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INFLUENCE OF DISTANCE DECAY ON THE MEASUREMENT OF SPILLOVER EFFECTS OF TRANSPORT INFRASTRUCTURE: A SENSITIVITY ANALYSIS*

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ABSTRACT

The market potential model is frequently used to analyse conditions relating to the accessibility of an area. In recent times, it has also been applied for evaluating spatial spillovers produced by infrastructures. However, the results of this indicator are influenced by the distance exponent value, representing the effect of distance decay on economic flows. In order to justify the choice of distance exponent value, the model is calibrated using data on interregional trade, both in tonnage and in Euros. This study also analyses how variation in the distance exponent affects the results obtained, with respect to spatial spillovers. As a previous step we also look to the influence of this exponent on the market potential results. The sensitivity analysis indicates that an increase in the distance exponent leads to a dramatic fall in the market potential of different areas (at the same time as the self-potential value increases in relative terms). This drop in market potential is particularly marked in regions with smaller internal markets and this translates into greater differences between regions. Moreover, the spatial range of exported spillovers is reduced with an increase in the distance exponent, although the general tendency of the geographical distribution of spillovers remains relatively stable. Generally speaking, the analysis of monetised spillovers gives much more stable results than the analysis of market potential.

Keywords: Accessibility, market potential, spatial spillovers, GIS, distance decay, sensitivity analysis

LA INFLUENCIA DE LA CAÍDA DE LA DISTANCIA EN LA MEDIDA DEL EFECTO DESBORDAMIENTO DE LAS INFRAESTRUCTURAS DE TRANSPORTE: UN ANÁLISIS DE SENSIBILIDAD

* The views expressed are purely those of the author and may not in any circumstances be regarded as stating an official position of the European Commission.

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RESUMEN

El modelo de potencial de mercado se utiliza con frecuencia para analizar las condiciones de accesibilidad del territorio. Recientemente ha sido también aplicado para evaluar el efecto desbordamiento de las infraestructuras de transporte. Sin embargo, los resultados de este indicador están influidos por el valor del exponente distancia, que representa el efecto de caída de la distancia de los flujos económicos. Para justificar la elección del valor del exponente de la distancia, el modelo se calibra con datos de comercio interregional, tanto en toneladas como en euros; obteniendo un exponente mucho más alto en el primer caso que en el segundo. Además, se analiza cómo la variación del exponente de la distancia afecta a los resultados obtenidos sobre el efecto desbordamiento. Como paso previo se estudia la influencia del exponente de la distancia en los resultados del potencial de mercado. El análisis de sensibilidad indica que un aumento en el exponente de la distancia produce una caída drástica en el potencial mercado (al mismo tiempo que aumenta el valor del autopotencial en términos relativos). Esa caída de potencial de mercado es especialmente acusada en las regiones con menor mercado interno, lo que se traduce en un aumento de las diferencias entre regiones. Por otro lado, con el incremento del exponente de la distancia se reduce el alcance espacial de los *spillovers* exportados, aunque la tendencia general de distribución geográfica de los *spillovers* se mantiene bastante estable. En general el análisis de los *spillovers* monetarizados muestra resultados mucho más estables que el análisis del potencial de mercado.

Palabras clave: Accesibilidad, potencial de mercado, desbordamiento espacial, SIG, caída de la distancia, análisis de sensibilidad

1. Introduction

In transport planning, accessibility analyses have gradually gained ground for assessing impacts associated with projects involving transportation. This type of analysis have been reported for example by Lineker and Spence (1992a, 1992b), Dundon-Smith and Gibb (1993), Reggiani (1998), Gutiérrez and Urbano (1996), Gutiérrez and Gómez (1999) and Halden (2003). The advent of Geographic Information Systems (GIS) has facilitated both the calculation of accessibility indicators and mapping of the results. One of the most frequently used accessibility indicators in transport planning is without doubt that of economic or market potential, which was applied for example by Keeble *et al.* (1988), Spence and Linneker (1994), Geertman and Ritsema van Eck (1995), Gutiérrez (2001), López *et al.* (2008), Muhammad *et al.* (2008), Yoshida and Deichmann (2009). However, as happens with other gravity models, the results obtained depend to a large extent on the value given to the distance exponent, which represents the effect of distance decay. This can be taken as a given value or it can be obtained empirically from calibrating it with data on the mobility of people and goods.

On the other hand, as Monzón *et al.* shows (2008), the impacts of plans and projects are not confined to the regions or countries in which they are undertaken but spill over their borders to benefit neighbouring areas in what is known as cross border spillovers or simply spatial spillover effect. This can be defined as the impact on a region of construction or infrastructural improvement carried out in other regions. Spillovers of transport infrastructure are particularly relevant because of the network properties of transport infrastructures. In fact, the benefits resulting from improvement of a section are transmitted over the network to other sections, both located in the same region or in other regions. Spillover effects can be measured in terms of market access, based on the idea that such access not only makes use of infrastructures in the region itself, but also of those existing in other regions. The market potential indicator is particularly appropriate for this.

Both market potential and spillover analysis are strongly influenced by the choice of the distance exponent value. Ideally this parameter should be calibrated according to some sort of flows that are actually using the transport infrastructure in question. However, often these data are not available and, as Linneker and Spence (1992a) indicate, some researchers, as Keeble *et al.* (1988), Dundon-Smith and Gibb (1993) or López *et al.* (2008), use the standard value of 1. Other researchers calibrate this value. Thus, for example, Gutiérrez *et al.* (2011) found a value of 1.77 for a group of Eastern Europe countries.

The article is structured as follows: This brief introduction is followed by a section that analyses the importance of the distance exponent in gravity models, with particular regard to the market potential indicator. Section 3 focuses on spatial spillovers and their measurement. Section 4 presents a methodology for analyzing the spillover effect through accessibility indicators and GIS, while Section 5 is dedicated to the calibration of the distance exponent value, using data from commodity flows. Section 6 shows the results of the sensitivity analysis performed both for the market potential indicator and for the spillover methodology. The last section, Section 7, summarizes the final considerations.

2. The market potential indicator

Ever since the pioneering work done by Harris (1954) and Hansen (1959), the market or economic potential indicator has been widely used in different spatial contexts. This indicator relates accessibility of a location directly with the number and range of opportunities available, and inversely with the distance necessary to attain these opportunities. It is formulated as follows:

$$P_i = \sum_{j=1}^{n} M_j \,/\, d_{ij}^{\alpha} \qquad (1)$$

where P_i is the market or economic potential of the location *i*, M_j are the opportunities available at destination *j*, and d_{ij} the distance between origin *i* and destination *j*. Finally, α is the exponent representing the distance decay effect.

The importance of destinations can be represented with different variables, such as population, employment or production, depending on the aim of the study. Distance is usually expressed in terms of length, time or the generalized transport costs, this last element being the economic value of a journey, a function which may include elements such as value of the driver's time, fuel costs, vehicle maintenance, tolls, etc.

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Although distance always has a negative effect on spatial interaction, this effect may be greater or lesser. Its variability can be represented on the model by the distance exponent, as Haynes and Fotheringham (1984) point out. High values imply strong resistance to movement between one place and another, with more relations produced over short distances. Conversely, low values mean a lower distance decay effect and, as a result, although relations over short distances continue to be the most important, those that are established over long distances gain more weight.

With respect to freight, the effect of distance decay varies depending on the type of cargo being transported. Goods that are heavy, bulky or of low value are transported over short distances within small market areas; in contrast, when goods have a high value and low weight and volume resistance to movement is reduced and, as a result, commercial relations are established over much greater distances, even worldwide. As Black (1972) indicates, the transferability of different types of goods has for a long time been studied by calibrating the distance exponent from commodity flow data.

Where passenger transport is concerned, variation of the distance exponent depends on different factors, such as the mode of transport (distance exerts greater decay on transportation by land than by air) or reasons for the journey (people are willing to travel greater distances on holiday trips than on the daily commute to work).

Resistance to movement from one place to another has also progressively been reduced throughout history as transportation systems have improved. Any variations observed depend on the spatial structure of different areas, that is, on the differing levels of development of their transport networks and the different spatial configurations of their origins and destinations, as Fotheringham, (1983) and Eldridge and Jones (1991) highlight.

3. Spatial spillovers of transport infrastructure

In economics, special attention is paid to the spillover effect because of the ongoing debate initiated by Aschauer (1989a y 1989b) on the role of public capital in the productivity of private capital. Some studies, as for example Munell (1990 y 1992) or Pereira and Roca-Sagalés (2003), have shown that this influence is not only intersectorial but also interregional, especially in the case of transport infrastructure. The estimated benefits of public capital for productivity are lower as territorial units get smaller, i.e., elasticities at the provincial level are smaller than those at the regional level, and these, in turn, are smaller than those at the national level. This difference in elasticity is interpreted in terms of spillover effects: the productivity of one region depends not only on its own particular factors of production (including infrastructure), but also on the transport infrastructure of neighbouring regions; in other words, analysis of a small geographical area does not allow all the public investment from which that area benefits to be considered, as pointed out Avilés *et al.* (2003). The most paradigmatic example is found in investment in transport networks, such as road or railway systems, due to the network effect, widely analyzed by Laird *et al.* (2005):

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improving a stretch of road in one region has a positive effect not only on that particular region but also on many other regions that use the road for their economic relations.

In order to consider the spillover effect on production functions, Holtz-Eakin and Schwartz (1995), Boarnet (1998), Pereira and Roca-Sagalés (2003) or Crescenzi and Rodríguez-Pose (2008) include not only the infrastructure of a particular region but also that of adjacent regions, as they are spaces that generate spatial spillovers. More specifically, Cantos *et al.* (2005) consider infrastructure endowments according to the intensity of trade relations, in such a way that infrastructure of regions with which there are greater trade links carry more weight.

There is no doubt that with these successive approaches the contribution of infrastructure in neighbouring regions to the productivity of each region can be considered in a more realistic way. Nevertheless, consideration of the capital stock of neighbouring regions as an aggregate depending on commodity flows does not allow us to differentiate the infrastructures in these regions that are used from those that are not, nor can we tell how much they are used or for what sort of relations. Moreover, infrastructures in neighbouring regions may be used to trade not only with these regions themselves, but also with more distant regions that are accessed via the former.

These problems can be overcome by using accessibility indicators and GIS to obtain an accurate reproduction of the behaviour of transport networks with respect to market access. Using the hypothetical extraction method, Gutiérrez *et al.* (2010) have evaluated spatial spillovers generated by investment in a series of motorways envisaged in a transport infrastructure plan. The study is based on use of the economic potential indicator and the construction of different evaluation scenarios. Spillovers generated by motorways planned for each region are computed by comparing scenarios: firstly, the scenario with plan 2020; and secondly the scenario which includes the improvements envisaged for the year 2020 in all the regions except the region whose spillovers are being analyzed (hypothetical extraction). Calculating the potential indicator for both scenarios and comparing the results will give the benefit that roads planned for that region will produce in other regions in terms of improved accessibility. The same operation is repeated for each region in such a way that it is eventually possible to determine the spillovers between regions; these can be shown as a matrix, either in units of economic potential or in monetary units. The logic of this procedure is the same as that of the hypothetical extraction method used by Dietzenbacher *et al.* (1993) to analyse input-output tables in order to know the effect of each region on the multi-regional model.

This approach, based on market potential and GIS, is a step forward in calculating spillovers. Nevertheless, it should be borne in mind that results from this indicator depend to a large extent on the value used to represent the effect of distance decay. It is precisely this issue that is under investigation in this study: the extent to which results obtained from the estimation of interregional spillovers depend on variation of the distance exponent value (see Section 2).

4. Data and methodology

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The spillovers analysed are those generated by motorways envisaged in the Spanish Transport Master Plan (*Plan Estratégico de Infraestructuras de Transporte-PEIT*), due for completion in the year 2020. This contemplates the construction of 6,129 km of motorway at a cost of 32,105 million Euros (current prices). Figure 1 shows the Spanish motorway network before and after implementation of the Plan. Each arc contains information on the type of road, speed, length and travel time. Travel time was obtained on the basis of the length of the arcs and estimated speeds. Estimation of speed depends on the type of road: 120 km/h for toll motorways, 110 km/h for other expressways, 90 km/h for national roads, 80 km/h for secondary roads and 50 km/h for roads in urban areas. Lower velocities were stored on sections affected by congestion near the most populated cities (urban zones with more than 75,000 inhabitants). The aforementioned simplification to use free flow speeds except in urban areas is widely accepted in accessibility studies at large scales, as López *et al.* (2008) pointed out. Using network analysis routines included in the GIS (ArcGIS 9.3 Network Analyst), it is possible to calculate journey times between each pair of origins and destinations (parameter d_{ij} in equation 1), as described in detail below.

The area under study comprises the whole of Spain except the Balearics and the Canaries islands. As well as the 15 regions of peninsular Spain, Portugal is also considered, as are the regions of south-west France (Aquitaine, Midi-Pyrénées and Languedoc-Roussillon), in order to avoid the border effect (the accessibility of frontier regions depends to a large extent on relations with the other side of the border).

The study area was divided into 815 transport zones, the centroids of which were taken as points of origin and destination of journeys. In peninsular Spain, the transport zones are the result of a process of aggregation based on almost 8,000 municipalities, as it is described in Gutiérrez *et al.* (2010). First, an automatic process was followed, assigning each municipality to one node of the network using the minimum path as a criterion. Second, some adjustments were necessary according to the following criteria: the zones should be compact, spatially continuous and similar in size. In Portugal and France the zonification is based in the administrative units of the respective countries (Concelhos in Portugal and the Departments in France).

Each transport zone contains information on its population, which acts as a proxy for the attraction capacity of the destinations (parameter M_j in equation 1), is because of its availability at municipal level. The high number of transport zones enables a more precise calculation of the distances between them to be carried out and mitigates the problem of calculating self-potential. According to Frost and Spence (1995) and Bruinsma and Rietveld (1998), self-potential can be defined as the contribution of the internal accessibility of each zone to its total accessibility. This contribution cannot be measured in an accurate way since it is obtained by dividing the mass of the zone by its estimated intrazonal distance. Usually each zone is represented as a circle of equivalent area and intrazonal distance is estimated from some transformation of the radius, r, of that circle, for example 0.5r. But it was demonstrated by Owen and Coombes (1983) that total potential values are very sensitive to the different transformation used (0.25r, 0.33r, 0.50r, etc.). This problem is particularly important in large metropolitan areas, where self-potential is very high because of the gravity-based formulation of the potential indicator. Thus, for example, Frost and Spence (1995) and Gutierrez (2001) found a self-potential contribution of some 60% and 50% in London and

Madrid, respectively. Disaggregated and small transport zones, especially in metropolitan areas, help to estimate more accurately travel times and to reduce the self-potential problem.

The internal time of each zone is estimated to be 10 minutes in rural areas. In order to allow for the effects of congestion, it increases in urban zones to a maximum of 28 minutes, corresponding to the transport zone of the municipality of Madrid. These data have been adjusted using information of a number of urban mobility surveys collected by TRANSyT (2007). With respect to travel times between transport zones, these are obtained from journey times between the centroids of the zone plus two penalty times, expressed as:

$$t_{ij} = t_i + tn_{ij} + t_j \qquad (2)$$

where:
t_{ij} is the total journey time between origin i and destination j.
t_i is half the internal time in the zone of origin i.
tn_{ij} is the minimum journey time across the network between the centroids of zones i and j.
t_j is half the internal time in the destination zone j.

These penalty times at the origin and destination simulate the time taken on local streets and roads to leave and enter the transport zones.

Spillovers resulting from investments envisaged in the Plan are measured by the process described in Gutiérrez *et al.* (2010). The market potential indicator is calculated for each region, using two scenarios: a reference scenario (A_{iP1}) representing the year 2020, the expected completion date for all the motorways included in the Plan, and a second scenario (A_{iPx0}), which is different for each region and represents the year 2020, except in the case of the region under study; this remains the same as in the year 2005, meaning it does not receive the investment envisaged in the Plan. For each zone i, the spatial spillovers resulting from new high capacity roads built in region x SE_x are obtained by comparing the market potential of the two scenarios above, expressed as:

$$SE_{xi} = A_{iP1} - A_{iPx0} \qquad (3)$$

The differences between each scenario express the benefits brought by the motorways planned for this region in terms of the market potential of different regions. A distinction can be made between internal benefits (in the same region where investment is envisaged) and spillovers (in other regions). By using raster analysis tools it is possible to map the spillover effect. The IDW model (inverse distance weighted interpolation) has been used to interpolate each cell value from the average value of the nearest centroids in the zone, weighted by inverse distance. In this way, the interpolated value of the spillovers received by each municipality can be obtained. These values are then added by region to obtain a weighted average, expressed as:

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$$S_{ij} = \frac{\sum_k s_{kij} p_{kj}}{\sum_k p_{kj}} \qquad (4)$$

where:
S_{ij} is the average value of the spillovers (gains in economic potential) in region j from investment made in region i;
s_{kij} are the spillovers in each municipality k in region j from investment made in region i;
p_{kj} is the population of each municipality k within region j.

The regional spillover matrix, expressed in units of economic potential, can be changed into economic units. Investment in motorways envisaged for each region is allocated (see table 1) in accordance with the spillovers produced (in terms of greater accessibility) and the total population of each region (the potential beneficiaries of the spillover effect), expressed as:

$$M_{ij} = \frac{I_i S_{ij} P_j}{\sum_{j=1}^{n} S_{ij} P_j} \qquad (5)$$

where:

M_{ij} is the investment that region j imports from investment in region i
I_i is the total investment in Euros in region i
S_{ij} is the average of the spillovers (gains in economic potential) in region j
P_j is the population of the region that imports benefits from investment in region i

The results obtained can be displayed as matrices showing exported and imported spillovers between regions (Tables 7 and 8).

5. Calibration of the distance exponent

As we stated in section 2 the selection of the distance exponent can have a significant influence on the market potential results and consequently also on spillover effects. So, as long as it is possible, its choice has to be justified according to the aims of the study. Numerous papers use exponent 1 directly for calculating market potential, the justification for this decision being that relations over long distances have more value and reach a strategic dimension. Other studies opt for calibrating the value using real mobility data. If data is available the distance exponent should be

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calibrated in order to represent as much as possible the real friction that distance exerts over transport relations.

In our case we had information on trade between Spanish provinces in the year 2005 Llano *et al.* (2010), available in both tons and Euros that we used for calibration. The unconstrained gravity model employed by Reggiani and Bucci (2008) was used. The values obtained were 1.97 for adjustment of interprovincial trade in tons and 1.33 for adjustment in monetary units (Euros) (table 1).

These data confirm what was said in Section 2 about types of cargo transported and the effect of distance. In the economic sphere, there is considerable movement of low value goods over short distances, whereas high value goods are moved over greater distances. When it comes to studying the economic impact of transport infrastructure, it is not enough to calibrate gravity models with mobility data (tons transported) as these give a distance exponent value that is excessively high in relation to that obtained from data in monetary units. From the market access perspective, the relevant calibration is the one obtained with data in Euros, without denying the use of calibration in tons for the purpose of traffic studies.

6. Sensitivity analysis of the distance exponent

Sometimes data are not available for calibration and researchers use a value for the distance exponent that is in between 1 and 2, as Dundon-Smith and Gibb (1993) and Vickerman (1995). For those cases, understanding the implications of their choice is crucial and a sensitivity analysis can shed some light on the subject. As Malczewski (1999) and Saltelli *et al.* (2008) highlight, sensitivity analyses are used to evaluate whether small changes in the input variable significantly alter the results obtained in a model.

In the following sections the results of the market potential indicator are analysed for robustness with relation to the distance exponent value (parameter α in equation 1); this entails repeating the calculation process several times, on each occasion using a different exponent value, while other parameters are kept fixed. Then the robustness of estimations of spillover effects with relation to the distance exponent value is also tested in order to understand the effect of this parameter on this new methodology. Estimating first the sensitivity of market potential results to variations in the distance exponent is an important step to understand its effects on spillovers.

6.1. Sensitivity of the results of the potential economic indicator to the distance exponent

In order to test sensitivity of the results of the potential economic indicator to changes in the distance exponent, accessibility in the year 2020 (plan scenario) was calculated using six different exponent values ranging between 1 and 2.

Table 2 shows the descriptive statistics of the distribution of the economic potential indicator according to regions, with each of the exponents considered. A significant reduction in economic potential can be seen, due to the increase in the distance exponent value. This reduction is

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not uniform but it increases the differences in market potential between regions: the greater the exponent, the greater the coefficient of variation.

When the distance exponent value is increased, market potential values are reduced because of the increase in value of the denominator in equation 1. However, this increase in the denominator is much greater over longer distances than over short ones so that in relative terms the former become less relevant with respect to the latter. This is why the self-potential of each region tends to gain more in relative importance than the total potential of the region (table 3). This is consistent with the logic of the way the economic system functions: when distance decay is very high, the markets are fundamentally local; when this friction is reduced, national or even supranational markets are formed and long distance relations become more important. Self-potential is a deciding factor, particularly in those regions where there are major urban centres, because most relations are established internally.

If the results of the economic potential of each region are analysed in relative terms, using index numbers (giving a value of 100 to average accessibility in Spain with exponent 1), it can be seen that the two most densely populated regions, Madrid and Catalonia, are always above the national average (figure 2). As the value of the exponent increases, all the regions reduce their accessibility with respect to the national average except Madrid and Catalonia, where the opposite effect is observed. These regions are characterised as having high self-potential; therefore, when distance decay increases, their accessibility decreases less in absolute terms than that of other regions.

In the rest of the regions, economic potential is reduced with respect to the national average. This reduction is not uniform, however, which leads to changes in the ranking of regional economic potential (figure 2). Regions with low self-potential but high market potential, either because of their central location or proximity to densely populated destinations (for example, Castile-La Mancha, Aragon and Castile and Leon), lose their position to regions that, although peripheral, are more densely populated and as a consequence have greater self-potential (for example, the Valencian Community).

Nevertheless, the general trend in economic potential distribution according to region presents little variation with the change of exponent, as shown by the matrix of bivariate correlations between the results obtained for each of the six exponents (table 4). Only between exponents 1 and 1.8 or 1 and 2 does the coefficient of determination fall below 0.9.

In short, the sensitivity analysis of market potential demonstrates that:

- With a rise in the distance exponent value, there is a dramatic fall in average market potential values of the different regions, especially those that have a smaller internal market. As a consequence, the differences in accessibility between regions show a significant increase.

- As the importance of relations between long distances diminishes the self-potential value increases dramatically in all regions in relative terms. This is an important issue from the

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point of view of the appraisal of large infrastructure projects and plans. Using high exponent values, potential values depend to a great extent on local accessibility, when local accessibility has nothing to do with national or trans-European infrastructure plans. In fact, large projects primarily aim at increasing interregional transport directed to more distant destinations.

- Regions with low self-potential lose more accessibility; this is because, with higher exponents, relations with the other regions lose their importance to the advantage of internal relations within each region.

6.2. Results of the sensitivity analysis of spillovers

The results of measuring spillovers from new high capacity roads in accordance with the proposed methodology can be visualised in map form. Figure 3 shows a map of the spillovers generated by motorways envisaged for Castile-La Mancha in units of market potential. The region is coloured grey to highlight increased accessibility produced outside its boundaries, in other words, the spillovers. Darker colours represent stronger spillovers. Each map shows the results obtained according to different values of the distance exponent, from 1 to 2.

Generally speaking, the spillover effect is more intense in areas close to the region receiving the investment and diminishes as distances get larger. However, not all areas near to Castile-La Mancha benefit from new investment in the same way; the areas receiving most spillovers are found beyond the new high capacity roads. As expected, there tends to be a dramatic decrease in spillovers as the distance exponent value increases, since many of them derive from relations over medium or long distances.

Using the process explained in Section 4, spillover matrices based on these results were constructed in potential units and monetary units. Tables 5 and 6 show the spillover matrices in monetary units obtained from exponent 1 and 2 respectively. The diagonal of the matrix represents the internal benefits of each region from investments made in its own territory. Each row represents the total investment "exported" to each of the other regions. The sum of the rows is logically the equivalent of the investment envisaged in the plan for each region. The columns reflect "imported" investment and the sum of each column is equivalent to the "real" (i.e., not official) investment received by each region. This value takes into account both the benefit gained from each region's own infrastructures and that which is obtained from the use of infrastructures in other regions.

Interregional investment flows are asymmetric. For example, in table 5 it can be seen that Andalusia exports a total of 201 million Euros to Castile-La Mancha, while its imports from that region amount to 849 million Euros. This is because Andalusia, which is a peripheral region, benefits from the roads of Castile-La Mancha for accessing other parts of Spain, whereas, with respect to Castile-La Mancha, new roads in Andalusia are used almost exclusively for access to this

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region. Moreover, Andalusia has a much larger population (potential beneficiaries) than Castile-La Mancha and this influences monetised results.

The influence of the increase in the distance exponent value on the share of investment envisaged for new motorways can be seen by comparing table 5 and table 6 (exponents 1 and 2). The use of a higher exponent increases internal benefits at the same time as spillovers tend to decrease. This reduction in exported spillovers depends on the proximity between regions; it is much more marked in those that are farthest away, while in those that are nearer there may even be an increase in spillovers. The gain in internal benefits does not mean that internal accessibility of the regions increases but that each region retains more of the share of investment envisaged because the value of internal relations increases with respect to that of more distant relations.

Changes in monetised spillovers based on increase of the distance exponent can be analysed by comparing exported spillovers for each region, or by working with all the matrix, cell by cell:

- Analysis of exported spillovers according to region- table 7 shows the exported spillovers for each region obtained from the corresponding matrices. Exported spillovers tend to decrease with the increase in the distance exponent: with an exponent of 1 they represent 58.9% of total investment but with an exponent of 2 they fall to 47.1%. This expected trend is reproduced in all the regions: the value of the spillovers falls the more the distance exponent increases. The spillover average in the regions tends to fall at the same time as the coefficient of variation shows a slight rise (table 8), but these changes are very small compared to those observed for market potential (table 2) or even for spillovers in units of potential (figure 3). This greater stability is largely due to the monetization procedure used: the direct investment (the sum of the benefit retained and exports of each region) is always the same regardless of distance exponent used, whereas the market potential of each region varies dramatically with an increase in the exponent. Moreover, it can be proved from calculating the coefficients of determination between the columns in table 9 that in relative terms the distribution of spillovers according to region remains quite stable, since the coefficients, which are always very high and significant, are always greater than those attained in the analysis of market potential.

- Cell-by-cell analysis of spillovers- if analysis of the changes in spillovers with the distant exponent is carried out cell by cell, using the different spillover matrices, the same basic tendencies are observed. The average value of each cell tends to fall but the coefficient of variation rises (table 10). This also confirms that the general tendency of spillover flows between regions tends to remain stable, as shown by the high correlation coefficients obtained between different spillover matrices, all of which are significant at the 0.001 level (table 11).

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Sensitivity analysis of the spillovers proves that:

- With an increase in the distance exponent there is an increase in benefits gained for the region itself and in some cases for adjacent regions, but these are reduced in regions that are at a medium distance and in particular a long distance away.

- Nevertheless, general tendencies are maintained as shown in the table on correlations between matrices (table 11). The greatest amounts of exports are those that go to neighbouring regions, regardless of what the distance exponent is.

7. Final remarks

The market potential indicator has been widely used to measure accessibility and evaluate the impacts of plans and projects for transport infrastructure. However, the results obtained when this indicator is applied are influenced by the distance exponent value. High values emphasise relations over short distances and impacts are therefore more local; conversely, it is relations over large distances that stand out with low values and impacts are therefore more far-reaching. Because the effects of new infrastructures are not confined to the regions where they are constructed, but spill over their limits into other regions as well, selection of the distance exponent must also affect spillover measurement to some degree: lower exponent values should be reflected in more far-reaching spillovers.

If data about flows on that particular infrastructure is available, distance exponent values should be obtained by calibration procedures. In this analysis we had data on commercial flows between Spanish provinces, in Euros and in tones. As this study was concerned with the impact of new infrastructure in terms of market access, it seemed logical to calibrate the model with data on interregional trade in millions of Euros. The exponent obtained was 1.33, which was much lower than the 1.97 obtained using interregional trade data in tons. This confirms that over short distances there is considerable movement of low value goods, whereas goods transported over long distances have a high value. Although calibration with data on tons transported may be useful from a mobility study perspective, it is the value of interregional trade that is the important variable in the analysis of economic impacts in terms of market access.

Sometimes flow data is not available for calibrating the distance exponent and values of 1 or 2 are used to represent the friction of distance, however researchers should understand the implications of such a choice. For that reason a sensitivity analysis was carried out in order to find out to what extent variation in the distance exponent produces changes on market potential scores and consequently on spillovers generated by transport infrastructure. The new motorway program envisaged in the Spanish Transport Master Plan was used as a study case.

In order to explain the sensitivity of spillover to variations on distance exponent values, we first analyse the effects of this parameter on market potential indicator. The results show that when the values of this exponent are high, market potential is drastically reduced. Relations established over short distances, i.e., access to local and regional markets, become comparatively more important, thereby increasing the self-potential of all the regions. Reduction in accessibility depends on the region under consideration; it is less marked in the most densely populated regions, like Madrid and Catalonia, as a result of the greater importance of their self-potential. In relative terms, an increase in the distance exponent leads to an increase in differences in accessibility between the regions as it dilutes the importance of the national market and emphasises that of local markets.

The assessment of the sensitivity analysis on the monetised spillovers shows that the spillover matrices obtained for different exponents directly depends on the exponent value used, which means that more of the investment received by each region is retained and less is exported to other regions (see table 7). Results are much more stable than those obtained for market potential. Whichever exponent is used, the benefits from investment envisaged for all the proposed motorways are shared almost equally between internal benefits and spillovers. This greater stability in the case of spillovers is largely due to the monetisation procedure used: the sum of the retained benefit and exports from each region is always the same, even if the distance exponent changes, whereas the market potential of each region varies dramatically with an increase in the exponent.

These results corroborate the importance of the choice of exponent in measuring spillovers and market potential. About the spillover methodology the results seem robust, especially when compared to those obtained for market potential: spillovers show moderate variation with changes in the distance exponent value. Regarding the calibration results, it can be concluded that spillovers from the new high capacity roads envisaged for Spain are around 55% of the value of total investment. If trade data were not available in Euros and calibration were carried out in tons, the spillover value would be underestimated as being about 47% of total investment. Finally, with respect to analysis of the regional effects of a transport plan, it can be deduced from the figures above that consideration of "direct" investment in a region is less relevant than that of the "real" investment it receives, once the importance for market access of all new infrastructures (not only those constructed in the region itself) has been taken into account.

Transport planning decisions are often characterized by conflicting goals of the various policymakers involved. Usually regional decision makers solely focus on their own region neglecting spillover effects. Consideration of spillover effects can provide information of great importance in evaluating the real benefits a region receives from an infrastructure plan and in resolving conflicts between national and regional governments. From an international perspective, spatial spillovers should be taken into account in project financing, since trans-national projects produce trans-national spillovers of special relevance. In the case of the European Union, the projects with greatest spillover effects (the ones that contribute most to the goal of European integration) should receive special funding attention from the European Union.

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TABLES

Table 1: Calibration of the distance exponent from interprovincial trade data

Distance exponent value	
In tons	1.97
In Euros	1.33

Source: Own results

Table 2: Descriptive statistics of the distribution of market potential according to regions

Exponent	N	Range	Minimum	Maximum	Mean	Standard deviation	CV
1	15	193673	243209	436882	298518.7	47369.0	15.9
1.2	15	92832	86129	178961	109531.0	23214.3	21.2
1.4	15	44651	31793	76444	41755.3	11445.1	27.4
1.6	15	22016	11857	33873	16593.5	5660.8	34.1
1.8	15	11032	4466	15498	6890.2	2809.7	40.8
2	15	5527	1754	7281	2989.1	1398.5	46.8

Source: Own results

Table 3: Contribution of self-potential to the total potential of each region (as a percentage)

Regions	*Distance exponent value*					
	1	**1,2**	**1,4**	**1,6**	**1,8**	**2**
Andalusia	4.6	6.3	12.4	15.2	20.2	25.5
Aragon	6.2	9.9	14.7	21.1	29.1	38.3
Asturias	3.9	6.5	10.0	14.5	20.0	26.0
Cantabria	2.9	4.9	7.7	11.4	16.3	22.0
Castile - La Mancha	1.9	3.1	4.7	7.0	10.1	14.1
Castile and Leon	2.8	4.6	7.2	11.0	16.1	22.7
Catalonia	11.7	16.1	20.7	25.6	30.5	35.3
Extremadura	1.6	2.8	4.8	7.8	12.3	18.6
Galicia	4.3	6.9	10.6	15.5	21.5	28.4
La Rioja	2.8	4.7	7.4	11.3	16.5	23.1
Community of Madrid	16.0	20.5	25	29.4	33.5	37.2
Region of Murcia	6.0	9.3	13.5	18.7	24.7	31.3
Navarra	4.2	6.9	10.5	15.4	21.6	29.0
Basque Country	5.2	8.1	11.9	16.8	22.5	28.9
Valencian Community	5.8	8.8	12.4	16.7	21.6	26.8

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Table 4. Coefficient of determination matrix (r2) of market potential averages according to region *

Exponent	1	1.2	1.4	1.6	1.8	2
1	1					
1.2	0.988	1				
1.4	0.960	0.992	1			
1.6	0.925	0.972	0.994	1		
1.8	0.891	0.949	0.982	0.996	1	
2	0.857	0.924	0.964	0.988	0.998	1

* N = 15. All correlations are significant to the 0.01 level.

Source: Own results

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Table 5: Spillover matrix (in millions of Euros) α=1

	Andalusia	*Aragon*	*Asturias*	*Cantabria*	*Castile - La Mancha*	*Castile and Leon*	*Catalonia*	*Extremadura*	*Galicia*	*La Rioja*	*Community of Madrid*	*Murcia*	*Navarra*	*Basque Country*	*Valencian Community*	*Direct Investment*
Andalusia	**3333**	12	18	9	201	78	101	277	48	4	251	146	7	26	269	*4782*
Aragon	117	**735**	29	38	116	102	848	23	29	56	417	113	235	343	865	*4069*
Asturias	3	4	**391**	64	2	21	16	1	680	2	8	1	6	114	3	*1315*
Cantabria	27	1	17	**264**	13	88	0	8	3.0	1	72	4	0	24	10	*534*
Castile - La Mancha	849	84	26	5	**1499**	137	294	132	55	5	656	328	8	18	926	*5024*
Castile and Leon	236	257	135	190	172	**1234**	729	109	222	125	852	36	229	183	143	*4851*
Catalonia	47	101	7	7	34	25	**2024**	11	10	6	167	31	23	41	195	*2729*
Extremadura	1124	4	36	19	94	140	9	**437**	78	7	126	35	6	52	106	*2275*
Galicia	17	6	286	53	11	171	21	6	**1461**	9	56	5	15	101	17	*2235*
La Rioja	4	10	4	1	1	62	21	3	11	**46**	5	0	42	4	1	*215*
Community of Madrid	10	9	4	3	141	44	19	18	7	0	**59**	9	0	7	41	*372*
Murcia	276	16	0	0	26	2	132	2	1	1	14	**472**	5	4	232	*1185*
Navarra	17	41	23	26	15	44	238	3	10	125	67	6	**323**	207	60	*1207*
Basque Country	8	2	0	0	3	22	0	2	4	5	26	0	4	**63**	2	*142*
Valencian Community	10	61	2	4	23	11	65	2	3	8	38	36	17	29	**863**	*1171*
Real Investment	*6078*	*1343*	*978*	*685*	*2350*	*2183*	*4519*	*1034*	*2623*	*402*	*2816*	*1224*	*921*	*1218*	*3734*	**32105**

Source: Own results

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Table 6 : Spillover matrix (in millions of Euros) α=2

	Andalusia	*Aragon*	*Asturias*	*Cantabria*	*Castile - La Mancha*	*Castile and Leon*	*Catalonia*	*Extremadura*	*Galicia*	*La Rioja*	*Community of Madrid*	*Region of Murcia*	*Navarra*	*Basque Country*	*Valencian Community*	*Direct Investment*
Andalusia	**3847**	4	6	3	157	36	32	260	16	2	138	122	2	9	148	*4782*
Aragon	56	**1133**	17	27	96	94	800	11	14	59	315	76	262	288	819	*4069*
Asturias	1	2	**566**	51	1	23	6	0	583	1	5	0	3	72	1	*1315*
Cantabria	11	0	16	**272**	9	119	0	5	2	1	58	2	0	34	5	*534*
Castile- La Mancha	567	70	12	4	**2135**	116	127	96	23	3	896	280	5	12	677	*5024*
Castile and Leon	134	202	128	196	170	**1795**	343	97	156	148	985	19	218	178	81	*4851*
Catalonia	11	71	2	2	11	8	2427	2	2	3	55	10	12	18	94	*2729*
Extremadura	1001	3	21	11	93	125	4	**741**	43	4	115	21	4	29	60	*2275*
Galicia	5	2	242	30	5	167	6	3	**1687**	4	27	1	6	46	5	*2235*
La Rioja	2	10	2	1	1	69	11	2	6	**65**	5	0	33	8	0	*215*
Community of Madrid	6	7	2	3	166	52	9	11	5	0	**73**	6	0	6	25	*372*
Region of Murcia	159	7	0	0	34	1	47	1	0	1	8	**693**	2	1	232	*1185*
Navarra	6	58	10	14	10	45	149	2	5	190	48	3	**465**	165	37	*1207*
Basque Country	3	2	0	0	2	29	0	1	2	12	18	0	5	**67**	1	*142*
Valencian Community	4	35	0	1	17	4	28	1	1	3	18	24	6	9	**1020**	*1171*
Real Investment	5812	1608	1026	614	2908	2683	3989	1232	2545	497	2765	1257	1023	941	3205	***32105***

Source: Own results

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Table 7: Spillovers exported according to region (in Euros)

	Exponents						
Regions	**1**	**1,2**	**1,4**	**1,6**	**1,8**	**2**	**Direct investment**
Andalusia	1448.9	1362.3	1266.1	1161.3	1049.9	934.7	4782
Aragon	3333.7	3269.7	3199.1	3120.7	3033.3	2935.5	4069
Asturias	924.4	892.8	859.7	824.8	788.1	749.2	1315
Cantabria	269.5	270.0	269.9	268.7	266.3	262.4	534
Castile - La Mancha	3525.2	3415.6	3297.6	3170.7	3034.4	2888.7	5024
Castile and Leon	3616.7	3521.8	3418.3	3306.0	3185.0	3055.8	4851
Catalonia	705.4	612.7	523.9	441.5	409.9	302.5	2729
Extremadura	1838.1	1792.8	1740.8	1681.1	1612.5	1533.6	2275
Galicia	774.1	740.9	700.9	654.8	603.5	548.4	2235
La Rioja	169.1	166.7	163.7	160.0	155.3	149.6	215
Community of Madrid	313.0	311.3	309.0	306.1	302.4	298.5	372
Region of Murcia	712.6	673.0	630.2	584.9	538.5	492.4	1185
Navarra	884.1	862.7	837.9	809.5	777.5	742.4	1207
Basque Country	79.2	78.2	77.3	76.4	75.5	74.5	142
Valencian Community	307.5	277.0	244.2	211.3	179.8	150.8	1171
Total	18901.0	18248.0	17538.0	16778.0	16012.0	15119.0	32106
% of direct investment	58.9	56.8	54.6	52.3	49.9	47.1	100.0

Source: Own results

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Table 8: Sensitivity analysis: descriptive statistics of the changes in exports from the regions (in Euros) according to the increase in the distance exponent value

Exponent	N	Range	Minimum	Maximum	Mean	Std. Deviation	C.V.
1	15	3537.5	79.2	3616.7	1260.1	1248.5	99.1
1,2	15	3443.6	78.2	3521.8	1216.5	1219.8	100.3
1,4	15	3341.0	77.3	3418.3	1169.2	1188.8	101.7
1,6	15	3229.6	76.4	3306.0	1118.5	1154.9	103.3
1,8	15	3109.5	75.5	3185.0	1067.5	1116.0	104.5
2	15	2981.3	74.5	3055.8	1007.9	1077.1	106.9

Source: Own results

Table 9: Coefficients of determination (r2) between exports from the regions according to the distance exponent (Table 7 columns)

Exponent	1.0	1.2	1.4	1.6	1.8	2.0
1.0	1					
1.2	0.998	1				
1.4	0.993	0.998	1			
1.6	0.984	0.993	0.998	1		
1.8	0.973	0.985	0.993	0.998	1	
2.0	0.959	0.974	0.985	0.993	0.998	1

* N = 15. All correlations are significant at the 0.001 level.

Source: Own results

Table 10: Sensitivity analysis based on the spillover matrix in Euros (number of cases = 210)

Exponent	N	Range	Minimum	Maximum	Mean	Std. Deviation	C.V.
1	210	1124.32	0	1124.3	90.0	179.4	199.3
1.2	210	1108.8	0.01	1108.8	86.9	176.1	202.6
1.4	210	1089.61	0.01	1089.6	83.5	172.7	206.8
1.6	210	1065.95	0.01	1066.0	79.9	169.4	212.0
1.8	210	1036.79	0.01	1036.8	76.2	165.7	217.4
2	210	1000.9	0.01	1000.9	72.0	161.9	224.8

Source: Own results

Condeço-Melhorado, A., Gutiérrez Puebla, J., García Palomares, J.C. (2013): "Influence of distance decay on the measurement of spillover effects of transport infrastructure: a sensitivity analysis", GeoFocus (Artículos), nº 13-1, p.22-47. ISSN: 1578-5157

Table 11: Coefficients of determination (r2) between the spillover matrices according to different distance exponents (cell by cell)

Exponent	**1.0**	**1.2**	**1.4**	**1.6**	**1.8**	**2.0**
1.0	1					
1.2	0.996	1				
1.4	0.987	0.996	1			
1.6	0.972	0.987	0.996	1		
1.8	0.950	0.971	0.987	0.996	1	
2.0	0.925	0.951	0.972	0.988	0.996	1

* N = 225 (15x15). All correlations are significant at the 0.001 level

Source: Own results

FIGURES

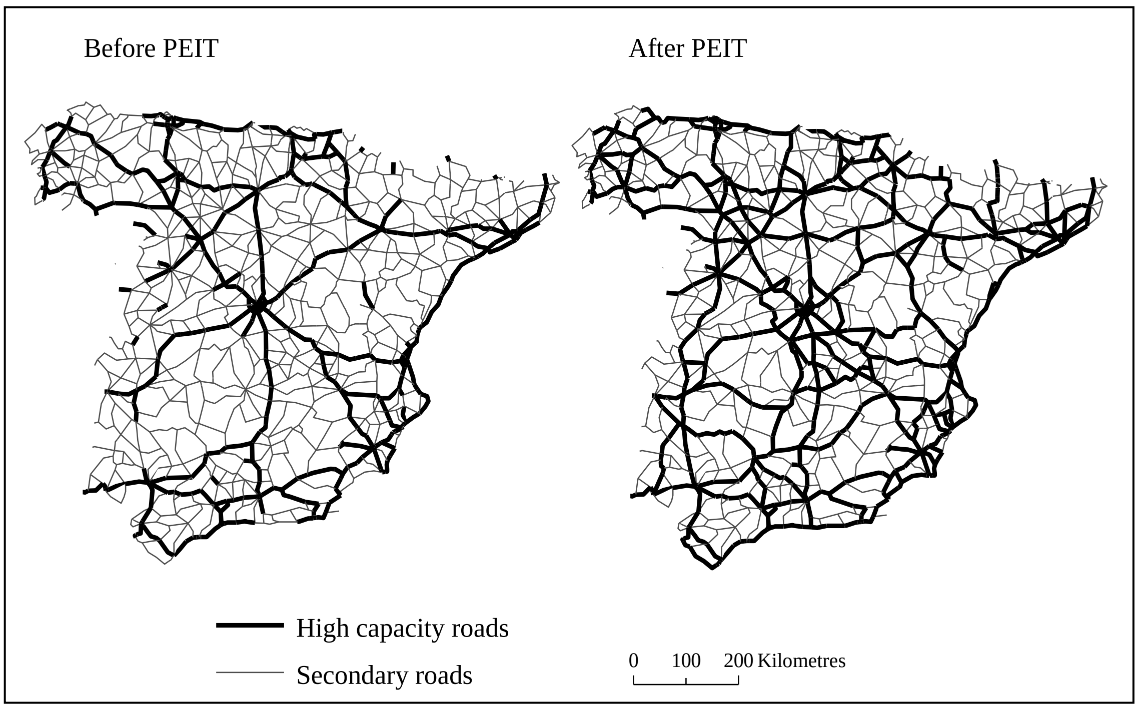

Figure 1: Motorway network before and after the Plan.

Source: Own results

Condeço-Melhorado, A., Gutiérrez Puebla, J., García Palomares, J.C. (2013): "Influence of distance decay on the measurement of spillover effects of transport infrastructure: a sensitivity analysis", GeoFocus (Artículos), nº 13-1, p.22-47. ISSN: 1578-5157

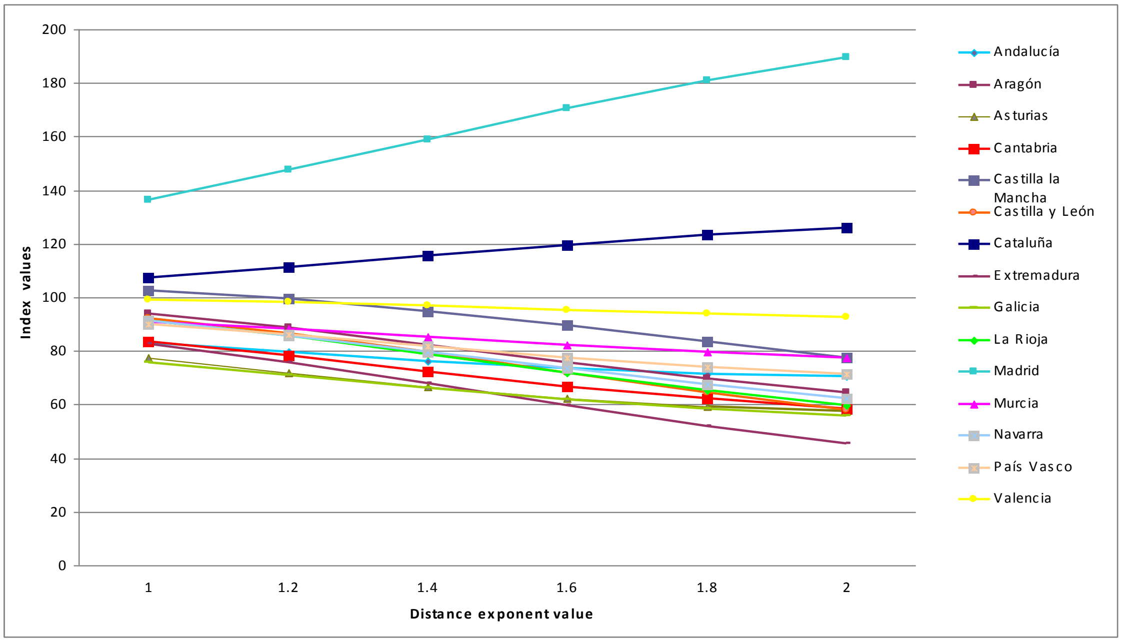

Figure 2: Regional accessibility in the plan scenario in index numbers (average accessibility of peninsular Spain with distance exponent 1 = 100).
Source: Own results

Condeço-Melhorado, A., Gutiérrez Puebla, J., García Palomares, J.C. (2013): "Influence of distance decay on the measurement of spillover effects of transport infrastructure: a sensitivity analysis", GeoFocus (Artículos), nº 13-1, p.22-47. ISSN: 1578-5157

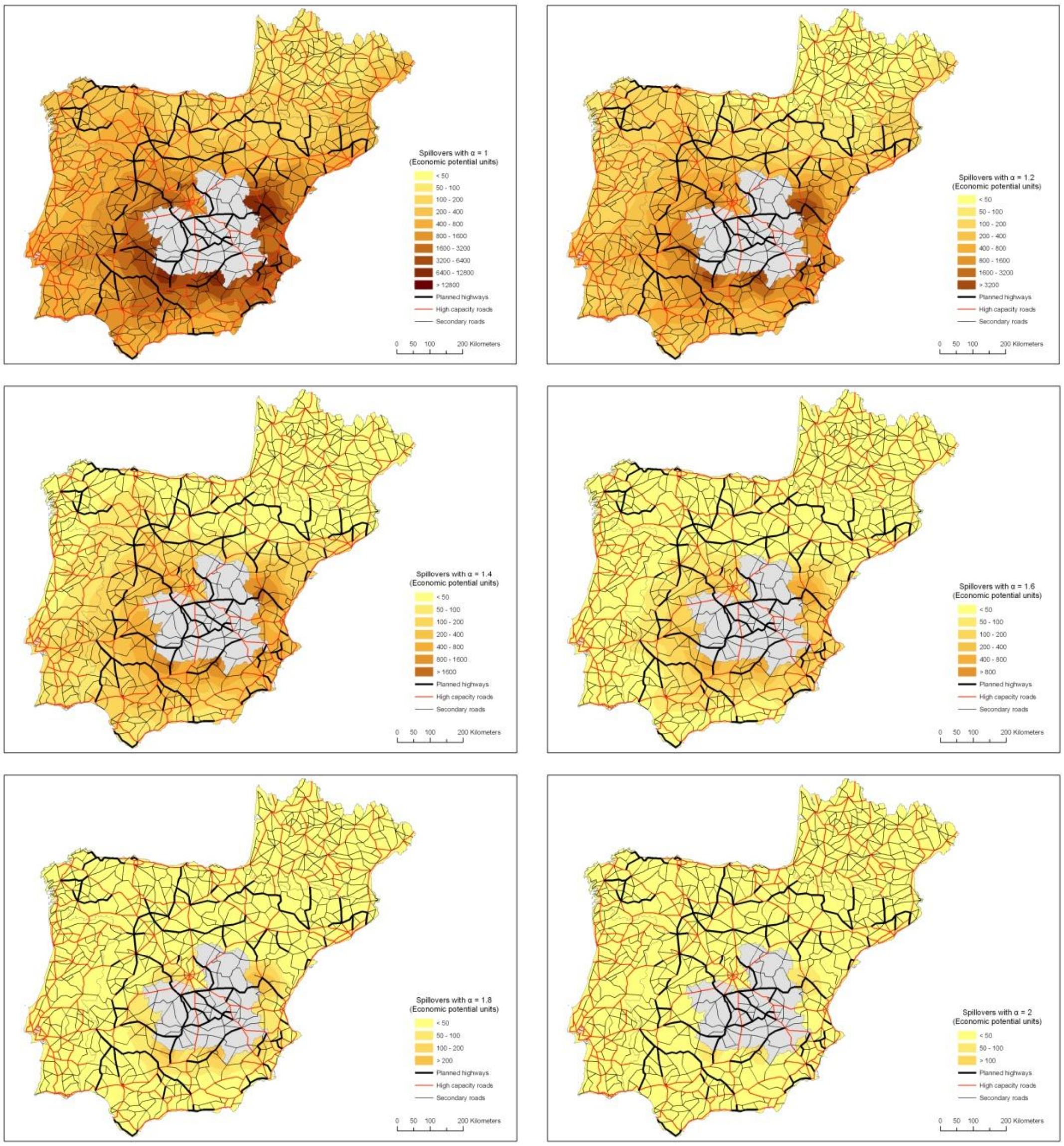

Figure 3: Spillovers, in units of economic potential, generated by new high capacity roads in Castile-La Mancha, considered with different distance exponent values (high capacity roads envisaged in the PEIT are shown by thick lines).
Source: Own results