran's I can also be derived and tested for significance. Figure 3 shows a global of $I = 0.585$ for road transport, meaning that, as a whole, the economic zone has a considerable accessibility/performance correlation, hinting that locally the same might be expected for at least some regions.

3.3 Logit regression model

To analyse the results provided by the LBR, in particular research question Q3, a binary logit regression model was used. Logistic regressions are used to model the probability of events whose outcome falls within a discrete set of possibilities. Binary regression models in particular have outcomes of type "yes/no" and are expressed by the mathematical expression

$$\mathrm{logit}\big(P(Y=1)\big) = \beta_0 + \sum_i \beta_i X_i + \varepsilon \qquad (2)$$

where Y is the output variable ($Y = 1$ for "yes"; $Y = 0$ for "no"), P stands for probability, and $\mathrm{logit}(p) = \log\left(\frac{p}{1-p}\right)$. The β_0, β_i are regression coefficients (β_0 is the intercept), X_i the regressor value, and ε is a statistical error, modelled by the logistic function. Logit regressions support both discrete (categorical or numeric) and continuous input variables, i.e., regressors. The binary logit model is adequate to analyse existence (or not) of a significant Moran relationship between performance and accessibility, as the output is of "yes/no" type.

4. Case study, results and discussion

4.1 Case study

The methodology is now applied to the case study, a dataset composed of 186 NUTS 2 regions and covers 19 European countries. Table 1 presents summarizing statistics on the variables analysed and their origin.

Table 1. Case study data summary

Indicators	unit	Average	Std. Dev.	Min	Max	Source	Year
Capital stock per employee	€/employee	2.4	0.68	0.09	4.05	Jäger, 2016	2016
Active population rate	%	64	5	46	75	Eurostat	2015
Regional Well-being Index	Index	65.4	9.2	39.7	81.9	OECD	2018
GDP per capita	€/inhab	26897	13626	4100	90700	Eurostat	2015
Road accessibility	Index	95	69	9	281	Annoni et al., 2017	2016
Rail accessibility	Index	94	56	14	255	Annoni et al., 2017	2016
Air accessibility	Index	447	495	0	2338	Annoni et al., 2017	2016

The European Regional Competitiveness Index was used to gauge accessibility. Values were taken from the Directorate-General for Regional and Urban Policy - European Commission (Annoni et al., 2017). The indexes are defined as follows:

- Road accessibility: sum of the population living in surrounding regions weighted by travel time along motorways. The accessibility model uses centroids of NUTS 2 regions as origins and destinations.
- Railway accessibility: sum the population living in surrounding regions weighted by travel time along railways. The accessibility model uses centroids of NUTS 2 regions as origins and destinations.
- Air accessibility: this is defined in three steps. In the first step, a service area of 90 minutes driving by car is derived around each airport. In the second step, each region gets assigned, additively, the number of passenger flights available from every airport whose service area intersects that region. In the third stage, the total number of passenger flights is combined with population of the region under consideration.

4.2 Results

According to Vickerman (2018) major transport infrastructure investments do not always have a significant impact on the economy. It is thus necessary to find which criteria characterize the cases where such investment is expected to have a significant and positive impact. This work can be seen as a contribution to answering that question, addressing to what extent the regional social and economic performance is related to transport accessibility. Figure 4 displays the DEA regional performance scores, obtained from the EMS software (recall these are output slack distances to the Pareto front), with the efficient regions coloured green (score of 0) and increasingly inefficient regions coloured from yellow to dark red (up to a score of 6). The higher the score, the less efficient the region is, meaning that a higher the level of GDP per capita and regional well-being that region should have been achieved, given its capital stock and active population rate. After standardization, the efficiency scores form the x_i variable of the LBR equation (3).

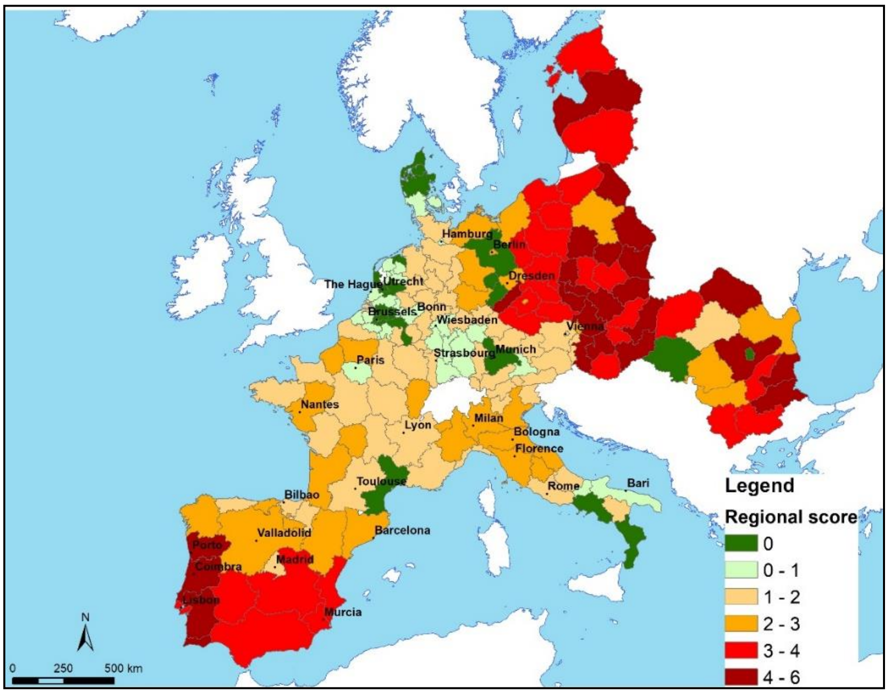

Figure 4. DEA efficiency scores

The 21 efficient regions are concentrated in seven countries, six of which lay in central Europe (Belgium, Germany, Denmark, Italy, Netherlands, France) and two in eastern Europe (Romania), while inefficient regions locate in the east and south of Europe.

Since the efficiency of a region depends on the balance between inputs and outputs, rather than their absolute values, efficiency is usually achieved when outputs are above average (e.g., some Belgian regions), but may also happen when outputs are below average, provided inputs are (sufficiently) below average. Examples of the latter are the Romanian regions, with a similar scenario emerging in Italy: some southern regions present better performance than the richer northern regions because they have fewer resources, especially active population rate.

The central regions of Germany and Benelux countries exhibit the strongest impact of human capital (population share of workers with tertiary education) on economic growth (Cuaresma et al., 2014). Figure 4 results validate those findings and can be read as a sign of those regions' capacity to maximize human resources. Concerning The Netherlands, it has very high rates of interregional commuting, so some workers in peripheral regions travel to the efficient regions, enabling them to have higher GDP (output) while not increasing the active population rate of those efficient regions (input). This why central Dutch regions are more efficient than their neighbor regions.

Before deriving the local bivariate relationship results, it is worth taking a geographic look at accessibility values. These are shown in Figures 5 A-C, as levels of their standard deviation from the overall mean.

Road and rail accessibility levels across Europe exhibit a central/periphery pattern, with Central Europe presenting higher levels than Eastern and Southern Europe. However, thanks to rail corridors there are regions in Southern Europe (e.g., Madrid and Barcelona) that present higher rail accessibility than road accessibility. Although the countries located in Eastern Europe present accessibility values below average, there are some differences. Seidenglanz et al. (2021) has recently demonstrated that the rail network of the V4 region (Czech Republic, Hungary, Poland and Slovakia) has gone through considerable rearrangements between 1990-2019, now is possible to travel greater distances in less time.

Regarding air accessibility, is possible to identify regions (e.g., Eastern regions) that present higher levels of air accessibility than road and rail accessibility. However, air accessibility has quite a steep decline once out of the airport regions (Spiekermann and Neubauer, 2002) as it is possible to see in the case of Bucharest (Romania).

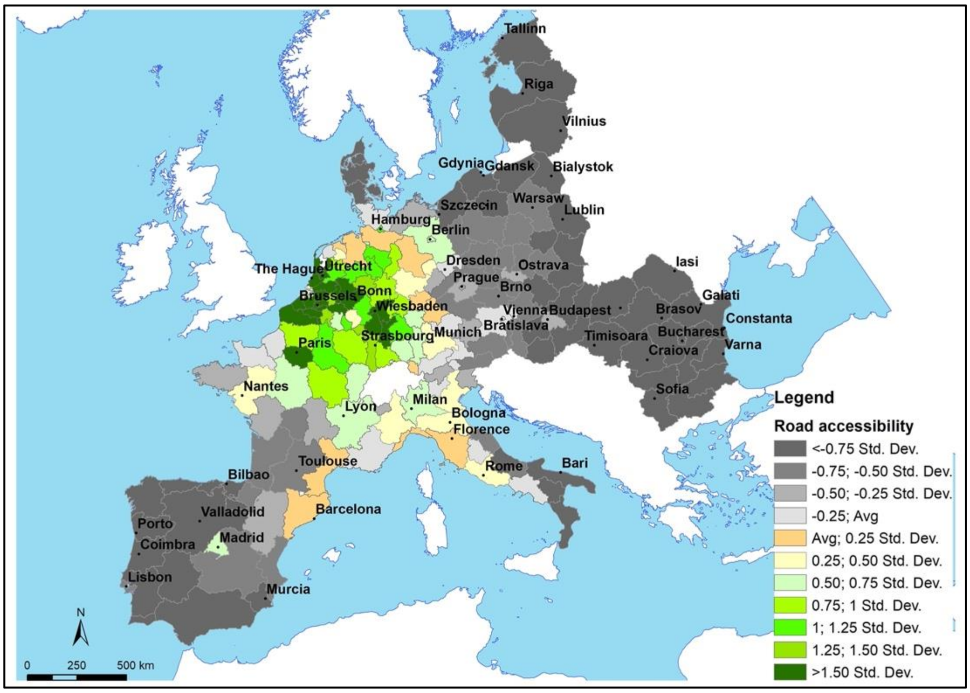

Figure 5A. Road accessibility (Source: Annoni et al., 2017)

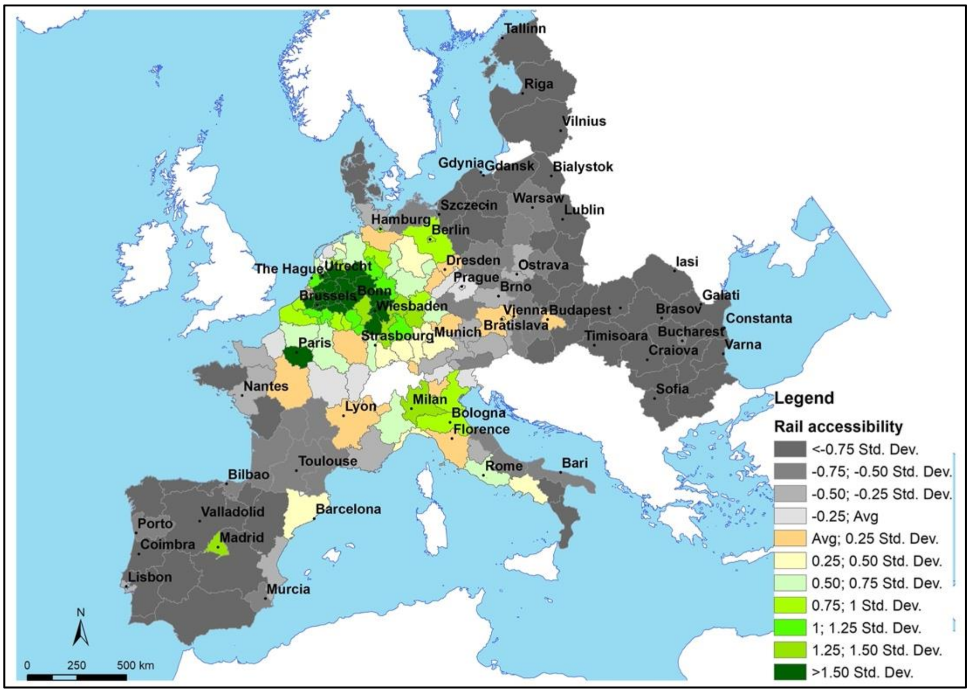

Figure 5B. Rail accessibility (Source: Annoni et al., 2017)

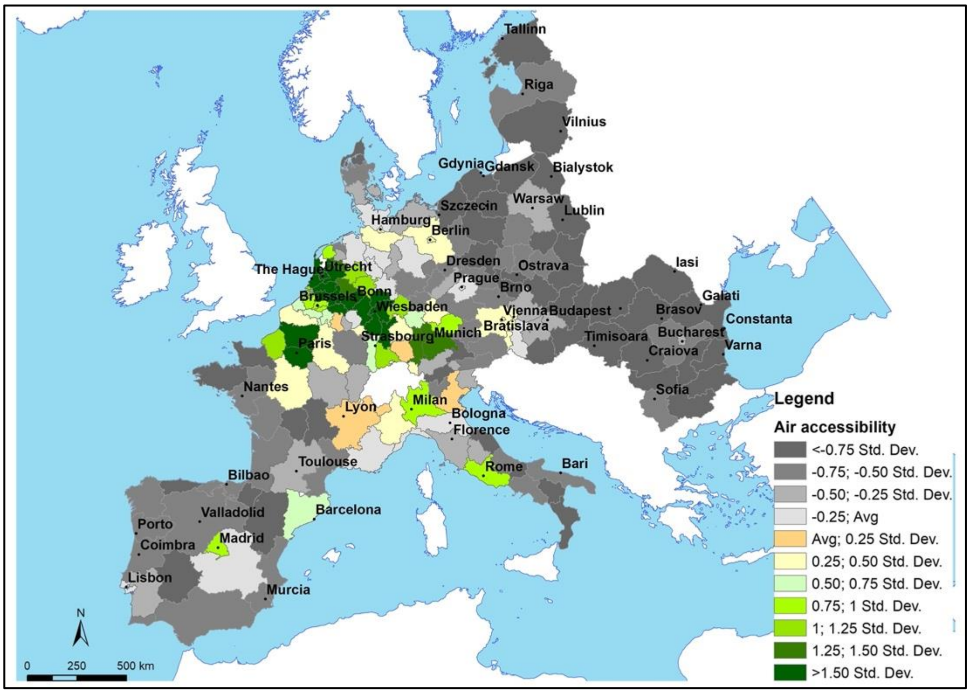

Figure 5C. Air accessibility (Source: Annoni et al., 2017)

Moving on to the calculation of the LBR between transport accessibility and regional performance, results are summarized in Table 2. In the Annex Moran diagrams for Table 2 are presented.

Table 2: Statistics for local bivariate relationship between regional performance and transport accessibility

Accessibility mode	Significance	HH	LL	HL	LH	Total
Road	Yes	46	47	4	1	98
	No	27	23	31	7	88
Rail	Yes	40	43	7	2	92
	No	33	25	28	8	94
Air	Yes	34	35	6	1	76
	No	30	39	38	3	110

Map representations of Moran significance are given in Figures 6A to 6C below. The term ‘Moran significance’ is used as short for ‘significance of the relationship between accessibility and performance’.

Table 2 results allow addressing the first research question:

Q1. Is there a significant relationship between transport accessibility and regional performance in the 186 European NUTS 2 regions?

In 53% of the 186 regions a significant relationship exists between regional performance and road accessibility, and in 49% of the regions that relationship is also significant for rail accessibility. For air accessibility the percentage of significant regions drops to 41%. Summing up, road accessibility is the transport mode that accounts for more regions with a significant relationship with regional performance estimate, followed by rail accessibility and lastly air accessibility. The fact that for all transport modes in roughly half the regions the accessibility/performance relationship is significant indicates that factors should therefore exist which determine the existence (or not) of such relationship. If those factors were found and proven relevant, they could help understand contradicting results of other research on the subject.

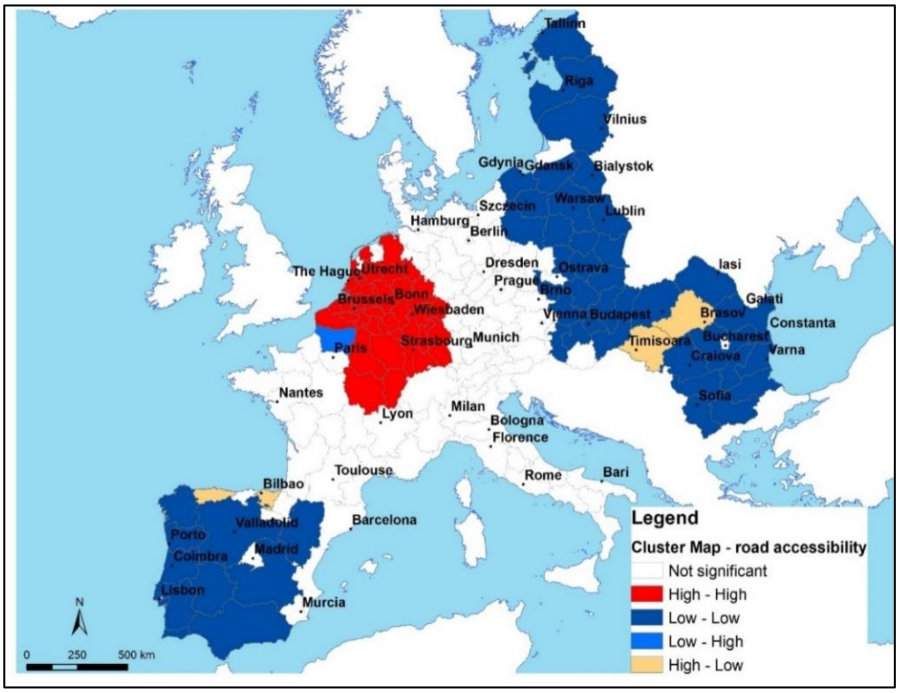

Figure 6A. Regional performance and road accessibility

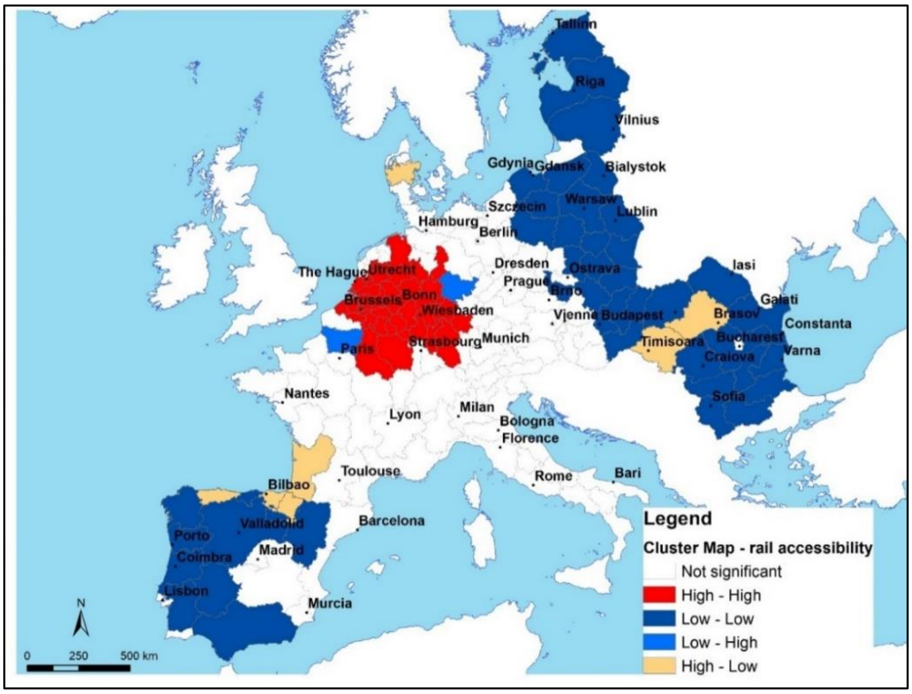

Figure 6B: Regional performance and rail accessibility

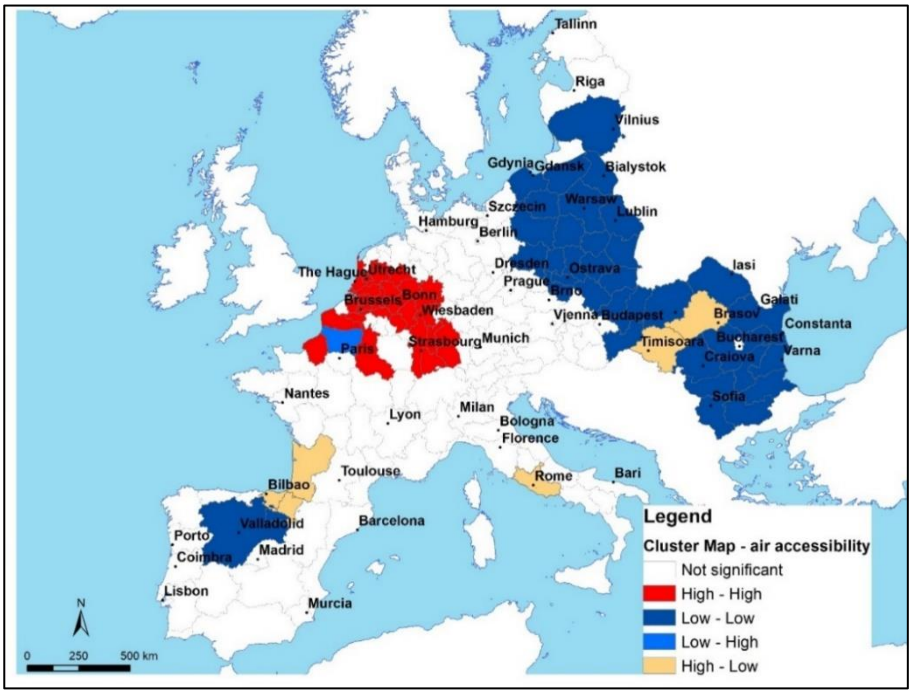

Figure 6C. Regional performance and air accessibility

The map representations of Figures 6A to 6C give a tentative answer to the second research question, i.e.,

Q2. If so, in what regions can it be found, and of what kind is that relationship?

Regions where the road accessibility/performance relationship is HH are located in central Europe. For LL-type, these are located in southern and eastern Europe (Figure 6A). For rail accessibility (Figure 6B), the spatial pattern is quite similar to the road accessibility one. In both in road and rail accessibility the spatial pattern is driven by the 'central vs. periphery' regional dynamic. However, when it comes to air accessibility the spatial pattern is slightly different (Figure 6C). While the spatial pattern of air significance (and type thereof) still shares some similarities to the road and rail cases, there are fewer significant regions, and some important differences should be noted. In particular, the spatial pattern of Portugal and Spain is different, with only a few regions located in the north of Spain showing significance, in contrast with overall LL-type significance for road and rail in this peninsula. The same happens, albeit to a lesser extent, with the Baltic regions of Tallin and Riga.

In what concerns the *type* of relationship, table 2 shows that this relationship, when it exists, is mainly of HH or LL type, with 50-60% of these regions having Moran significance, which contrasts with 10-20% for HL or LH regions. The fact that around half of the regions present HH or LL relationships between regional performance and accessibility suggests a positive influence of accessibility in regional performance, especially for the ground modes (road, rail).

4.3 Discussion

The above answer to Q2 indicates that a high (low) regional efficiency might be related to a high (low) accessibility. Consequently, the improvement of transport modes in general can be one of the aspects that public administrations have to promote regional performance.

However, to better predict the effect of such large investments one should try and verify whether underlying factors may be found that help understanding the descriptive statistics and map representations obtained thus far. This brings one to the third research question, namely

> Q3. Are there any factors that may predict the existence (or not) of a significant relationship between transport accessibility and regional performance?

Many factors (geographic, socio-economic, etc.) can be envisioned to explain the existence of such a relationship. Rather than carrying out an exhaustive search, which is beyond the scope of this article, three possible explanatory factors were selected for analysis, which directly relate to this research: Moran cluster type, centrality, and capital region (i.e., whether a region contains a national capital).

To answer Q3 binomial logit regression models were used, with cluster type, centrality, and capital region as independent variables and Moran significance as binary dependent variable Y, with $Y = 0$ for not Moran significant and $Y = 1$ Moran significant.

Factor: cluster type

Table 2 values suggest the type of Moran relationship (HH, LL, HL or LH) may predict Moran significance. So, cluster type was the first factor to test for explanatory power. This is a categorical variable with four levels and the logit regression analysis led to the results of Table 3 below. The goodness-of-fit indicator is the Nagelkerke pseudo-R^2, which compares predictive power of the full model vs. an intercept-only model.

Table 3. Cluster type as a predictor of Moran significance

(Asterisks mark significant regressors at 5%)

Accessibility type		Estimate	Std. Error	z value	p-value
Road	(Intercept)	0.5328	0.2424	2.198	0.0280 *
(Nagelk. R^2: 27%)	typeHL	-2.5805	0.5840	-4.419	9.92×10^{-6} *
	typeLH	-2.4787	1.0962	-2.261	0.0237 *
	typeLL	0.1818	0.3515	0.517	0.6049
Rail	(Intercept)	0.1924	0.2352	0.818	0.4133
(Nagelk. R^2: 15%)	typeHL	-1.5787	0.4836	-3.264	0.0011 *
	typeLH	-1.5787	0.8248	-1.914	0.0556
	typeLL	0.3500	0.3443	1.016	0.3095
Air	(Intercept)	0.1252	0.2505	0.500	0.617
(Nagelk. R^2: 15%)	typeHL	-1.9710	0.5057	-3.898	9.72×10^{-5} *
	typeLH	-1.2238	1.1816	-1.036	0.300
	typeLL	-0.2334	0.3420	-0.682	0.495

In a binary logistic regression with a categoric regressor there exists a base, or reference scenario, in this case that a region is of HH-type. Other categories (LL, HL, LH) then compare against this scenario. For road accessibility, the regression coefficient for the intercept is significant and positive, leading to base log-odds of $Y = 1$ of $\operatorname{logit} p = 0.5328 \Leftrightarrow p = 63{,}01\%$ (the empirical value is very close: 46/(46+27) = 63%; see Table 3). There is thus a statistically significant trend, with p-value 2.8%, that HH-type regions are more likely to be Moran significant for the road case. For LL-type regions this probability increases slightly to $\operatorname{logit} p = 0.5328 + 0.1818 \Leftrightarrow p = 67{,}14\%$. For HL- and LH-type regions however, this probability decreases to $p = 11{,}43\%$ and $p = 12{,}50\%$ respectively in a statistically significant manner (p-values < 1%), meaning that outlier regions exhibit a clear trend of being Moran *non*-significant.

For rail accessibility and air accessibility the situation is different. The intercept is not significant and the fact that a region is of LL- or LH-type does not change that. However, for HL-type the probability of Moran significance drops to $p = 20{,}00\%$ (rail) and to $p = 13{,}64\%$ (air). So, for the rail and air modes, region type does not help predicting whether that region is Moran significant (a 50%-coin flip is just as good a predictor), except for HL-type regions, which are likely to be Moran non-significant.

A word on the interpretation of the logistic regression results is due here. The fact that a region is of HH- or LL-type is not a predictor of Moran significance for the rail and air modes does *not* mean the accessibility/performance LBR is inexistent for these regions. It merely says that it happens roughly 50% of the time. By contrast, the fact that a region is of HL-type (also LH for the road mode) is predictor of Moran *non*-significance means the accessibility/performance LBR *is* likely inexistent, i.e., the two variables are not spatially related for these region types. This provides statistical support to claims made in sections above that a synergy may exist between accessibility and regional performance.

Cluster type policy implications

For the road mode, the trend that HH- and LL-type regions have a higher chance to be Moran significant may be interpreted, as mentioned, as road accessibility having a moderate synergy with performance. Public investment implications may be drawn from this fact. If a region is brought to the HH cluster, the accessibility/performance synergy is more likely to kick in and benefit the region due to higher chance of Moran significance.

Road accessibility investments in HL-type neighbouring regions may bring it to the HH cluster and achieve that synergy. Bilbao region, North of Spain, is an example of an HL-type region and that has overcome the expectations. Hendenreich and Plaza (2015) classifies Bilbao as a "role model for the regeneration of declining urban and industrial regions", thanks to culture-based policies based on the Guggenheim Museum. This region presents a good performance due to the positive impact of the Guggenheim Museum on the region's economic development, as demonstrated by Banks (2022). Despite its success, this region is surrounded by regions with low accessibility levels. This research strongly suggests that transport investment in Bilbao's neighbourhood regions would further increase the performance of the former. Concerning LH-type regions, these already have high neighbouring road accessibility, suggesting that further investment in this infrastructure is unlikely to generate the desired synergy. Picardie, located in the North of Paris, is an LH-type region for all transport modes. Binet and Facchini (2013) found that this region has a high proportion of long-term unemployed people and, according to these authors, conventional national policies to stimulate GDP to reduce unemployment might not be enough. This research suggests that such policies should nevertheless be considered because if Picardie is brought to the HH cluster, the accessibility/performance with its neighbouring regions might occur. In LL-type regions road accessibility investment must be done together with other policies, as it is unlikely to trigger the accessibility/performance synergy only by itself. This conclusion is in line with other research on the subject which advocates that in depressed regions transport investment might not be enough to foster economic welfare and other investments must be pursued, such as workforce training. Capello (2016) argued that in the case of South of Italy transport infrastructure policies must be coordinated with human capital strategies. However, the South of Italy is mostly of HL-type, so, according to the present research, transport infrastructure investment might suffice. Crescenzi and Giua (2020) have demonstrated that for Spain investment in transport infrastructure is disconnected from issues such as social inequalities, in line with conclusions of Matas et al. (2015) who studied the effects of infrastructure improvements on productivity and concluded that the upgrade of a road corridor in the western part of Spain would not have significance due to the low level of development of those regions. Regarding Eastern Europe, Rokicki et al. (2021) have demonstrated that in the case of polish regions the impact of major road network investment on GDP is almost negligible, a conclusion that is supported by the present research as these are mostly LL regions.

For the rail and air modes the conclusions are similar, although Moran significance is slightly less related to HH and LL cluster types. HL regions are still likely to benefit from rail and air investments to achieve an accessibility/performance synergy, but this is not so clear for LH-type regions. However, given the small number of regions of the latter type (table 2), the inexistence of a statistical trend might be a consequence of lack of data, especially for the air mode. Nonetheless, because the statistical conclusions drawn from cluster type analysis for the road mode go in line with previous research on the effectiveness of transport investment on regions with economic difficulties, it is expectable that similar statistical conclusions for the rail and air modes will hold, making rail and air investments questionable for LL and LH regions. Also, Álvarez et al. (2016) concluded that the impact of road investment on GDP is not linear, the authors have identified negative spillovers for poor regions and positive for the rich ones. The spatial statistical results found in the present research strength to previous findings on the impact of transport investments and add the predictive power of where such investments might work out best, leading to the policy implications identified in this section.

Factor: centrality

The maps of figures 5a-5c suggest testing for the geographic factor of centrality and analysis was thus carried out. Following the European Commission (2001) classification, regions were classified as central, peripheral, and neutral, these categorical values were used as regressor values, with central as default. Table 4 below gives a detailed breakdown of the empirical values for centrality vs. significance.

Table 4 values hint at the existence of significant trends in the relationship between Moran significance and centrality. These are checked now, using the respective regression model. The result is given in table 5.

Table 4. Cross-table of centrality vs. Moran significance

Accessibility mode	Significance	Central	Neutral	Periphery	Total
Road	Yes	47	1	50	98
	No	14	52	22	88
Rail	Yes	42	1	49	92
	No	19	52	23	94
Air	Yes	34	3	39	76
	No	27	50	33	110

Table 5. Centrality as a predictor of the Moran significance

(Asterisks mark significant regressors at 5%)

Accessibility mode		Estimate	Std. Error	z value	p-value
Road (Nagelk. R^2: 53%)	(Intercept)	1.2111	0.3045	3.978	6.96×10^{-5} *
	Region_neutral	-5.1623	1.0544	-4.896	9.78×10^{-7} *
	Region_periphery	-0.3901	0.3977	-0.981	0.327
Rail (Nagelk. R^2: 48%)	(Intercept)	0.7932	0.2765	2.869	0.00412 *
	Region_neutral	-4.7445	1.0467	-4.533	5.82×10^{-6} *
	Region_periphery	-0.0369	0.3746	-0.099	0.92152
Air (Nagelk. R^2: 29%)	(Intercept)	0.23052	0.25778	0.894	0.371
	Region_neutral	-3.04393	0.64790	-4.698	2.62×10^{-6} *
	Region_periphery	-0.06347	0.34985	-0.181	0.856

The base scenario is of a central region. For road accessibility, the base odds of $Y = 1$ are $\operatorname{logit} p = 1.2111 \Leftrightarrow p = 77.05\%$ which coincides with the empirical value for central regions (47/(47+14) = 77.05%; c.f. Table 5). These odds are highly significant (p-value ~0%) and the fact that a region is peripheric does not statistically change it. In fact, the predicted change in the log-odds for a peripheric region is $\operatorname{logit} p = 1.2111 - 0.3901 \Leftrightarrow p = 69.44\%$ which again coincides with the empirical value. However, regions which are neither central nor peripheral exhibit significant changes the log-odds, namely to $\operatorname{logit} p = 1.2111 - 5.1623 \Leftrightarrow p = 1.89\%$. The conclusion validates the trends Table 5 hinted at: central and peripheral regions are likely to exhibit a significant Moran relationship, whereas neutral regions are highly unlikely to have significant Moran relationship. For rail accessibility the results are very similar, and the conclusions are essentially the same.

These results are consistent with those of Vickerman et al. (1999), who concluded that the impact of accessibility gains on economic development are higher in the region in the European core rather than in the peripheral regions. In the case of Polish regions, which in this work falls in peripheral regions category, Rokicki et al. (2021) concluded that the impact of accessibility on average employment was not significant and added that the road infrastructure investment in Poland has to be more extensive and embrace the regional development multiple perspectives.

For air accessibility, the results are slightly different. In this case, the base log-odds of a region exhibiting Moran significance are $\operatorname{logit} p = 0.2305 \Leftrightarrow p = 55.74\%$ but these are not statistically relevant at 5% significance level. Therefore, as in the cluster type analysis, the fact that a region is central cannot accurately predict whether that region is (or not) Moran significant for the air mode. Being peripheral does not change this (p-value 85.6%), but being neutral does, lowering the log-odds to $\operatorname{logit} p = 0.2305 - 3.0439 \Leftrightarrow p = 5.66\%$ One concludes that, contrary to road and rail accessibility, air accessibility does not predict Moran significance, except for neutral regions, where it predicts its *inexistence*.

It is not clear why centrality is a good predictor of Moran significance for the road and rail accessibility case, but not for air accessibility. According to several authors (Halpern and Brathen, 2011; Laurino et al., 2019; Bergantino et al., 2020), air transport plays a relevant role in the remote regions' development and the core-periphery analysis does not apply. Also, Elburz et al. (2017) in their extensive meta-analysis concluded that works focused on land transport have a higher probability of finding that transport infrastructure has a positive and significant impact on regional growth.

Factor: national capital regions

Literature research points at national capital regions (19 in this research) as having an advantage in terms of higher levels of inputs and outputs. To test whether this factor is a predictor of Moran significance a logit regression was carried out with capital region (yes/no) as categorical regressor. For all transport modes the logit model trends were not statistically significant (p-values of 80/35/25% for road/rail/air respectively), so the fact a region is national capital region does not increase its odds of having a significant accessibility/performance relationship. This may be due to higher levels of inputs and outputs not necessarily translating into more performance. Indeed, national capital regions have a mean efficiency score of 1,52 (unstandardized) whereas the full dataset of 186 regions has a mean efficiency of 1,45 (recall an unstandardized score of 0 indicates an efficient region). Capitals have thus performances similar to other regions and the accessibility scores of the neighbouring regions, even if higher than average, cannot move the capital points in the Moran plot away enough from the origin to give them Moran significance at a rate higher than non-capital regions.

Note that centrality and capital factors are hard to change, and therefore policy implications are mostly restricted to investment depending on cluster type.

5. Conclusions

This article presented a methodology, based on DEA and local bivariate relationships, to investigate whether regional performance is related to transport accessibility, with performance seen as a region's capacity to transform inputs into outputs. The motivation for this study was to fill a literature gap on the transport/development relationship discussion, by introducing regional performance into the debate and relating it with accessibility, trying to understand where Moran significant accessibility/performance relationships exist and whether accessibility improvements can be expected to have a positive impact on regional economy. Also, it goes beyond previous works by considering not only economic outcomes, but also social well-being outcomes.

The methodology was applied to a case study of 186 NUTS2 European regions and three transport modes; from which it was possible to determine that geographic centrality plays a role predicting the significance of the accessibility/performance relationship. Logistic regression models ran over the results show that central and peripheral regions tend to exhibit significant relationships for the road and rail modes, whereas regions that are neither central nor peripheral tend to have non-significant accessibility/performance relationships.

For the air mode the latter holds, but central and peripheral are no longer strong predictors. While it does not come as a surprise that centrality is a predictor of Moran significance, this was by no means a given beforehand.

Moran significance is also related to cluster type. According to these results, the largest number of regions that present a significant relationship between regional performance and accessibility fall into the HH and LL categories. These results indicate that a high regional efficiency might be related to a high accessibility, and indeed more than half of the HH regions exhibit Moran significance; road: 63%, rail: 55% rail, 53% air. Therefore, in HH regions, the improvement of transport modes in general can be one of the strategies available to public administrations to promote further increases of regional efficiency. For HL and LH regions the probability of significant accessibility/performance relationship is low. While for HL regions the improvement of transport modes in general may promote these regions to HH-type, increasing their likelihood of developing an accessibility/performance synergy, for LH regions such investments might not be enough to promote regional efficiency, a fact that public administrations should be aware of. Consequently, LL regions would require combined approaches to both accessibility and regional performance rather than going all-in on transport investment. The conclusion that transport investments in LL and HL regions is not expected to generate better performance is an important policy implication of this research which could not be made without this article's proposed methods and analysis. Note that this is vindicated by reports of past investments in transport infrastructure in depressed regions not leading to an increase in regional performance, a fact this research could have helped foresee.

Capital regions were also tested as a factor for Moran significance. Contrary to what might be expected the analysis shows, they are not a predictor for any mode.

More factors are expected to come into play in predicting significance of the accessibility/performance relationship. As future work it would be interesting to test other potentially predictive factors. Socio-economic factors such as population density, Gini index or efficacy of institutional frameworks, and geographic factors such as network connectivity or national border effects have been taken into account in similar studies and could be considered as explanatory variables for the accessibility/performance relationship. The methodology could also be applied to other economic zones to assess e.g., whether centrality or cluster type again emerge as a determinant of significance. Comparative studies to other economic dependent variables or controlling for transport investment may also be envisioned. Repeating the analysis with more recent data, as it becomes available, could also provide clues as to whether transport infrastructure investment yield results as predicted by this research. The use of accessibility data of Spiekermann et al. (2015) is yet another way to refine results.

Besides the fact that the analysis is static in time, this research has further limitations. Firstly, NUTS2 regions vary in size due to the way they are defined, which is based on current administrative units and population, a NUTS 2 must have at least 800,000 residents and at most 3M. This may lead to lower accessibility scores for the larger regions. One way to mitigate this could be to control for this fact in the accessibility definitions. Precision of data may also be a limiting issue, as well as the need for seven different and spatially coherent datasets (four for regional performance assessment, three for accessibility). Finally, only three explanatory factors were considered, so a greater variety of those would lead to a more robust analysis.

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