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## Accessibility Indicators for Regional Economic Development: An Application to the Regional Distributive Effects of High-Speed Rail in Spain

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# **Accessibility Indicators for Regional Economic Development: An Application to the Regional Distributive Effects of High-Speed Rail in Spain**

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## **Abstract**

The inauguration of a HSR line increases the accessibility to people, resources, goods, and markets, which brings locational advantages, thus attracting new households, economic activities, allowing greater agglomerations. Intuitively, the locations where the accessibility increases higher than average may gain more economic opportunities and more growth. Accessibility indicators measure the relative location importance, affecting the attractiveness and economic development potentials of regions. They are also able to measure the disparities among regions to define how transport and development impacts are distributed across geographical areas or population.

In order to evaluate the impacts of accessibility on the regional economic growth, choosing the most suitable accessibility indicator is rather crucial. To analyze how well different types of accessibility indicators are able to capture the spatial distributions of the regional economic variables, this paper is set to study the ex-post impacts of accessibility due to the HSR network expansion in the 2000s at provincial level in Spain and its relation to the evolution of several economic performance indicators (GDP, population, employment and number of firms) during the same time period. Four accessibility indicators corresponding to different conceptualizations are introduced: one location indicator, two economic potential indicators and one daily accessibility indicator. The study area and the zoning level for the analysis is comprised of 47 provinces in continental Spain. The visualization procedure for accessibility indicators and the economic variables is supported by ArcGIS® software. To calculate the

accessibility values, travel times between all the municipalities by railway are computed for the year 2000 and 2010 using a GIS-based network with network analysis tool box in ArcGIS®.

The relative changes of accessibility and economic variables for all the provinces of Spain are presented and analyzed. The distribution patterns of the accessibility indicators and economic variables are compared. The obtained results are expected to help better understanding the concept of accessibility and its explanatory power in the economic impact analysis

**Keywords:** High-speed rail; Accessibility indicators; Regional development;

## 1. Introduction

Investment on transport infrastructure increases the accessibility to resources, goods and markets, thus improves the competitiveness of a region (Dodgson, 1974). Reduction of the distance impedance enlarges the potential market area, and thus removes the bottlenecks in production and trade, and enhances the economic integration (Blum, 1982; Rietveld, 1989). And, reductions in travel time and travel cost can also give rise to productivity growth through reinforcing agglomeration benefits (Graham, 2007; Venables, 2007). HSR is built primarily to improve the accessibility, increase the competitiveness of rail, decrease congestion in air transport, and to stimulate the economic development. The first and foremost expected impact of HSR is through the increased accessibility, which can then generate several types of impacts, mainly agglomeration and a wider labor market that bring about economic growth (Banister and Berechman, 2000). Good accessibility is a necessary condition in order to improve competitiveness of a city (Pol, 2003; Winden et al., 2007). In brief, regions may develop, because transportation infrastructure improvement increases the regional accessibility, which then increases potential markets, production levels, job catchment area, and attracts new households and economic activities.

The interrelationships between accessibility and the economic development have been the focus of many studies that directed to the construction of suitable models and indicators to evaluate whether and to what extent does accessibility contribute to the growth of regional production, regional employment, firm birth, etc. (Boarnet, 1998; Garcia-Mila et al., 1996; Gutiérrez, 2001; Holtz-Eakin, 1994; Jiwattanakulpaisarn et al., 2011; Levinson, 2012; Martin, 1997; Vickerman, 1997). In the existing studies, the most common approach to measure transport investment, which is often used in cross-sectional analysis, is to use a dummy variable to represent the presence of transport infrastructure, with the value of one assigned for the area containing the

transport infrastructure, and zero otherwise (Lichter and Fuguitt, 1980). Using a dummy variable to measure solely the presence of transport infrastructure has obvious disadvantages since it ignores the various physical conditions and qualities of the infrastructure in different areas. To capture the quantitative nature of the transport infrastructure, some studies have employed a more promising approach to measure transport infrastructure, using the volume of investment or stock of infrastructure capital in monetary terms (Cohen and Paul, 2004; Dalenberg et al., 1998; Haughwout, 1999; Seitz and Licht, 1995). But data on the monetary stock are usually unavailable and need to be calculated from other proxy variables. Basically, the stock of transport infrastructure at a particular year is obtained from summing up the real expenditures on transport infrastructure in the past, adjusted by the interest rate. However, the quality of capital stock estimates are questionable. Pritchett (1999) argued that governments do not act as profit-maximizing investors, and the public investment by the government usually does not create the equivalent worth of public capital. Eberts (1986) and Vickerman (2008) also pointed out that government is not subject to competitive market constraints and thus the price does not reflect the marginal productivity of public capital. Many other studies prefer to use physical measures of infrastructure, such as the length of roads and railways for each jurisdiction or density per square kilometer to standardize for the differences in region or country size. These simple measures have been criticized, since accessibility indicators should involve a combination of two elements: the easiness of reaching potential destinations (e.g. travel time, generalized travel cost) and the attractiveness or importance of the destinations (e.g. employment, population, GDP) (Gutiérrez, 2001; Gutiérrez et al., 1996). Moreover, due to the network property, the impact of the transport infrastructure may transcend the areal boundaries, for instance, the municipality may not have the direct access to the highway but can still benefit from the one in adjacent municipality (Pereira and Andraz, 2006).

In order to evaluate the impacts of accessibility on the regional economic growth, choosing the most suitable accessibility indicator is rather crucial. The concept of accessibility is used in a number of scientific fields such as transport planning, urban and regional planning, etc. It plays an important role in policy making and provides an important tool for addressing the economic impacts and exploring the link between the spatial structure of a region and the travel patterns of its residents. Accessibility with respect to a certain area can be strongly influenced by its definition and application. Therefore, it is very important to carefully choose an accessibility indicator that is closely related to the purpose of the research.

Against this background, the aim of this paper is to scrutinize how well different types of accessibility indicators are able to capture the spatial distributions of the regional economic variables. This paper is set to study the ex-post impacts of accessibility due to the HSR network expansion in the 2000s at provincial level in Spain and its relation to the evolution of several economic performance indicators (GDP, population, active population, employment and number of firms) during the same time period. Four accessibility indicators corresponding to different conceptualizations are introduced: one location indicator, two economic potential indicators and one daily accessibility indicator. The study area and the zoning level for the analysis is comprised of 47 provinces in continental Spain. The visualization procedure for accessibility indicators and the economic variables is supported by ArcGIS® software. To calculate the accessibility values, travel times between all the municipalities by railway are computed for the year 2000 and 2010 using a GIS-based network with network analysis tool box in ArcGIS®. The relative changes of accessibility and economic variables for all the provinces of Spain are presented and analyzed. The distribution patterns of the accessibility indicators and economic variables are compared. The obtained results are expected to help better understanding the concept of accessibility and its explanatory power in the economic impact analysis

The contents of this paper are presented as follows. In the next section, we provide explanations of the chosen accessibility indicators and how they are computed. In the third section, we present the results from the application of the four indicators for the case study of Spain and study their correlations with the economic variables. The fifth section concludes this paper with comments and final remarks on the main results of our study.

## **2. Methodology**

Rather abundant reviews and analyses can be found on the classifications of accessibility indicators, such as Baradaran and Ramjerdi (2002), Gutiérrez (2001), Bruinsma and Rietveld (1998), López et al.(2008) and Geurs and van Wee (2004), etc. Considering the data availability and the easiness in results interpretation and communication, we have followed the classification of Gutiérrez (2001) and López et al. (2008) and selected three types of accessibility indicators, which are location indicator, economic potential indicator and daily accessibility indicator. Each of the indicators corresponds to different concepts and offers complementary information to the problem of changes in accessibility brought by a new HSR line.

To calculate the accessibility values, the essential input is travel times between all the municipalities in continent Spain. The computation of the travel times is supported by a Geographical Information System (GIS). The travel time ( $TT_{ij}$ ) from municipality  $i$  to municipality  $j$  takes into account the travel time by car from the origin centroid to the nearest station  $TT_C(i, E_i)$ , the travel time by railway  $TT_R(E_i, E_j)$  from the origin railway station to the destination railway station and the travel time by car from the destination railway station to the destination centroid  $TT_C(E_j, j)$ . The transfer time penalty when a transfer between car and train or a transfer between trains is not introduced for simplification purposes.

$$TT_{ij} = TT_C(i, E_i) + TT_R(E_i, E_j) + TT_C(E_j, j)$$

### 2.1.1 Location Indicator

Weighted average travel time is a measure that takes into consideration the travel times between each node and all urban agglomerations and the mass of each urban agglomeration as weight for the importance of every travel time. Gutiérrez et al. (1996) used weighted average travel time as the indicator to evaluate the impact of the future European HSR network on accessibility. Later, Gutiérrez (2001) used the same indicator to measure the accessibility impacts of the future Madrid-Barcelona-French border HSR line. Here, we adopt the same formulation, but using the municipal population as weight in order to value the importance of the shortest travel time routes, referred as “wTT” in the following sections.

$$wTT: A_i = \frac{\sum_j (TT_{ij} * Pop_j)}{\sum_j Pop_j}$$

This measure expresses the relative location of each municipality and the extent to which a new link modifies this location by reducing access times to all the municipal centers. The results are easy to be interpreted, for example, the average travel time from the municipalities inside Sevilla province to all the municipal centers in the rest of Spain is 375 min in 2000 and 310 min in 2010, a travel time saving of 65 min.

### 2.1.2 Economic Potential Indicator

To incorporate the distance decay effects, the economic potential accessibility measures are often used. They are gravity-based measures, which are widely adopted in urban and regional studies (Chandra and Vadali, 2014; Gutiérrez, 2001; Hansen, 1959; Keeble et al., 1982). The measure has the following form, assuming a negative exponential impedance function:

$$A_i = \sum_{j=1}^n M_j / f(c_{ij})$$

Where,  $C_{ij}$  is the generalized travel cost between zone  $i$  and  $j$ ,  $M_j$  is the opportunities in zone  $j$ .  $f(c_{ij})$  is the impedance function, and the most two common formulations are exponential and power formulation,  $f(c_{ij}) = \exp(\beta * c_{ij})$  and  $f(c_{ij}) = c_{ij}^b$ . Population or GDP is usually the variable representing the mass of opportunities available at the destination (Bruinsma and Rietveld, 1993).

This type of measure can be easily computed using existing demographic, economic, land-use and transport data. It is appropriate for analyzing the level of access to social and economic opportunities for different groups. Its disadvantages are related to a more difficult interpretation and sensitivity to the form of impedance function. Although the most common specification for the impedance function is a negative exponential other specifications have also been used (e.g. power functions). It is widely used because it offers the appropriate balance between complexity and interpretability, and its validity has also been empirically proved (Gutiérrez, 2001; Linneker and Spence, 1996; López et al., 2008; Martín et al., 2004; Monzón et al., 2013).

In this paper, we use two different impedance functions as a weight for each municipality pair in order to take into consideration the effects of travel time in the intensity of possible interactions between the populations, referred as economic potential 1 (EP1) and economic potential 2 (EP2) in the following text.

$$EP1: A_i = \sum_j Pop_j * \exp(-\beta * TT_{ij})$$

$$EP2: A_i = \sum_j Pop_j / TT_{ij}$$

Where,  $A_i$  is accessibility of municipality  $i$ ,  $Pop_j$  is population of municipality  $j$ ,  $TT_{ij}$  is the travel time between  $i$  and  $j$  and  $\beta$  is the coefficient for the impedance function. In this paper, the parameter value beta used is 0.1.

Between the two economic potential indicators, they both take into account all relationships within the study area, but inversely to the travel times, however, the one with exponential impedance (EP1) function gives much higher weights to short travel times than the other one (EP2) and the weights decreases much faster using EP1 than in EP2 as one can observe from Figure 1.

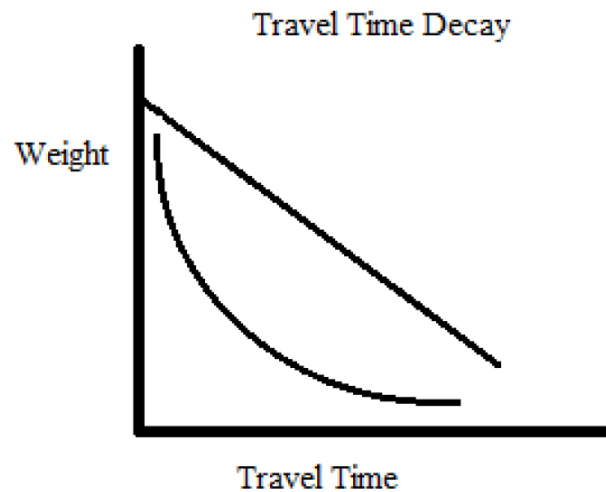


Figure 1 - Travel Time Decay Comparison

### 2.1.3 Daily Accessibility Indicator

Another type of accessibility measure is daily accessibility, which consists on the amount of population or economic activity that can be reached from a node within a specified travel time (Bruinsma and Rietveld, 1998). This indicator is useful for calculating the accessibility for business and touristic trips (Bonnafous, 1987; Gutiérrez, 2001). In this paper, we define it as the number of population reachable within the connectivity criteria of travel time by railway less or equal to 90min between the municipal centroids, termed as “POP90” in the following sections. In the context of HSR, this indicator provides basically how much population can be reached from a place in a certain travel time limit and the changes in accessible population brought about by a new infrastructure. The results are of the following type: for all the municipalities inside Alicante province, within travel time limit of 1h and 30 min, 1.5 million inhabitants can be reached in the year 2000 and 2.2 million in 2010, which means an increase of 0.7 million inhabitants.

### 2.1.4 Resemblance and Correlation Analysis

The calculated accessibility values allow us to analyze the effects of HSR in terms of efficiency. By comparing the values of accessibility indicator in 2000 and in 2010, we obtain the absolute differences and the growth rates to assess the efficiency of the HSR expansion.

Since accessibility is often considered as an intermediate indicator of development (it is normally assumed that an increase in accessibility will result in an increase in economic indicators), it is very important to analyze the relation between the equity measured for each accessibility indicator and the equity in economic growth or other development indicators to



clearly ascertain which indicators could be better to measure the spatial equity. To analyze the equity, we use the coefficient of variation (CV) and Gini coefficients. These coefficients have been previously used for this purpose in similar studies (Kim, 2000; López et al., 2008; Martín et al., 2004; Monzón et al., 2013). CV is computed using the population as the weight variable. An increased CV value means inequity reduction in equity, whereas a decrease in the CV value means more balanced spatial distribution of accessibility. Gini coefficients may range from 0 to 1, where 0 indicates a uniform distribution of benefits and 1 indicates the total concentration of an attribute in a single zone.

To analyze how well the accessibility growth can explain the economic growth, we calculated the correlation coefficients for the different accessibility indicators and the collected economic variables. The correlation coefficients range from 0 to 1, where 0 indicates no correlation and 1 indicates a perfect correlation. Different accessibility indicators are compared and ranked based on their correlation coefficients with the economic variables.

### **3. Case Description**

The HSR service was introduced in Spain in the year 1992, with the inauguration of a service covering the southern corridor between Madrid and Seville (471 km), which brought 5 stations into service: Madrid-Atocha, Ciudad Real, Puertollano, Córdoba and Seville-La Cartuja. The opening of this first HSR line also coincided with the Seville Expo'92. In 2003, the Spanish HSR network was considerably enlarged after the Madrid-Lleida (519 km) line came into service. This line added 4 more stations to the existing ones, which are Guadalajara-Yebes, Calatayud, Zaragoza-Delicias and Lleida-Pirineus (Bellet, 2009). In 2005, the La Sagra-Toledo (21 km) section of the network also came into service; this line took advantage of the previously constructed southern corridor, with a dead-end track between La Sagra and Toledo. The process of implementing the high speed train (HST) in Spain has received a notable impulse in recent years. In 2000s, more HSR lines are opened, under construction or planned. The lines connecting Madrid to Valladolid, Madrid to Barcelona and Madrid to Valencia were respectively inaugurated in 2007, 2008 and 2010. By 2010, Spain had a total of 2556 km of HSR in service. The length of Spain's HSR network is the second longest in the world and the longest in Europe, comparing to that of other major European states with extensive networks: according to recent data from the UIC (International Union of Railways): France has 1,872 km of high speed line and Germany has 1,285 km. The HSR network by 2010 is presented in Figure 2.

In this case study, we are aiming to analyze the ex-post effects of accessibility brought by the HSR network expansion happened during 2000s. As we are using population to represent the mass or weight of each municipality, the population evolution happened during that decade will also have influences on the accessibility evolutions, especially on the economic potential indicators. Thus, we present also the population evolution happened between 2000 and 2010 in Figure 2. Population relocation can also provide useful information on the importance of location determinants, in this case the proximity to the HSR stations. Between years 2000 and 2010. We observe a very clear population relocation among the municipalities, characterized by growth in the municipalities along the south and east coasts, northern and central areas, especially surrounding Madrid, Barcelona, Valencia, Sevilla and Málaga, the principal cities of Spain. We can also see a pattern of population concentration near the HSR corridors. The presence of HSR station increase the attractiveness of the municipalities, thereby enhances their competitiveness and economic growth.



Figure 2 HSR Network and Population Evolution between 2000 and 2010 in Spain

To analyze the accessibility impacts of the HSR network constructed in 2000s, we computed the travel times between all the municipalities by railway for both years of 2000 and 2010 using a GIS-based network with network analysis tool box in ArcGIS® software. The study area and the zoning level for the analysis is comprised of 8041 municipalities in continental Spain. The assessment is made by comparing the four accessibility indicators of 2000 and 2010.

#### 4. Data Description

The model is estimated based on the data of 47 provinces of continental Spain in the year 2000 and 2010. The descriptive statistics of the variables is presented in Table 1. The data items that used in the model are:

- Total population by province (POP);
- Active population by province (APOP);
- Number of firms by province (NOF);
- Number of employed population by province (EMP);
- Number of population graduated from high-school or above by province (EDU);
- Gross Domestic Product (GDP) by province;
- Calculated provincial accessibility by HSR (ACC<sub>HSR</sub>): the accessibility is measured at municipality level and then being aggregated to the provincial level.

$$ACC_m = \sum_m (ACC_i^m * POP_i^m) / \sum_m POP_i^m$$

Where,  $A_i^m$  is the accessibility of municipality  $i$  in province  $m$ ,  $POP_i^m$  is the population of municipality  $i$  in province  $m$ .

Table 1 Description of Variables and Descriptive Statistics

	Min	Max	Average	Stand. Dev.
<b>POP00</b>	91314	5372433	815156,0	1016856,3
<b>POP10</b>	94620	6421878	924850,7	1197734,4
<b>APOP_2000</b>	39700	2501075	356589,9	476788,3
<b>APOP_2010</b>	43475	3426025	454332,4	624822,3
<b>Emp_2000</b>	36925	2211975	306539,9	424635,1
<b>Emp_2010</b>	38200	2875100	365257,4	515250,0
<b>H_Edu_2000</b>	30531	2314634	276784,7	407882,1
<b>H_Edu_2010</b>	45194	3156015	367062,7	546133,7
<b>GDP_2000</b>	1412,7	111204,5	12478,5	19858,9
<b>GDP_2010</b>	2121,4	186630,3	20876,3	32760,1
<b>NOF00</b>	6312	411809	56722,1	79515,6
<b>NOF10</b>	6992	548663	72831,6	104815,8
<b>EP1_00</b>	4167,8	850603,2	80038,7	143614,8
<b>EP1_10</b>	5710,6	1093775,2	106964,8	186656,5
<b>EP2_00</b>	90421,0	418101,0	144879,9	56255,8
<b>EP2_10</b>	120884,7	549442,5	198526,0	77393,1
<b>POP90_00</b>	145456,6	6120062,5	1485608,9	1395476,8
<b>POP90_10</b>	256291,4	7556872,7	2149881,6	1925148,6
<b>wTT_00</b>	281,3	649,1	445,1	86,5
<b>wTT_10</b>	213,3	524,7	353,0	73,5

## 5. Results and Discussions

### 5.1 Accessibility Growth Analysis

In order to provide an overall view of change in the accessibility in terms of accessibility growth, the corresponding accessibility values have been mapped in various Figures in the follows sections respectively. Table 2 shows the accessibility values of a selection of 36 cities which are regional economic centers and a few intermediate cities. The accessibility change is shown in relative terms, meaning the percentage changes of the four chosen accessibility indicators between 2010 and 2000.

Table 2 Accessibility Improvements from 2000 to 2010

<b>Municipality</b>	<b>HSR Station</b>	<b>EP1 (%)</b>	<b>EP2 (%)</b>	<b>POP90 (%)</b>	<b>wTT (%)</b>
<b>Albacete</b>	<b>Yes</b>	<b>18,83</b>	<b>37,39</b>	<b>59,27</b>	<b>-21,05</b>
Alicante	No	41,40	41,78	44,11	-24,52
Almería	No	32,38	38,53	28,38	-23,01
Avilés	No	26,83	39,61	5,82	-28,82
Badajoz	No	13,61	39,83	33,42	-25,48
<b>Barcelona</b>	<b>Yes</b>	<b>31,55</b>	<b>39,63</b>	<b>27,48</b>	<b>-38,96</b>
Bilbao	No	11,57	28,24	25,97	-22,30
Burgos	No	17,85	44,52	38,03	-25,17
Castellón de la Plana	No	48,45	55,64	29,30	-34,65
<b>Ciudad Real</b>	<b>Yes</b>	<b>29,56</b>	<b>39,15</b>	<b>20,44</b>	<b>-30,94</b>
<b>Córdoba</b>	<b>Yes</b>	<b>7,63</b>	<b>35,07</b>	<b>73,81</b>	<b>-27,55</b>
<b>Cuenca</b>	<b>Yes</b>	<b>21,96</b>	<b>37,88</b>	<b>35,13</b>	<b>-19,78</b>
Granada	No	15,62	33,75	16,30	-23,05
<b>Guadalajara</b>	<b>Yes</b>	<b>59,13</b>	<b>47,55</b>	<b>26,73</b>	<b>-32,43</b>
Huelva	No	22,50	36,08	33,00	-24,13
La Coruña	No	20,58	31,02	25,47	-22,51
<b>Lleida</b>	<b>Yes</b>	<b>64,22</b>	<b>84,72</b>	<b>510,25</b>	<b>-41,11</b>
Logroño	No	39,38	49,21	152,90	-25,61
<b>Madrid</b>	<b>Yes</b>	<b>27,53</b>	<b>37,19</b>	<b>32,88</b>	<b>-35,50</b>
<b>Málaga</b>	<b>Yes</b>	<b>20,97</b>	<b>53,61</b>	<b>88,13</b>	<b>-36,27</b>
Murcia	No	28,97	35,38	43,48	-19,81
Oviedo	No	25,99	40,43	24,32	-29,34
Pamplona	No	30,20	46,78	41,57	-25,29
Salamanca	No	13,83	41,37	83,57	-26,73
San Sebastián	No	14,77	35,75	8,17	-21,76
Santander	No	28,16	43,90	18,75	-28,04
Santiago de Compostela	No	33,96	34,13	19,41	-24,10
<b>Segovia</b>	<b>Yes</b>	<b>813,34</b>	<b>108,49</b>	<b>49,91</b>	<b>-41,69</b>
<b>Sevilla</b>	<b>Yes</b>	<b>17,59</b>	<b>29,80</b>	<b>27,19</b>	<b>-25,92</b>
<b>Tarragona</b>	<b>Yes</b>	<b>76,97</b>	<b>60,36</b>	<b>42,71</b>	<b>-39,05</b>
<b>Toledo</b>	<b>Yes</b>	<b>88,81</b>	<b>48,79</b>	<b>28,09</b>	<b>-32,06</b>
Tomelloso	No	31,70	40,59	46,94	-23,76
<b>Valencia</b>	<b>Yes</b>	<b>23,37</b>	<b>47,89</b>	<b>25,04</b>	<b>-36,05</b>
<b>Valladolid</b>	<b>Yes</b>	<b>9,72</b>	<b>69,48</b>	<b>447,05</b>	<b>-36,74</b>
Vitoria	No	23,02	40,02	98,99	-22,47
<b>Zaragoza</b>	<b>Yes</b>	<b>23,62</b>	<b>73,46</b>	<b>151,13</b>	<b>-35,16</b>
<b>National Average Growth (%)</b>		<b>47,13</b>	<b>47,81</b>	<b>94,25</b>	<b>-28,07</b>

Generally, all these cities have accessibility increased in the year 2010 due to the introduction of more HSR lines. At the national level, the percentage of improvement in the level of accessibility are 47.1%, 47.8%, 94.3% and 28.1%, based on the indicator economic potential (EP1), economic potential (EP2), daily accessibility (POP90) and weighted travel time (wTT), respectively. The accessibility growth for the cities with HSR stations is mostly higher than the national average accessibility growth. More detailed analysis with respect to each type of accessibility indicator is presented in the following sections.

### *5.1.1 Weighted Travel Time*

In average, the newly constructed HSR lines during 2000s has brought about a reduction of 112 min (about 28%) in the weighted average travel times between all the municipalities in Spain, from 397 min in 2000 to 285min in 2010. All the municipalities across the country had their average travel times reduced. This travel condition is significantly improved with the extension of the HSR network during 2000s, as shown in Figure 3. In terms of the distribution of accessibility improvement, the greatest benefits occurred in the municipalities with a HSR station, as indicated by the darkest colors in Figure 3. The areas close to the HSR corridors and at the same time with good connections to conventional railway also experienced a fairly high level of improvement, such as the areas located along the corridor Zaragoza to Barcelona, Madrid to Valladolid, Madrid to Sevilla and Málaga. Out of all the municipalities newly connected with HSR links during 2000s, Cuenca and Albacete are the only two municipalities which had travel time improvement below national level.



Figure 3 Changes of Weighted Travel Time between 2000 and 2010 in Spain

### 5.1.2 Economic Potential

With the economic potential indicator, the average improvement of “EP1” and “EP2” (47.16%, 47.8% respectively) are much higher than the weighted travel time indicator (reduced by 28.1%). Figure 4 presents the distribution of economic potential changes measured by indicator “EP1” using exponential distance-decay function, and Figure 5 shows the results measured by “EP2” with linear distance-decay function. Comparing “EP1” with “EP2” in Figure 4 and Figure 5, we can observe that after switching from exponential distance decay function to linear distance decay function, the accessibility improvements are much less concentrated, much more evenly distributed across the nation. This is due to the fact that the economic potential indicator is a gravity-based measure so that most of the municipalities obtain decreasing benefits of economic potential as they move away from the HSR line. EP1 gives much more importance to the relations over short distances than EP2. Therefore, the reduction of travel time over long distances given by HSR is seriously discounted due to the nature of exponential distance decay.

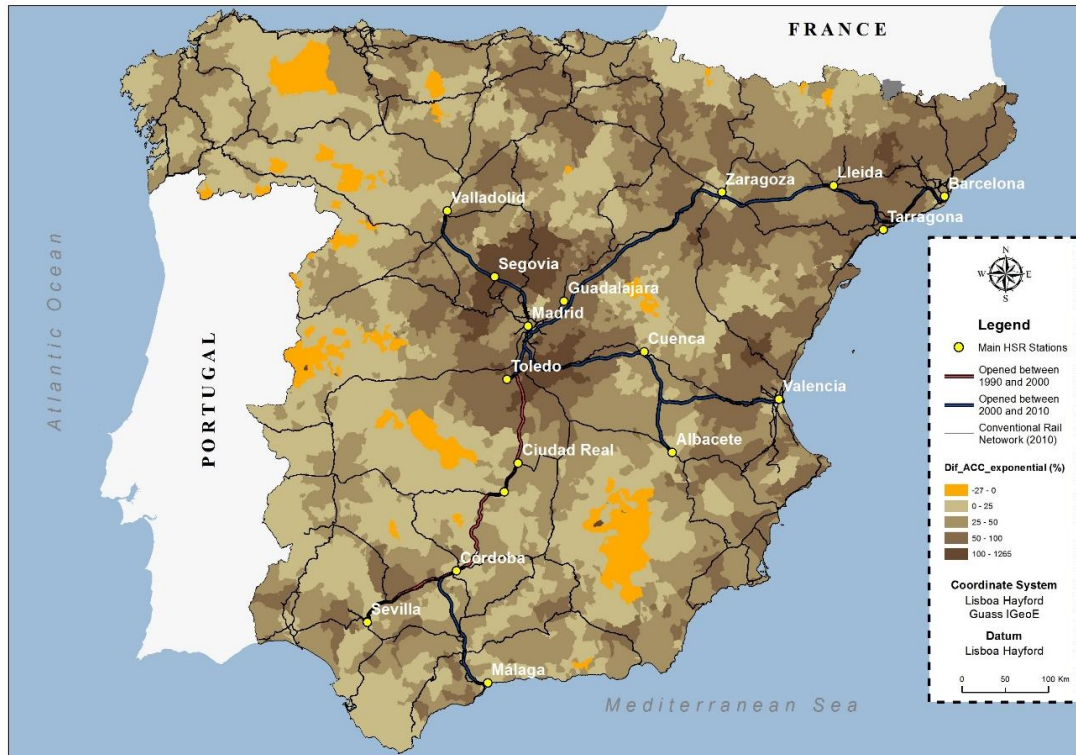


Figure 4 Accessibility Changes (EP1) between 2000 and 2010 in Spain

Comparing to the location indicator weighted travel time, the changes in accessibility measured by EP1 are much more concentrated on the municipalities which are close to the HSR corridors; the orange areas indicate loss in economic potential after the HSR network expansion. Those areas are the ones which also are far from conventional railway stations, and also experienced population loss during that decade (see Figure 2). On the contrary, in municipalities located in the north of Spain without direct access to HSR stations have experienced very high improvements, due to the good quality of the transport network from these cities to the HSR stations.

In general, the higher accessibility values are concentrated in the urban agglomerations around HSR stations, as HSR lines allow them to reach the major cities with a shorter travel time. The presence of “islands” can be much more clearly observed in Figure 5 than in Figure 4, with enhanced levels of accessibility in the vicinity of these stations. The spillover effects of HSR stations are much higher using the linear distance-decay function for measuring the accessibility, as we can clearly observe for the areas in the area of Zaragoza-Barcelona corridor, around Valencia and Valladolid, etc. In Figure 5, lower growth in economic potential levels correspond to the areas bounded by Toledo and Sevilla, because the value depends on their initial



accessibility values, which is lower since they were already served by HSR and their values are already high in 2000 (e.g. Madrid, Ciudad Real, Puertollano, Córdoba and Sevilla).



Figure 5 Accessibility Changes (EP2) between 2000 and 2010 in Spain

5.1.3 Daily Accessibility

With the building of a new HSR line, the average accessible population within the 1h30 limit for all the municipalities in Spain rises from 1.30 million to 2.05 million, which means an increase of 57.8%. According to the distribution of the accessibility growth measured by this indicator (see Figure 6), the areas which were previously served by HSR in 2000 did not experience relevant gains in terms of daily accessibility. A very obvious pattern can be seen around Madrid and Sevilla. Other major cities which previously did not have HSR stations but had very good conventional railway services also did not experience significant changes in accessing the population within 1 hour and 30 minutes travel time by railway (e.g. Barcelona and Valencia). In the rest of cities served by HSR, these effects occur mostly in the municipalities with HSR stations and who also experienced population growth due to migration happened between 2000 and 2010 (see Figure 2). The “island” effects cannot be observed in



this accessibility indicator, as the benefits happened to be very concentrated in the cities with HSR station and also along the conventional railway lines.



Figure 6 Accessibility Changes (POP90) between 2000 and 2010 in Spain

In comparison with the previous three indicators, the accessibility improvement gets very concentrated in the close vicinity of transport infrastructures, the spillover effects are not as strong as exhibited in the previous accessibility indicators. However, its distribution pattern resembles very much the population distribution, depending on the threshold travel time, the smaller the threshold time is, the more self-potential it contains, and the less spillover effects it captures.

**5.2 Resemblance and Correlation Analysis**

In this section, resemblance and correlation analysis is conducted to analyze how well different types of accessibility indicators are able to capture the spatial distributions of the regional economic variables. Different indicators are compared and ranked based on their correlation coefficients with the economic variables. Equity analysis takes into account the 47 Spanish provinces. The changes in the values of CV and Gini of all the four indicators point to the different directions. EP1 and POP90 pointed to the direction of reducing of spatial inequity, while EP2 and wTT pointed to the increasing of spatial inequity as presented in Table 3. The CV and Gini values for all the provincial economic variables, in general, pointed to the same

direction increasing in spatial inequity, except in GDP per capita (GDPCP) a decreasing in spatial inequity. Therefore, we can see that the indicators “EP1” and “POP90” which captures more concentrated effects in the surrounding areas (discount heavily the weight of the distant destinations) are able to explain better the GDP per capita, meaning people’s wealth. “EP2” and “wTT” capturing more spread out effects (do not differentiate so much the weights for the near and distant destinations) are able to explain better the spatial distribution of the other economic variables.

Table 3 Equity Indices of Chosen Indicators for 2000 and 2010

	Name	CV	Gini	Name	CV	Gini	Dif_CV%	Dif_Gini%
<b>Accessibility Indicators</b>	EP1_00	1,78	0,62	EP1_10	1,73	0,61	-2,8%	-0,8%
	EP2_00	0,38	0,17	EP2_10	0,39	0,18	2,6%	4,6%
	POP90_00	0,93	0,46	POP90_10	0,89	0,45	-4,3%	-2,2%
	wTT_00	0,19	0,11	wTT_10	0,21	0,12	10,5%	7,4%
<b>Economic Variables</b>	POP_00	1,23	0,49	POP_10	1,28	0,50	4,1%	2,7%
	APOP_00	1,32	0,51	APOP_10	1,36	0,52	3,0%	2,8%
	Emp_00	1,37	0,51	Emp_10	1,40	0,52	2,2%	1,8%
	HEdu_00	1,46	0,53	HEdu_10	1,47	0,53	0,7%	0,9%
	GDP_00	1,57	0,54	GDP_10	1,55	0,54	-1,3%	0,4%
	GDPCP_00	0,23	0,13	GDPCP_10	0,199	0,11	-11,6%	-11,8%
	NOF_00	1,39	0,51	NOF_10	1,42	0,52	2,2%	2,1%

Correlation coefficients measure the overall resemblance between the distributions of accessibility and economic indicators. Table 4 presents the correlation coefficients between the four accessibility indicators and the chosen economic variables at 2000 and 2010. We can see that all the accessibility indicators correlated very well with all the other economic variables except the indicator weighted travel time "wTT". “wTT” possess the right sign, meaning that the travel time of one municipality to other municipalities is negatively correlated with its economic potential. To rank the level of correlation, economic potential indicator “EP1” has the highest correlation level with the economic variables, followed by “EP2” and “POP90”.

Table 4 Correlation Coefficients for Accessibility and Economic Variables

	<i>EP1_00</i>	<i>EP2_00</i>	<i>POP90_00</i>	<i>wTT_00</i>	<i>EP1_10</i>	<i>EP2_10</i>	<i>POP90_10</i>	<i>wTT_10</i>
<b>POP00</b>	0,929	0,810	0,654	-0,104	0,932	0,774	0,550	-0,170
<b>APOP00</b>	0,935	0,817	0,668	-0,104	0,939	0,782	0,565	-0,173
<b>EMP00</b>	0,937	0,819	0,676	-0,101	0,943	0,788	0,576	-0,176
<b>HEDU00</b>	0,947	0,814	0,652	-0,100	0,949	0,773	0,543	-0,159
<b>GDP00</b>	0,960	0,843	0,687	-0,129	0,965	0,808	0,588	-0,198
<b>NOF00</b>	0,921	0,805	0,676	-0,083	0,930	0,777	0,580	-0,163
<b>POP10</b>	0,931	0,824	0,672	-0,128	0,936	0,792	0,573	-0,197
<b>APOP10</b>	0,939	0,833	0,679	-0,140	0,944	0,802	0,581	-0,210
<b>EMP10</b>	0,949	0,837	0,683	-0,131	0,954	0,805	0,584	-0,200
<b>HEDU10</b>	0,948	0,823	0,661	-0,117	0,950	0,785	0,555	-0,178
<b>GDP10</b>	0,962	0,846	0,689	-0,132	0,966	0,811	0,592	-0,200
<b>NOF10</b>	0,933	0,822	0,681	-0,112	0,941	0,793	0,585	-0,188

The same correlation pattern can be observed if we measure how well the growth of accessibility values is able to capture the economic growth between 2000 and 2010. Table 5 presents the correlations coefficients based on the direct growths (values in 2010 minus values in 2000) or growth rates. It is logical that all the coefficients lowered a little bit comparing to the values in Table 4, but it is again clear that the correlation coefficients show strong similarities. The direct growth of “EP1” is highly correlated with the direct growth of the economic variables, with the coefficient values ranging from 0.85 to 0.93, followed by “EP2” ranging from 0.61 to 0.72. The coefficients calculated from the growth rates show lower level of correlation, but nevertheless the ranking of the accessibility indicators remain the same.

Table 5 Correlation Coefficients for Growths of Accessibility and Economic Variables

	<i>Direct Growths</i>				<i>Growth Rates</i>			
	<i>EP1</i>	<i>EP2</i>	<i>POP90</i>	<i>wTT</i>	<i>EP1</i>	<i>EP2</i>	<i>POP90</i>	<i>wTT</i>
<b>POP</b>	0,914	0,721	0,312	-0,120	0,645	0,469	0,125	-0,405
<b>APOP</b>	0,889	0,677	0,249	-0,073	0,536	0,397	0,052	-0,289
<b>EMP</b>	0,855	0,606	0,215	0,017	0,394	0,156	-0,080	-0,075
<b>HEDU</b>	0,895	0,633	0,211	-0,121	0,344	0,243	-0,041	-0,223
<b>GDP</b>	0,926	0,635	0,226	-0,139	0,408	0,275	0,107	-0,155
<b>NOF</b>	0,898	0,635	0,221	-0,079	0,153	0,126	0,025	-0,046

For the best accessibility indicator “EP1”, the spatial distribution of accessibility also highly depends on the value of the beta parameter and on the spatial scale of the analysis. A correct estimate of beta is necessary to properly capture the sensitivity of travelers to the travel time increase and to draw conclusions for further evaluation of accessibility. Although knowing the

fact that the decay parameter  $\beta$  could possibly vary through time (Luoma et al., 1993; Mikkonen and Luoma, 1999), we do not have the real travel demand data for Spain in 2000 and 2010 for calibration. Therefore, for simplicity, we used the most commonly adopted value  $-0.1$  in the correlation analysis. Shen (2000) estimated the value of  $\beta$  being approximately  $0.1$  for the Boston metropolitan area. The same value  $0.1$  was estimated by Kotavaara et al. (2014) from trip survey data of Oulu region in Finland for intra-regional accessibility.

To explore the most suitable  $\beta$  for the impedance function for “EP1”, a sensitivity analysis is conducted to describe how the correlation coefficients of “EP1” with respect to the economic variables changes with respect to the values of  $\beta$ . The results are presented in Figure 7.

From Figure 7, we can see that within the range of  $\beta$  smaller than  $0.14$ , the correlation coefficients between the accessibility growth and the economic growths are very sensitive to the changes in  $\beta$  value. Between  $0.14$  and  $0.20$ , the correlation coefficients are much more stable with respect to the changes in  $\beta$  values, meaning decreasing or increasing  $\beta$  value will not contribute significantly to the changes in the correlation coefficients. Then the correlation levels start to decrease obviously after  $0.20$ . Similar values were estimated and adopted in the literature. For example, Handy and Niemeier (1997) estimated the impedance parameter for the local accessibility equal to  $0.1813$  using travel survey data collected for Oakland (a city in California) in 1980. It is located within the stable range of the curve.

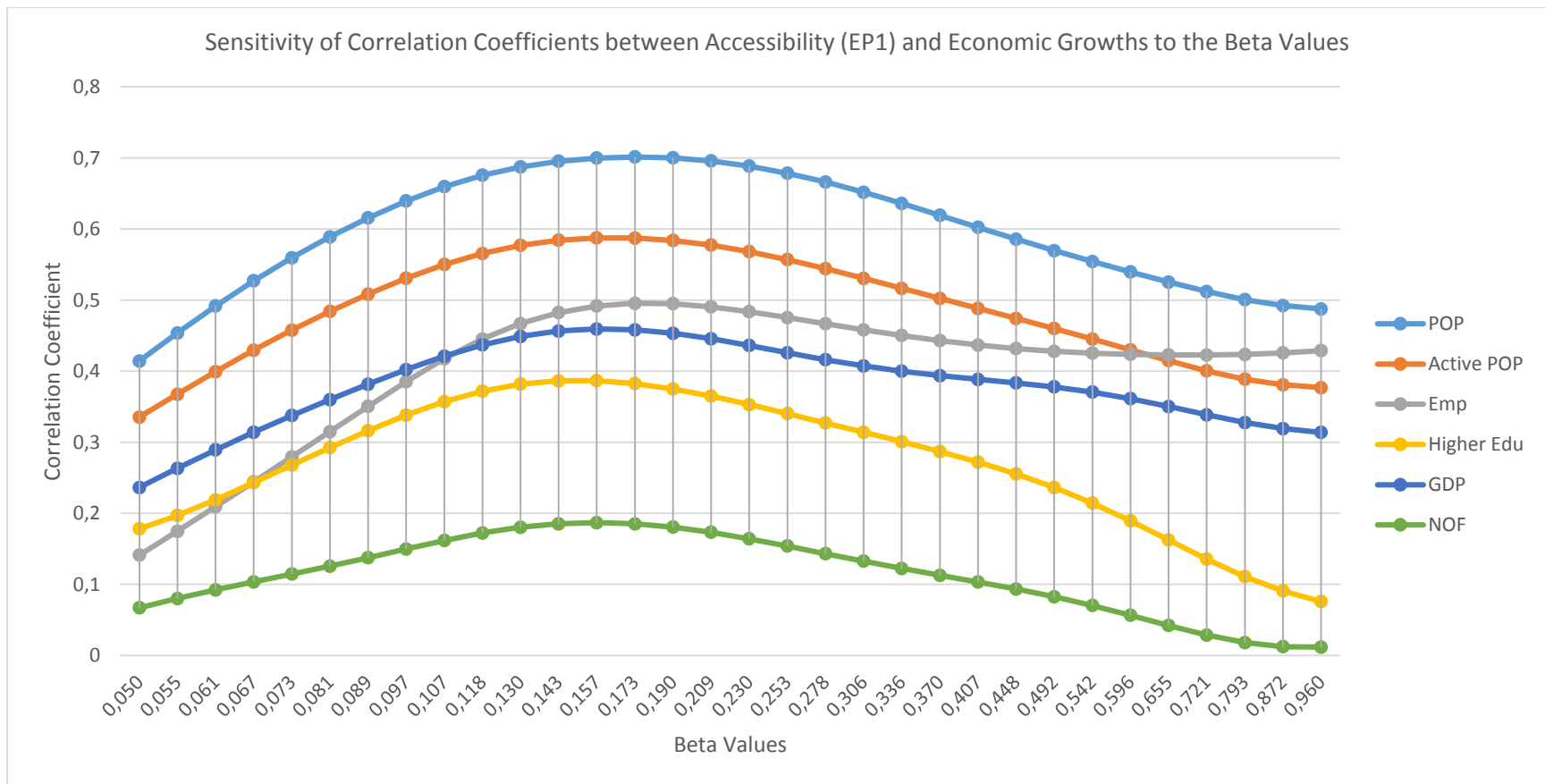


Figure 7 Sensitivity of Correlation Coefficients between Accessibility (EP1) and Economic Growths to the Beta Values

## 6. Conclusions

This paper contributes to the debate on the questions of how much the HSR expansion in the 2000s can contribute to the railway accessibility improvement of the provinces in Spain and how well accessibility is able to evaluate the relationship between HSR and economic development as an intermediate variable. We analyzed whether the spatial distribution and growth of accessibility in the provinces can explain the growths and the spatial distributions of the economic aspects, such as GDP, employment, active population, higher education level and the number of firms. This analysis method is not restricted to HSR and could be applied to other transport investments.

Considering that the conclusions on accessibility improvement can be quite inconsistent depending on which accessibility indicator is used, we calculate four accessibility indicators: an index of location, two economic potential indicators and daily accessibility. The four indicators offer complementary information about accessibility issues, since they respond to different conceptualizations. The magnitudes and the distributions of the accessibility improvements at the provincial level are discussed and compared for the chosen accessibility indicators. The results vary from indicator to indicator: very concentrated effects in the daily accessibility indicator and in the economic potential indicator EP1 (with exponential impedance), and more dispersed in the economic potential EP2 (with linear impedance) and the location indicator (weighted travel time).

Through exploring the spatial distributions of accessibility and economic variables across the provinces, we found that the “EP1” and “POP90” are the ones which can capture better the spatial distribution of GDP per capita, and “EP2” and “wTT” can capture much better the spatial distribution of the other economic indicators. Our correlation analysis proved that, from an economic point of view, there is no doubt that the economic effects of a new transport infrastructure are inversely related to the travel times, so that in this context it would seem appropriate to use a gravity-based measure. The economic potential indicator with exponential decay function “EP1” proved its highest power in explaining in the economic growths, followed by “EP2”, “POP90” and “wTT”. The interpretation of the results provided by “EP1” must be carried out from an economic point of view. The indicator measures the economic potential of a province in 2000 and 2010 and the changes in potential caused by the new transport infrastructure. However, special attention has to be given to the choice of the distance decay parameters, which may either focus too much on the

agglomeration effects in large cities or overestimate the long distance trips, so that it becomes very similar with location indicators.

In summary, one has to be cautious when considering the accessibility effects of a new transport infrastructure. Different conclusions could be achieved according to the geographical scale and accessibility indicator selected. If the analysis is more economic oriented, the economic potential indicator is the best intermediate indicator to explain the economic growth, because it tends to highlight the differences between the zones directly served by the new infrastructure (in the present case HSR) and the ones who are not. On the contrary, an infrastructure-oriented indicator such as weighted travel time tend to underestimate the relative location advantages between the zones with and without HSR stations.

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