Universidad de Alcalá

Departamento de Geografía

SPATIAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE

Tesis doctoral presentada por

Ana Margarida Condeço Melhorado

Bajo la dirección del

Dr. Javier Gutiérrez Puebla

Catedrático de Geografía Humana

Alcalá de Henares, Enero 2011

AGRADECIMIENTOS

Llegando el final de esta tesis doctoral no podría dejar de agradecer los numerosos apoyos que he recibido y sin los cuáles no hubiera conseguido el mismo resultado.

Debo comenzar por agradecer al director de esta tesis, el profesor Javier Gutiérrez Puebla, del cual no podría decir si es mejor persona o mejor profesor. Cuando lo conocí en mi año de ERASMUS me di cuenta de que es uno de esos profesores con los que se disfruta aprendiendo y que pasan a ser uno de nuestros referentes. Aunque en ese momento yo no era consciente, él tuvo parte de la responsabilidad en que iniciara esta aventura por la investigación. Durante la tesis he aprendido casi todo con él, no solo los conocimientos técnicos y científicos aquí plasmados, sino también valores humanos que espero conservar y utilizar en mi carrera profesional. Le agradezco, estimado profesor, sus enseñanzas, las aportaciones brillantes que mucho han contribuido en la realización de los artículos de la tesis y sobre todo la humildad con la que es capaz de ponerse en la piel de un joven investigador.

Agradezco la contribución de todos los coautores de los artículos presentados en esta tesis. Su aportación ha sido fundamental para mejorar la calidad de los mismos.

Me gustaría agradecer al profesor Tom de Jong y Taede Tillema por recibirme y apoyarme durante mi estancia de tres meses en la Universidad de Utrecht (Holanda). Durante este tiempo tomé contacto con el software desarrollado por el profesor de Jong (Flowmap) y que ha resultado de gran utilidad para la tesis. Igualmente agradecer al Ministerio de Educación por la beca concedida y que ha posibilitado el que este doctorado opte a la Mención Europea en el título de Doctor.

Mi mayor agradecimiento también a todos los profesores del Departamento de Geografía Humana de la Universidad Complutense, a los expertos que he ido conociendo a lo largo de la tesis, en proyectos de investigación, congresos, por sus comentarios y ánimos recibidos para continuar. A los revisores de los artículos, por sus valiosas aportaciones que sin duda han mejorado su calidad. A todos mis profesores de la carrera geografía en Coimbra y del doctorado de Cartografía SIG y Teledetección de la Universidad de Alcalá, por inculcarme el gusto por la geografía.

Agradecer también a todos los amigos y compañeros de trabajo, por su apoyo y por hacer este período más ameno.

A toda mi familia (portuguesa y española) debo el cariño y confianza que me han demostrado. Pero sobre todo, obrigada aos meus pais por estar sempre a meu lado, por ensinar-me tantas coisas, por aguentar esta distancia sempre com afeto.

A Néstor, por animarme desde un principio a hacer el doctorado, por ser tan buena gente y por regalarme tan buenos momentos. Contigo he aprendido que es posible superarse a uno mismo y a encarar el futuro con optimismo.

CONTENTS

RESUMEN 5
ABSTRACT 6
1. INTRODUCTION 6
1.1 PRESENTATION 6
1. 2 OBJECTIVES AND RESEARCH QUESTIONS 9
1.2.1 General objective 9
1.2.2 Specific objectives 9
1.2.3 Research questions 13
1.3 THEORETICAL AND METHODOLOGICAL BASES 15
1.3.1 Accessibility and regional development 15
1.3.2 Accessibility and territorial cohesion 20
1.3.3 Measuring accessibility: accessibility indicators 24
1.3.4 The spillover effect and its measurement 30
1.4 SOURCES AND METHODOLOGY 37
1.4.1 Sources 37
1.4.2 Methodology 40
1.5 STRUCTURE OF THE THESIS 47
2. ARTICLES 51
2.1 - USING ACCESSIBILITY INDICATORS IN A GIS TO ASSESS SPATIAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE INVESTMENT 52
2.2 – REGIONAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE INVESTMENT: A TERRITORIAL COHESION ANALYSIS 66
2.3 – INFLUENCE OF FRICTION OF DISTANCE IN MEASURING THE MARKET POTENTIAL AND THE SPATIAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE 93
2.4 – SPATIAL IMPACTS OF ROAD PRICING: ACCESSIBILITY, REGIONAL SPILLOVERS AND TERRITORIAL COHESION 121
2.5 - EVALUATING THE EUROPEAN ADDED VALUE OF TEN-T PROJECTS: A METHODOLOGICAL PROPOSAL BASED ON SPATIAL SPILLOVERS, ACCESSIBILITY AND GIS 143
3. CONCLUSIONS AND FUTURE RESEARCH LINES 157
3.1 CONCLUSIONS RELATING TO THE SPECIFIC OBJECTIVES 157
3.2 FINAL CONSIDERATIONS IN RELATION TO THE GENERAL OBJECTIVE 171
3.3 FUTURE RESEARCH LINES 173
REFERENCES 175

RESUMEN

Los efectos desbordamiento se definen como los beneficios recibidos por una región gracias a las infraestructuras de transporte construidas en otra región. Estos efectos han sido tradicionalmente analizados a través de técnicas econométricas como las funciones de producción, pero algunas críticas pueden ser apuntadas al uso de estas metodologías. Esta tesis doctoral propone una nueva metodología que mejora la medición de los efectos desbordamiento de las infraestructuras de transporte, utilizando indicadores de accesibilidad y los sistemas de información geográfica. La metodología fue testada con diferentes políticas de transporte, en particular la construcción de nuevas infraestructuras (tanto nacionales como transnacionales) o la tarificación de las infraestructuras existentes. En todos los casos se ha demostrado que las actuaciones llevadas a cabo en el sistema de transporte de una región generan efectos sobre las demás regiones. La metodología es una herramienta útil para comprender los beneficiarios reales de las inversiones en el sistema de transporte. Los resultados muestran que por veces las inversiones estimadas para una región son sobrevaloradas, porque parte de sus beneficios se dirigen hacia otras regiones debido a los efectos desbordamiento. Los efectos desbordamiento son también analizados desde el punto de vista de la cohesión territorial, determinando si estos efectos se dirigen desde las regiones periféricas hacía las regiones centrales, o viceversa. Otra de las aportaciones de la metodología aquí propuesta es la que permite evaluar el valor añadido europeo (VAE) de las infraestructuras incluidas en la red transeuropea de transporte (TEN-T). El VAE se define como la contribución de las políticas de transporte a los objetivos de integración territorial y de cohesión establecidos por la Unión Europea. Los proyectos que generen importantes efectos desbordamiento (beneficios registrados en países externos al proyecto) tendrán un alto VAE, en tanto que contribuyen a mejorar las conexiones internacionales y consecuentemente a consolidar el mercado único.

ABSTRACT

Spillover effects are understood as the benefits received by a region due to transport infrastructure built in another region. These effects have traditionally been analyzed with econometric techniques such as production functions, but some major criticism are pointed out to the use of such methodologies. This doctoral thesis proposes a new methodology that improves the measurement of spillover effects of transport infrastructure, based on accessibility indicators and the use of geographic information systems. The methodology has been tested with different transport policies, namely the construction of new infrastructure (either at national or transnational scale) or the pricing of the existing ones. In all cases it is clear that any actions carried on a region's transport system generate effects in other regions. The methodology is a useful tool to understand the real beneficiaries of transport investments. The results have shown that sometimes the investments planned for a region is overestimated, because is diverted to other regions in form of spillovers. Spillovers are also analyzed from the standpoint of territorial cohesion. It is important to determine whether the spillovers are directed away from the less developed/peripheral regions to the more developed/central regions or vice versa. For transport infrastructure, such as the trans-European transport networks (TEN-T), the spillover methodology can be useful for assessing the European added value (EAV) of projects. The EAV is defined as the contribution of transport policies to the objectives of territorial integration and cohesion established by the European Union. Projects which generate high spillovers (benefits recorded in countries outside the project) will have a greater EAV as they contribute to improving international links and thereby to the consolidation of the single market.

INTRODUCTION

1. INTRODUCTION

1.1 PRESENTATION

Easy access by people and goods through journeys which take place in a fast, efficient and economic manner is essential from an economic and social point of view. Transport planning therefore plays a major role in assessing future demands for transport, and in establishing the construction of new infrastructure or optimising already existing ones.

Due to the wide variety of impacts this infrastructure generates, transport planning involves a range of different sciences. Impacts of an economic, social, environmental and territorial nature –among others– require engineers, economists, geographers, ecologists and urban planners to join forces in order to measure all the possible effects which may result from transport policies. For this reason, interdisciplinarity is a key factor in transport planning studies.

The branch of geography wholly dedicated to the importance of transport systems and their territorial impacts is known as *transport geography*. Although its existence dates from the beginning of the last century (Crozet, 1930; Cavailles, 1948; Demangeon, 1952; Ullman and Mayer, 1954), it is only since the 1960s that there has been a progressive increase in the number of publications (Torrego, 1986). This period saw the emergence of issues such as transport in the urban environment and the increase in traffic density as the problems which aroused the greatest interest for geographic research. The role of transport in the organisation of space and in regional development also took on greater importance at this time (Berry, 1959; Taaffe, 1963; Haggett, 1975). The phenomenon known as *quantitative revolution*, which led to the *new geography*, gave rise to innovative research based on the use of models. The advances in Geographic Information Systems (GIS) and in spatial databases represented a further step forward in geography in general, and in transport geography in particular.

A GIS can be defined as a system which uses a spatial database to provide answers to queries of a geographic nature. A generic GIS is understood as a number of spatial routines built on a relational database management system (Goodchild, 1987). These applications enable geographic information to be captured, stored, manipulated, analysed and presented. The early phases of development took place throughout the 70s and 80s and gradually incorporated new tools for the study of transport. The importance of GIS in analysing, managing and planning transport is such that in the English-speaking world, the term GIS-T (GIS for Transport) is used specifically to designate this type of application.

Accessibility analyses are a good example of transport methodologies whose application has benefited substantially from the improvements in GIS. Accessibility studies analyse the ease of access of individuals and territories to markets and services. Greater accessibility is associated to lower transport costs, more competitive regions and to improved quality of life, objectives which are very closely linked to transport planning.

This thesis aims to contribute to the advances in accessibility analyses. Until now, accessibility analyses have been used primarily to characterise a study area from the point of view of its access to markets and services, or to measure the impact of actions in the transport system on a particular region. However they have never before been applied to the study of the spillover effect. This effect, also known as spatial spillovers, is defined as the benefits derived by one region from the infrastructure built in another (Pereira and Roca-Sagalés, 2003). This occur because the impacts in a transport network which stem from a particular action “spill over” from the territories where these actions take place and may benefit (or harm) more distant regions.

The main contribution of this thesis is the proposal of a methodology capable of measuring the spillover effect produced by transport infrastructure; this methodology is based on accessibility indicators, and on the application of GIS as a support for the calculations and the presentation of the results. The spillovers measured in this way can contribute valuable information to the transport planning process, as certain infrastructure may generate greater impacts on the neighbouring regions than on the regions where they are built.

The spillover effect of transport infrastructure has been measured in different studies with an economic slant. The methods used so far provide aggregate results which are capable of determining the existence and magnitude of the effects, but which reveal little of their spatial distribution. These studies have had negligible repercussions on transport planning works, even though far-reaching political conclusions can be drawn from them. An infrastructure generates a series of negative externalities on the region where it is built (for example pollution, noise and accidents), and yet the benefits (reduction in travel time, increase in transport reliability, for example) extend to many regions. An analysis of the spillover effect can contribute valuable information as to which territories are the primary beneficiaries of a particular infrastructure, and this information should be taken into account in the decision-making process in transport planning.

The implementation of accessibility analyses in GIS (network analysis functionalities) offers several advantages over the econometric methods which have traditionally been used to measure the spillover effect. Accessibility analyses consider the spatial organisation of economic activities and enable a simulation of the behaviour of transport networks. The results they obtain can be as disaggregated as desired. The methodology presented here is intended to provide a useful tool for transport planning, and the sections below therefore demonstrate its application in a range of problems with which planners are faced.

1. 2 OBJECTIVES AND RESEARCH QUESTIONS

1.2.1 General objective

The general objective of this thesis is to propose a methodology for measuring the spillover effect produced by transport infrastructure. This methodology is based on the implementation of accessibility indicators on a GIS. Its application will make it possible to determine how far the changes in a transport system in one region generate impacts – both positive and negative– on other regions. The methodology is proposed as a useful tool for transport planning, and particularly for the analysis of the territorial impacts of infrastructure.

This general objective is achieved by addressing a series of specific objectives which are explained below:

1.2.2 Specific objectives

1. *Establish a theoretical framework which allows an understanding of the importance of accessibility and of the spillover effect, and select the most suitable accessibility indicators to measure this effect*. Accessibility is a concept which covers a wide range of definitions; therefore the method of measuring this phenomenon varies from simple formulations to other more complex calculations requiring a greater amount of data. A thorough review of the bibliography on accessibility analyses and their indicators enables the comparison of the advantages and disadvantages of each indicator according to the objectives of the thesis.

2. *Implement the methodology for measuring the spillover effects on a GIS*. Once the case study has been set out and the accessibility indicators which will be used have been selected, the GIS database must be constructed using all the information required for the analyses. Then the processes which will form part of the calculation of the accessibility indicators and spillover effects need to be

systematised. The GIS enables the results of the spatial spillover analyses to be presented in the form of maps and tables.

3. *Identify the spatial patterns of the spillover effects in order to understand the main factors which determine the spatial scope and the intensity of these effects.* The impact of the transport infrastructure and, specifically, the spillover effects are related not only to the magnitude of the investment, but also to the characteristics of the transport networks and the distribution of the population and economic activity in the territory. Questions such as the prior quality of the infrastructure, the localisation of the regions receiving the investment or the spatial configuration of the centres of economic activity may be factors which determine variations in the spillover effect of a new infrastructure.

4. *Monetarise the spatial spillovers deriving from the investment in new transport infrastructure*. Once the investment in new infrastructure is known, this can be redistributed among the different regions based on the changes in accessibility generated, both internally and on the other regions, and the number of potential users of the new infrastructure. Obviously a part of the benefit is retained by the region which receives the investment, but another part will benefit other regions due to reduction in transport costs and an increase in commercial flows (spatial spillovers).

   Investment in transport infrastructure frequently becomes a source of conflict between regions, particularly in countries where there are regional governments; most of the investment however is made by the central government, as is the case in Spain. The regions vie to secure the maximum investment for their territories. Conflict may also arise between countries, as the benefits of an infrastructure can be "exported" towards neighbouring countries without their having contributed financially to the project. In these and other cases the monetarisation of spillover effects is a useful tool for political negotiation processes, as it highlights the balance between "exports" and "imports" of benefits produced by the new infrastructure.

5. *Analyse the spillover effect from the standpoint of territorial cohesion*. One of the objectives of any transport plan is to decrease interregional disparities in

order to mitigate the phenomenon of peripherality and to favour a convergence in income levels. There are various experiments where accessibility analyses have been applied to the study of territorial cohesion (e.g., Schürmann et al., 1997; Martín et al., 2004; López, Gutiérrez and Gómez, 2008). Normally the degree of dispersion of the accessibility distribution is measured before and after the plan or project, in order to determine whether there are improvements (reduction in the disparities) from the point of view of territorial cohesion. However the role played by spillovers has not as yet been analysed from the standpoint of territorial cohesion. The spatial spillover matrices reveal whether these are directed primarily from the more accessible regions to the more peripheral regions or the reverse, thus affecting the final result.

6. *Conduct a sensitivity analysis of the results obtained.* The aim is to determine to what degree the results of the spillover matrices are sensitive to variations in the parameters of the model, and particularly the distance exponent.

7. *Apply the spillover methodology to various transport planning contexts, not only to the construction of new infrastructure, but also to the improved management of existing roads by means of pricing policies.* Both cases reflect two of the most common transport policy approaches which take very different viewpoints. On the one hand there is the philosophy of "*predict and provide*" which mandates the construction of new transport routes based on the forecasted growth in traffic demand; and on the other hand, the efficient management of existing infrastructure, transferring to the users the costs which they themselves generate in their journeys, in order to encourage a more sustainable mobility. From the standpoint of the impact on accessibility and spatial spillovers, the application of one or another type of policy produces very different effects. In principle, the construction of new transport infrastructure will have a positive effect on the accessibility of the territories, insofar as it produces savings in travel time and a reduction in transport costs. However the introduction of pricing represents, at least in the short term, an increase in transport costs and a reduction in accessibility, which can be "exported" to other regions in the form of spatial spillovers. Although it is true that road pricing policies should produce savings in travel time in congested roads, the changes in accessibility will essentially

depend on the relation between the reduction in congestion and the price to be paid, generally resulting in an increase in transport costs.

8. *Develop a methodology based on spillover effects to measure the European added value of transport projects in the European Union (EU)*. The EU considers transport to be a key element in the process of European integration, and a considerable investment is therefore dedicated to the construction and improvement of transport infrastructure designed to efficiently connect its member countries. The TEN-T (Trans-European Transport Networks) are the maximum exponent of the EU's transport policies, and are considered to be essential for European integration and the improvement of competitiveness and the connections between peripheral regions and the central markets (CEC, 2001). This infrastructure is financed in part by the EU, up to a maximum of 30% (OJ L162/2) for projects with high European value.

   Some of the projects included in the TEN-T have yet to see the light, partly due to their lack of economic feasibility when assessed from the standpoint of individual countries. In the case of roads and railways, these are usually built in segments: the segments connecting the main cities inside the country itself are usually built first, where demand justifies the investment, and the connections in less populated, usually peripheral areas are postponed until a future date, and particularly the cross-border connections. For this reason there are currently a series of segments in transport corridors designed to link the different countries which have not yet been built (*missing links*). These links are of vital importance for the EU's avowed objective of European integration.

   A project or segment of a project will have high European added value if the investment made in one country generates benefits in other countries; otherwise, if its effects are barely perceived beyond the borders of the country which builds it, the project will have an overridingly national interest. Thus the methodology for measuring spillovers can be used to measure the European added value of transport infrastructure and to justify the EU's greater or lesser financial contribution to the project.

1.2.3 Research questions

The questions presented below are closely related to the declared objectives.

Can accessibility analyses and GIS measure spillovers more correctly?

This question is related to the general objective and proposes that the spillover effect, insofar as it is a spatial phenomenon, depends on the distribution of the economic activities in the territory and on the characteristics of the transport infrastructure. These effects can therefore be adequately measured with accessibility indicators using the network analysis tools available in the GIS.

What role do spillovers play in the distribution of investment in new transport infrastructure?

The second question posed by this research concerns the redistribution of investment in transport infrastructure. The amount invested in transport infrastructure in a region generates internal benefits for that region as well as benefits for other regions. It is not enough simply to know how much is to be invested in a particular region; it is also necessary to know which territories will benefit most and to what degree. The proposed methodology for measuring spillovers will reveal how the investment is redistributed based on the changes in accessibility that are generated, that is to say, by monetarising the spillover effect.

Do spillovers from transport infrastructure alter levels of territorial cohesion?

The question addresses the fact that the transport policies' objective of increasing territorial cohesion through investment in transport infrastructure in peripheral/disadvantaged regions requires an analysis of spillovers, as the spillover effects from these regions towards the central regions may largely cancel out any intended cohesive effects. Thus spillovers may have a detrimental effect, as they deflect a large part of the benefits of the investment in peripheral regions towards the central regions. Thus when analysing the effects of a plan as a whole, the pattern of spillovers must be taken into account: if the spillovers from peripheral regions exceed those which go in the opposite direction, then the spillover effect will be contributing to an increase in regional disparities and thus to a reduction in territorial cohesion.

Does the spillover effect contribute information of relevance to the transport planning process?

This question is tested by applying the methodology to practical cases involving the construction of new transport infrastructure or the pricing of existing infrastructure. It will also be applied to a transport corridor, that is, an infrastructure such as a road which crosses different countries. It is assumed that each one of its segments will have a different spillover effect. In border segments, spillovers can be expected to have a greater importance than in segments located in the interior of the country. Thus an analysis of the spillovers of the different segments of a project could be used to estimate the European added value of each one, and thence to establish various different conditions for European financing.

1.3 THEORETICAL AND METHODOLOGICAL BASES

Accessibility is a concept known to all, but for which there is no unanimous definition. It can be defined as the facility with which activities within a given location can be reached using a particular system of transport (Morris, Dumble and Wigan, 1978); that is to say, the opportunities available to individuals and companies to access the places where they conduct their activities (Linneker and Spence, 1992). Territory is therefore accessible when it can interact with a significant number of opportunities (Hansen, 1959; Breheny, 1978; Jones, 1981; Bruinsma, Rietveld, 1998). From an economic standpoint, accessibility refers to the ease with which markets can be accessed (Muraco, 1972; Morris et al., 1979).

Accessibility is a feature of territories but also of individuals. Individuals are anchored in a particular space and time in which they develop their activities, such as work, shopping, care of the family, leisure etc. In this respect, accessibility is defined as the freedom of individuals to participate in activities in their environment (Hangstrand, 1970; Kwan, Mei-Po, 1998; Salado García, 2001). Other authors have defined accessibility as the utility obtained by individuals from the utilisation of the transport system and land uses (Ben-Akiva and Lerman, 1979).

It is necessary to distinguish the terms accessibility and mobility. The first refers to a potentiality (the facility for accessing opportunities), whereas the second refers to a reality (real movements for accessing opportunities).

The present thesis focuses on accessibility from the territorial perspective and assumes the classic definition, namely the ease of access to opportunities; and more specifically and from an economic standpoint, the ease of access to the markets.

1.3.1 Accessibility and regional development

Accessibility is seen as a key aspect of regional economic development, and most governments therefore include improvements in accessibility as one of the primary objectives of their transport policy. The European Union underlines the importance of building trans-European transport networks (TEN-T) as a political tool for improving accessibility throughout the whole of Europe, and very particularly in border and peripheral regions hampered by a lack of access to the central markets. Equitable accessibility to markets is considered a factor which is crucial to the success of the social and economic integration of the EU and to the achievement of harmonious economic development. The Green Paper on TEN-T (CEC, 2009) explicitly states that the main objectives of the TEN-T are to guarantee "the adequate functioning of the interior market" and "to guarantee accessibility and reinforce socio-economic and territorial cohesion" (p. 2). In Spain one of the main objectives of the Strategic Transport Infrastructure Plan (PEIT 2005-2020) is to guarantee equal conditions of accessibility to the whole of the Spanish territory (Ministerio de Fomento, 2005). The objectives of the autonomous regions' own transport plans usually include the improvement of accessibility in their respective territories. Given the importance of this issue, it is not surprising that there is an extensive bibliography on the accessibility impact of transport investments (for example, Geertman et al., 1995; Gutiérrez et al., 1996; Gutiérrez and Urbano, 1996; Linneker and Spence, 1996; Gutiérrez, 2001; Martín et al., 2004; López, 2007; Tillema, 2007).

Accessibility is the main "product" of the transport system (Schürman, Spiekermann and Wegener, 1997). The construction of transport infrastructure has an immediate repercussion on a territory's conditions of accessibility, reducing transport costs and improving the potentialities of some regions over others. The space is contracted, in the sense that travel times become shorter and transport costs are reduced.

In the era of global markets, flows of goods, travellers and information are increasingly important to countries' competitiveness. The deregulation of the markets and the reduction of trade barriers highlight the importance of accessibility, which can be enhanced by building new transport infrastructure and/or improving the efficiency of existing ones. The globalisation of the markets and the restructuring of productive processes (with the increasing importance of *just-in-time* and *outsourcing* practices, among others) require greater rapidity and reliability of transport.

Investments in the transport system produce a reduction in travel times and transport costs, and at the same time increase convenience and reliability. This leads to an induced demand, as can be seen by the increase in the number of journeys (commercial, business, tourism etc) between the territories which benefit from the new investments. Thus improvements in accessibility affect increased mobility.

From the firms' perspective, improved infrastructure entail a reduction in transport costs, which can increase regional competitiveness and produce economies of specialisation and scale (Forslund and Johnson, 1995). The increase in accessibility produces significant benefits for economic agents in terms of savings in transport costs, which enables them to expand their markets. These improvements can also lead to a reduction in prices and in the costs of goods and services. All these changes can also affect the regional wage level by increasing the area from which the workforce can be recruited.

For users of the transport system these improvements represent savings in the time needed for business travel and to and from work, which can be used to increase production, or else be dedicated to leisure and tourism. The savings in travel time may lead to an increase in work opportunities, as a greater number of companies can be reached in the same amount of time.

Improvements in accessibility give rise to changes in the value of a region's economic potential (Keeble et. al, 1982; Dundon-Smith and Gibb, 1994; Vickerman, R., 1996; Vickerman, R. et. al, 1999), understood as the market area to which a region has access. The companies in that region have lower transport costs, both from the point of view of their customers and their suppliers, which in turn affects their productivity and regional production. Changes in regional accessibility can trigger changes in companies' localisation patterns and in interregional commerce. Companies localised in more accessible territories benefit from greater proximity to their customers and suppliers, as well as enjoying greater proximity to technical innovations and know-how. Territories with greater accessibility are more attractive for the installation of new companies, and companies perceive the conditions as being conducive to the performance of their activities. As an example of this, Holl (2004b) demonstrates how the construction of new motorways in Portugal in the period between 1986 and 1997 has modified the spatial distribution of firm localisation and led to the decentralisation of economic activities, by making peripheral districts appear more attractive for the installation of new companies. In Spain there is also evidence (Pardo and Arauzo, 2009; Holl 2004a; Arauzo, 2005) to indicate that regions located near motorways are more attractive for the installation of new companies, compared to other less accessible districts.

In contrast, somewhat inaccessible or peripheral regions usually incur higher transport costs deriving from their geographic situation, but also from their limited offer of infrastructure and transport modes (Vickerman, R., 1998), which reduces their competitiveness. This leads to the existence of companies which operate in systems of spatial monopoly, charging higher prices and incurring greater costs due to the lack of economies of scale.

Several studies corroborate the positive relationship between greater endowment in infrastructure and higher regional productivity (Aschauer, 1989 a and b, Forslund and Johansson, 1995; Wegener and Bökeman, 1998). These studies consider infrastructure to be public property used by companies as an input for improving their productivity. Thus regions with a greater provision of infrastructure will be more productive than less well-endowed regions.

The reduction in transport-related costs may lead to a decrease in the price of the services associated to the infrastructure, which can favour a substitution between transport services and other inputs. In fact, some studies relate the socio-economic differences between the territories to their different provision of infrastructure (Munnel, 1990). These studies are based on the underlying idea that regional development does not depend solely on traditional production factors such as capital and work, but also on infrastructure –and particularly on transport infrastructure (Aschauer, 1989a, b).

Transport infrastructure can give rise to distributive and generative effects (Rietveld, P., 1989). The first effects concern the redistribution of economic activity among the regions, although the national total remains constant. Generative effects appear when the national total changes. In reality these effects are usually combined, as the re-localisation of economic activity only makes sense if it is associated to greater production efficiency, greater competitiveness or to the emergence of agglomeration economies and thus to greater productivity.

Some authors maintain that the intensity of the impacts depends largely on the quantity and quality of the existing infrastructure (Banister and Berechman, 2001). The positive effects on regional development will be particularly intense in regions with low network density or where new infrastructure leads to the elimination of existing bottlenecks (Biehl, 1991), and lower in territories with dense transport networks. These decreasing returns, as the provision of infrastructure increases, can be seen both in accessibility improvements and in economic development.

Although accessibility is a key factor in regional economic development, it is not the only one, as other factors such as investment in education play an important role (Ribeiro and Páez, 2010; Crescenzi and Rodríguez-Pose, 2008). A territory must have favourable economic and political conditions, for the increase in accessibility to be translated into greater economic development and improved territorial cohesion (Banister and Berechman, 2001). If the territory previously offered good economic conditions for the installation of companies, the increase in accessibility may lead to these conditions appearing even more attractive. If this does not occur, the improved accessibility could expose these territories to the products of companies localised in other areas, thus reducing the power of regional monopolies. Regions which are economically more dynamic and competitive are better placed to exploit improvements in accessibility; and it is sometimes the case that these are precisely the regions which most benefit from investments in transport infrastructure (Gutiérrez and Urbano, 1996; Vickerman et al., 1999).

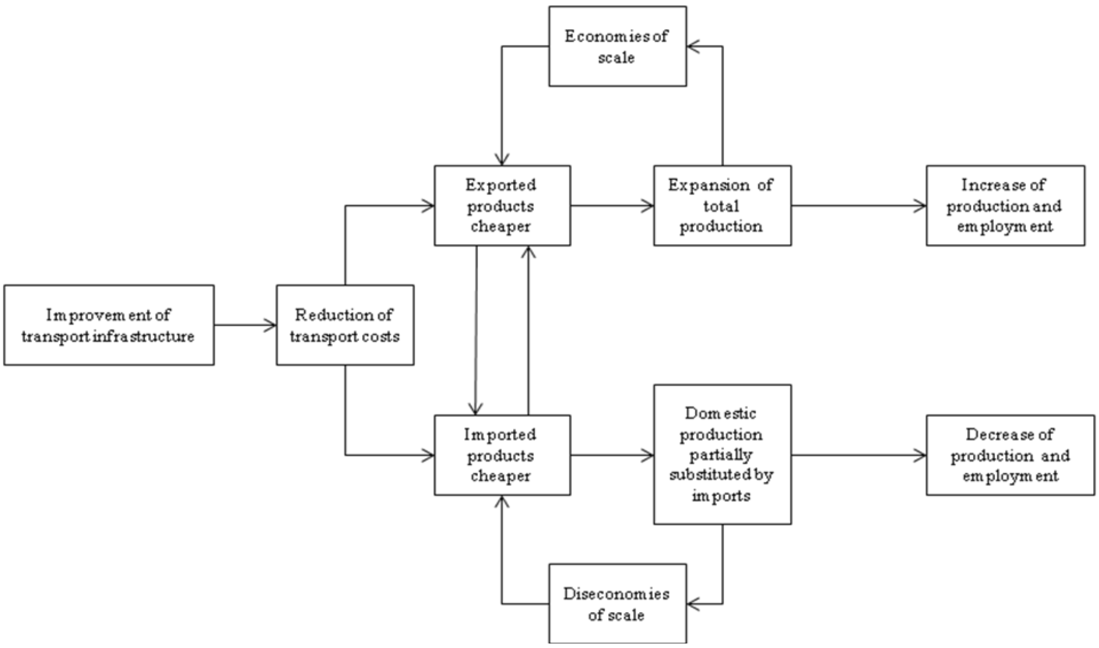

Figure I.1. Effects of improving transport infrastructure.
Source: Adapted from Rietveld, 1989

Figure I.1 shows the dual effects generated by improvements in transport infrastructure. The reduction in transport costs associated to new infrastructure gives rise to cheaper exports, which in turn can lead to an increase in total regional production and to economies of scale. If this occurs, the infrastructure improvements enhance the production and creation of regional employment. However a reduction in transport costs also means cheaper imports, thereby posing a threat to local production, which can be substituted by imported products. Depending on the magnitude of this phenomenon, this may give rise to diseconomies of scale and lead to a loss of production and a drop in employment.

In fact there is a high likelihood of both processes occurring at the same time, and that the rise in production and employment caused by the increased accessibility to other markets may be counteracted by losses in the local economy due to the growing competition from new companies located in other territories. The final balance between one situation or another will depend above all on the response capacity of the local production system, the dynamism of the demand, the degree of differentiation of the products, and on the scope of the economies of scale (Krugman and Venables, 1990). Another important role is played by the political authorities, who can supply a set of complementary elements to favour regional competitiveness (Banister and Berechman, 2001), such as the availability of land for urban development, investment incentives, the creation of business parks, etc.

1.3.2 Accessibility and territorial cohesion

The concept of territorial cohesion, also known by the terms “equity” or “justice” has a rather ambiguous definition. According to the EU, territorial cohesion represents “a more balanced development by reducing existing disparities, avoiding territorial imbalances and by making both sectoral policies which have a spatial impact and regional policy more coherent” (CEC, 2004, p. 27). This concept refers particularly to the equality of access to services and to other fundamental aspects of human life (Thomopoulos et al., 2009).

Territorial cohesion is one of the EU’s main objectives. It was proposed by the Commission in 2004 (CEC, 2004), together with the objectives of economic and social cohesion. This objective was subsequently included in the draft for the European

Constitution (Article 3) and ratified in the Treaty of Lisbon. The importance of territorial cohesion was highlighted in the Community Strategic Guidelines for Cohesion adopted by the Council in 2006, which declared that "promoting territorial cohesion should be part of the effort to ensure that all of Europe's territory has the opportunity to contribute to the growth and jobs agenda"[1].

High density, long distances and division can affect the rate of economic and social development. According to the Green Paper on Territorial Cohesion (CEC, 2008), which provides an in-depth analysis of this concept and its implications in political and cooperative terms, the political responses to the whole issue can be resumed in actions on three fronts: concentration, connection and cooperation.

Economic activity in the EU is largely concentrated in the central area of the pentagon[2], but also in the metropolitan areas of each member state. Thus in the capitals and in most other urban agglomerations, per capita GDP, productivity, employment, research and innovation activities are greater than the national average. These disparities often give rise to problems of increasing congestion and pollution which cause diseconomies and serious problems of urban decline and social marginalisation in metropolitan areas, leading to pockets of poverty, unemployment, delinquency and social discontent in many of the Europe's richest cities. On the other hand, many rural areas are beset by difficulties in accessing activity centres located in neighbouring regions, which undermines their economies and in some cases leads to problems of poverty, social exclusion and an ageing population. All these concerns threaten the competitiveness of the EU as a whole and can accelerate the decline of peripheral regions. According to the Green Paper on Territorial Cohesion, the key challenge is to avoid excessive concentrations of growth and to facilitate access to the increased advantages available in urban centres in all the territories. In this context it is essential to reinforce the model of polycentrism.

Territorial cohesion also entails connecting territories and overcoming distances. According to the Green Paper, this implies guaranteeing good intermodal connections and access to services such as healthcare, education and sustainable energies, broadband

---

[1] Official Journal L 291 of 21.10.2006, p. 29.

[2] Delimited by North Yorkshire in England, Franche-Comté in France, Hamburg in northern Germany and Milan in northern Italy.

internet, efficient connections to energy networks and the strengthening of links between companies and research centres.

The problems of connectivity and concentration can only be addressed efficiently by means of widespread cooperation on several levels, in some cases involving cooperation between local authorities in neighbouring regions, in others between countries, and in others even between the EU and third countries. Transport policies are a good example of actions which require coordinated planning to guarantee their effectiveness and minimise negative effects.

All these considerations lead to the conclusion that good accessibility is a prior condition for attaining the objective of territorial cohesion pursued by the EU. One of the central aspects of European policy on cohesion is to guarantee that no one within the Union is disadvantaged due to the location of their place of residence or employment. All citizens should have good access to essential services such as healthcare and education. Regions with better accessibility to the markets are usually more productive and competitive. In fact the EU’s central regions, characterised by their greater economic development, usually have transport networks of greater density and better quality in comparison with peripheral regions where network density is lower than the European average, particularly in the new member states. One of the primary factors used by the EU to determine the peripheral nature of a region is precisely whether or not it has good transport connections with the main centres of regional economic activity.

In view of the above, transport infrastructure represent a key element for the achievement of territorial cohesion within the EU. In fact a substantial proportion of the structural funds have been earmarked for transport infrastructure. Spain is a good example of the importance of investment in transport infrastructure out of the total expenditure of community funds. During the period between 1994 and 1999, transport infrastructure absorbed 40% of the structural funds, which jointly financed almost 2,400 km of motorway and 3,400 km of roads in Objective 1 regions (CEC, 2004).

One of the foremost European policies for promoting territorial cohesion is the building of trans-European transport networks. The primary objective of the TEN-T is to “provide the necessary infrastructure for the adequate functioning of the interior market and the achievement of the objectives of the Lisbon Agenda in favour of growth and employment” and to “guarantee accessibility and reinforce socio-economic and territorial cohesion" (CEC, 2009). The structural funds have financed the development of the TEN-T in Objective 1 regions and in cohesion countries. In the period between 2000 and 2006, €4.1 billion annually were earmarked for the construction of the TEN-T, a third of which were used for road-building (CEC, 2004).

The investment in transport infrastructure affect the economic development of the regions and enhance the attractiveness of these territories for the localisation of activities, thereby boosting economic development and wage levels, and citizens' standard of living. In the third report on economic and social cohesion (CEC, 2004), the EU forecast that the effect of the cohesion funds invested in transport infrastructure would represent significant economic improvements for the receiving regions. To give an example, the GDP for Andalusia was estimated to be 3% higher thanks to programmes which were jointly financed with the EU in 2006.

The importance of territorial cohesion in the EU's political agenda has been the subject of various studies which seek to apply this concept to the assessment of the impact of spatial planning policies, and particularly to transport policies (Camagni, 2009; Thomopoulos et al., 2009, López, et al., 2008). The impacts of infrastructure on territorial cohesion are classified within the category of more general policy impacts, known as "wider policy impacts" (Nijkamp et al., 1990). These impacts have been included in the transport planning process by analysing the spatial distribution of socio-economic variables such as GDP, density of transport infrastructure, accessibility, congestion and CO2 emissions. Some studies assess territorial cohesion by considering different variables integrated in cost-benefit or multi-criteria analyses (Camagni, 2009; Thomopoulos et al., 2009). However there are also studies which analyse territorial cohesion using accessibility distribution as the sole variable (López et al., 2008), in view of the fact that according to the EU, a greater balance in a region's accessibility conditions is a key element in achieving the objective of territorial cohesion[3].

Accessibility studies applied to territorial cohesion offer conclusions as to the effects of investment in transport infrastructure on the reduction/increase in regional disparities. The usual method is to compare the accessibility distribution before and after the investment and then to analyse the increase or decrease in the differences

[3] Official Journal C 306/2 of 17.02.07

between the central and peripheral regions. The investment contributes positively to territorial cohesion when these differences decrease.

The spatial distribution of accessibility is one of the variables used to measure the disparities between the regions (CEC, 2004, CEC, 2008) together with other macroeconomic indicators such as GDP, levels of employment and investment in R&D. The improvements in accessibility deriving from investment in transport infrastructure have direct consequences on territorial cohesion through the increased well-being of families (who benefit from improved access to work, healthcare centres, education and services in general) and companies (due to the reduction of transport associated costs). These improvements are particularly important in peripheral regions, which tend to be characterised by low population and employment densities, weak industry, as well as being poorly endowed with transport infrastructure (Spikermann and Neubauer, 2002).

1.3.3 Measuring accessibility: accessibility indicators

Accessibility is measured using indicators which usually include at least two components: transport infrastructure and the spatial distribution of economic activities. The transport infrastructure component represents the location and characteristics of the infrastructure (type of infrastructure, speed, capacity, etc.), in short, the network behaviour. The type and availability of the transport infrastructure determines the impedance that is the effort (cost) necessary to cover the distance separating two points in space. Impedance is normally measured in units of distance, travel time, or generalised transport cost. Aspects such as safety, congestion or the change of transport mode may also form part of the impedance measure.

The component of the spatial distribution of economic activities reflects the territorial organisation of the economic system. The activities are usually concentrated in certain areas to the detriment of others, meaning that individuals or companies residing near the areas with the greatest concentration of activities benefit from more accessibility. Accessibility is measured for particular activities, or using variables of a more general nature such as population –which reflects accessibility to consumers (for example, Vickerman et al., 1999; Gutiérrez et al., 1996; Wegener et al., 2000); or GDP (for example, Dundon-Smith and Gibb, 1994; Keeble, 1988; Wegener et al., 2000) and employment (for example, Breheny, 1978; Frost and Spencer, 1995) –which represent accessibility to economic activities; or certain strategic points on the network such as a port or an airport (Forslund and Johnson, 1995). It is also usual to measure accessibility to services such as shopping centres (Vickerman 1974), health centres (Haynes et al., 2003), stations on the underground railway system (Gutiérrez et al., 2000) and childcare centres (Salado García, 2001), among others.

The international bibliography shows various indicators for measuring accessibility (for a complete review see for example, Morris et al., 1979; Reggiani, 1998; Bruinsma and Rietveld, 1998, Geurs and vaan Wee, 2004). Following the classification of Geurs and Ritsema van Eck (2001) the indicators can be grouped into three categories: indicators based on infrastructure, activities or on the utility of travel.

Infrastructure-based accessibility indicators take the simplest approach to the concept of accessibility and relate it only to the characteristics of the transport system. According to Izquiero and Monzón (1992), these indicators can be subdivided into three types: presence and absence indicators, grid density indicators, and route factor indicators.

- Presence/absence indicators are the simplest of this type of measures as they only reflect the existence or not of communication routes in each zone. Some versions of these indicators introduce weightings for the type or length of road in the area.
- Grid density indicators relate the number of infrastructure in a territory to the total area of that territory, and assume that the denser the network, the shorter the distance to be travelled within the study area. This is normally formulated as follows:

$$D = \frac{Km\ of\ network}{Area\ /\ population\ of\ study\ area} \tag{1}$$

- Finally, route factor indicators (MOPU, 1984) measure the quality of the infrastructure and compare their actual route with a straight line. They are formulated as follows:

$$r_{ij} = \frac{d_{ij}}{d_{gij}} \quad - \tag{2}$$

where r_{ij} is the route factor between point i and j, d_{ij} is the minimum distance on the network between point i and j, and d_{gij} is the geographic or distance in a straight line from i to j. The value associated to each point in the study area is determined by calculating the route factor between this point and the other points in the area, according to:

$$R_i = \sum_j \frac{d_{ij}}{d_{gij}} \qquad (3)$$

where the route factor of node i (R_i) is the sum of the values of each one of the itineraries which link node i with all the others.

Although these indicators offer valuable information on the coverage and characteristics of the transport infrastructure, they are still insufficient as they do not recognise the spatial distribution of economic activities. An exception is the network efficiency indicator (Gutiérrez, J., et al. 1998) which represents the quality of the infrastructure as well as considering the localisation and importance of economic centres. It is expressed mathematically as follows:

$$A_i = \frac{\sum_{j=1}^{n} \frac{N_{ij}}{E_{ij}} M_j}{\sum_{j=1}^{n} M_j} \qquad (4)$$

where

A_i is the accessibility of node i,
N_{ij} is the impedance in the network between the point of origin i and the activity centre at destination j.
E_{ij} is the euclidean distance between the two points, assuming optimum conditions of efficiency of the infrastructure and
M_j is the weight (importance) of the economic centre at the destination.

The second category of accessibility indicators are the activity-based indicators. They provide more detailed information than those in the previous category as they include both the component for transport infrastructure and for distribution of economic activities. The accessibility indicators in this category can be subdivided into indicators of contour, average travel times, potential accessibility and those based on space-time geography.

The most common contour indicators include those which maintain fixed transport costs and measure the number of available opportunities (Törnqvist, 1970; Lutter et. al., 1993; Vickermann et al., 1999). The daily accessibility indicator proposed by Törnqvist (1970) is one of the most commonly used in this category and is formulated from the standpoint of the business person who travels in order to establish contacts at a particular destination and returns within the day. The usual threshold is between three and four hours of travel.

Average travel time indicators include the localisation indicator used by Gutiérrez and Urbano (1996) to calculate the average time between the main European cities taking their per capita GDP as the weighting factor. It is formulated as follows:

$$A_i = \frac{\sum_{j=1}^{n} (I_{ij} * GDP_j)}{\sum_{j=1}^{n} GDP_j} \qquad (5)$$

where A_i is the accessibility of point *i*,
I_{ij} is the impedance in the network between the point of origin *i* and destination centre *j*, and
GDP_j is the GDP of the destination centre *j*.

This indicator represents the average travel time from each origin to all the destinations considered, attributing greater weight to the most important destinations. The lower the value of the indicator, the shorter is the average distance and the greater the accessibility.

The potential accessibility indicators (also known as market or economic potential) are based on the principles of social physics inspired by Newtonian theory and suggest that the movement between two centres is proportional to the product of their masses (populations), and inversely proportional to the square of the distance between them. Hansen (1959) was the first author to use such a gravity indicator in accessibility studies. Hansen’s work measures the accessibility of shopping centres, industrial and residential areas, and defines the accessibility as the “potential opportunities for interaction”. This author proposed the following formulation:

$$A_i = \sum_j D_j d_{ij}^{-\alpha} \qquad (6)$$

where
A_i is the accessibility of zone i to all the opportunities D in zone j,
d_{ij} is the distance between i and j, and
α is a parameter which expresses the dissuasive effect of distance.

This type of indicator offers an aggregate measure which relates the accessibility of a territory directly to the size of the opportunities at the destination, and inversely to the distance required to reach these opportunities. This is undoubtedly one of the most commonly used accessibility indicators (Vickerman, 1974; Keeble et al., 1982; Calvo et al., 1993; Geertman and Ritsema, 1995; Gutiérrez et al., 1996; Copus, 1999; Schürman and Talaat, 2000; Gutiérrez, 2001; Haynes et. al, 2003). This formula has been modified in different studies, mainly by varying the impedance function (Dalvi and Martín, 1976; Ingram, 1971; Hilbers and Verroen, 1993) or the variable for opportunities at the destination (Keeble et al., 1982; Gutiérrez et al., 1996; Vickerman, 1974; Calvo et al., 1993).

The indicators which use space-time geography also belong to the category of activity-based indicators. The main characteristic of these indicators is that they integrate a time component for the availability of activities at different times of day, as well as for the availability of each individual to participate in certain activities. The accessibility is analysed from the standpoint of the individuals and their limitations for moving through space. Although these indicators were first employed by Hägerstrand in the 70s, their use has been less widespread than other indicators due to the large amount of data required for their calculation. However, advances in information technologies have given rise to new and interesting applications for these indicators (Kwan, 1998; Salado García, 2001).

The final category consists of utility-based indicators. Derived from microeconomic theory, utility-based indicators interpret accessibility as the benefits obtained by each individual or company through the use of the transport system and economic activities. One of the best- known is the indicator proposed by Ben-Akiva and Lerman (1979) which assigns to each alternative k the degree of utility U_k, where each individual n will select the alternative which maximises their total utility, as expressed in the following formula, where E represents the expected value:

$$A_n = E(Max U_k) \tag{7}$$

Utility *U*, attributed by individual *n*, who is at location *i* and wants to reach an opportunity located at destination *j*, is calculated using the following formulation:

$$U_{ij} = V_{ij} - \beta \cdot c_{ij} + \varepsilon_{ij} \tag{8}$$

where

V_{ij} represents the utility of the travel between centres *i* and *j* for individual *n*, known in a deterministic manner,

c_{ij} is the cost of travel between centres *i* and *j*,

β symbolises the parameter of sensitivity to travel cost, and

ε_{ij} is a random term which is introduced to represent the part of the factors affecting the utility of each alternative not evaluated in a deterministic manner.

The main drawback of these indicators is that they are not easy to interpret, and their formulation cannot be explained without reference to certain relatively complex theories.

Given the wide variety of accessibility indicators, the indicators should be carefully selected according to the objectives of the study. The use of one or another indicator could lead to contradictory results. This is one of the conclusions of the study by Linneker and Spence (1992) on the impact produced by the M25 motorway in London on accessibility in Great Britain. Using the travel cost indicator (considering access time and generalized transport costs) they conclude that the centre of London has the lowest accessibility value. However, using a market potential indicator, the centre of London has precisely the highest accessibility value, due to the greater number of opportunities it concentrates.

Some studies opt to calculate different accessibility indicators as to exploit the information provided and combine it in order to impart greater richness to the results (Martín et al., 2004; López, et al., 2008).

1.3.4 The spillover effect and its measurement

Improvements in one element of the transport network benefit various other elements of that same network, and the impact of these improvements may affect distant regions. This effect, known as the network effect (Lair et al., 2003), is intrinsic to transport infrastructure and varies according to their characteristics. Aspects such as the degree of development of the network, the quality and diversity of the existing infrastructure or the importance of the centres which benefit from improvements in the network are determining factors in the intensity and scope of the impacts. These are expected to be more intense the lower the network density, the poorer the quality of the infrastructure, and the more important the centres which benefit.

Closely linked to the concept of the network effect is what is known as the spillover effect, understood as the benefits received by a region due to the infrastructure built in another region (Pereira and Roca-Sagalés, 2003). Transport infrastructures generate benefits in the region where they are built, but they also provide services to citizens and companies in other regions. Their benefits therefore transcend the borders of the regions where they are located.

Aschauer's studies (1989 a and b) opened a debate as to the role of the capital invested by the state in companies' productivity. Aschauer concludes that the provision of infrastructure is a factor of overwhelming importance in explaining the evolution of the economic growth of a region.

Most of the works investigating the relationship between infrastructure and economic development take a macroeconomic approach which centres on the effect of public investment/stock on aggregate variables such as national production (GDP, GNP or TVA), the economy's rate of growth, factor productivity or company costs (Nombela, 2008). They also tend to distinguish between productive infrastructure (mainly transport) and social infrastructure (for example education, health, security, etc.).

One of the most common methods in the bibliography for analysing and quantifying regional spillovers of public capital in transport infrastructure is the use of production functions, where private capital (K) and employment (L) are brought in as factors of production, with the incorporation of public capital stock (KP) as a third factor. They usually include a parameter to reflect technological progress. Due to its simplicity, the most popular production function is the Cobb-Douglas:

$$Y_t = A_t \, L_t^{\alpha} \, K_t^{\beta} \, KP_t^{\gamma} \qquad (9)$$

where Y_t is the GDP or other measure of the economy's total production, A_t is the parameter which includes technological progress, and the other variables are already known.

Infrastructures are compared to traditional production factors such as work and private capital. The public sector provides the infrastructures and these generate positive effects on the productivity of the other productive sectors.

Aschauer was one of the first to use this approach, and obtained a high goodness of fit with very high values for R^2 and highly significant parameters for public capital. His results revealed the high productivity of public capital, particularly when invested in transport infrastructure. This study has encouraged the appearance of a fertile branch of research (Munnel, 1990; García-Milá and McGuire, 1992; Más et al., 1994, Boarnet, 1998, Hotlz-Eakin and Schwartz, 1995, among others) using this same focus. The range of elasticities obtained for parameter *y* of equation (9) in these studies ranges between 0.1 and 0.6, which represents the significant impact of public investment on the economy, and furnishes an excellent argument to the debate as to the need for investment in transport infrastructure.

Although these studies have been severely criticised, the results in more recent works continue to show the positive effect of infrastructure on private sector productivity, although the magnitude of the elasticities is not as high as in previous studies.

An interesting result of some of these studies (García-Milá and McGuire, 1992; Cantos et al., 2005; Delgado and Álvarez, 2007) is that when using data with a level of regional disaggregation the values obtained for the elasticity of public capital are usually lower than when the studies are carried out on the national scale. This has been attributed to the fact that the positive effect of the infrastructure extends to a much wider sphere than the one in which they are localised, thus demonstrating the presence of spillover effects. The investment in infrastructure in a particular region generates positive externalities in neighbouring regions, and these externalities are lost when estimating production functions on a regional scale.

The bibliography contains several studies which quantify the spillover effects generated by transport infrastructure (Más et al., 1994; Holtz-Eakin and Schwartz, 1995; Pereira and Roca-Sagalés, 2003; Crescenzi and Rodríguez-Pose, 2008). In these studies, spillovers are measured by extending the public capital stock of a region to the public capital stock of the neighbouring regions, based on the principle that regional production benefits not only from its own infrastructure but also from the infrastructure of adjacent regions. These methodologies thus follow a criterion of proximity and consider that the positive external effects will be more intense in the nearest regions (Cantos et al., 2005).

The influence of the spillover effect on regional production levels can be very important. Thus for Spain, Pereira and Roca-Sagalés (2003) conclude that spillovers and internal infrastructure stock make an almost equal contribution to regional productivity. Other authors such as Boarnet (1998) and Crescenzi and Rodríguez-Pose (2008) find positive effects in regions where the infrastructure are located, but also negative spillovers in the neighbouring regions which compete for production factors.

When measuring the relationship between infrastructure and economic development, the above-mentioned studies use public capital stock. However improvements in transport infrastructure mainly change the accessibility to the markets and the providers, and these aspects are more closely related to the quality of the service provided by the infrastructure than to the cost of building them. Therefore public capital stock in transport infrastructure is an inadequate measure, as it primarily reflects the investment made in their construction but fails to reflect sufficiently the service provided by infrastructure to the healthy functioning of economic activities. Accessibility measures are a good means of quantifying the impact of transport infrastructure. As opposed to infrastructure stock, accessibility measures have the advantage of considering the characteristics of the transport network and the importance they represent for reducing distances and bringing the economic agents closer together.

One of the main criticisms levelled at the aggregate methods of measuring spillovers is that the same importance is attributed to all the infrastructures in the neighbouring regions, regardless of their role in commercial relations. The infrastructures in neighbouring regions will contribute differently depending on the localisation of the economic activities and the use which is made of these infrastructures. Cantos et al. (2005) improve this methodology by weighting the public capital stock by interregional market flows, based on the references to economic growth in the literature which relate the spillover effects to the market flows existing between them. There are advantages to attributing greater weight to the infrastructure in the regions with which more commercial ties are established, but it continues to be an aggregate method which offers little information as to the real functioning of the transport networks in interregional economic relationships.

Spillovers depend on the characteristics of the transport infrastructure. The first thing to consider is the localisation of these transport infrastructures, which obviously affects the intensity of the spillovers generated. To exemplify this idea let us analyse figure I.2, which represents the impact generated by three types of linear infrastructures:

- An infrastructure with a national scope, localised in the interior of the country, will have the primary function of connecting national economic centres, and its impact will be located above all in the interior of the country. However, the neighbouring countries may also benefit from this infrastructure if they use it in their commercial relations.
- In the case of a border project, located on the boundary between two countries, the spillover effect will be more extensive due to the importance of this type of infrastructure in promoting international relations.
- The spillovers reach an even greater extension in the case of transport corridors which cross several countries and benefit a greater number of international relations.

In contrast, some infrastructure in the neighbouring regions may be little used due to their geographic orientation. If the infrastructure runs more or less parallel to the border with an east-west orientation, the impact will be greater to the east and west of this infrastructure, but negligible on the other side of the border.

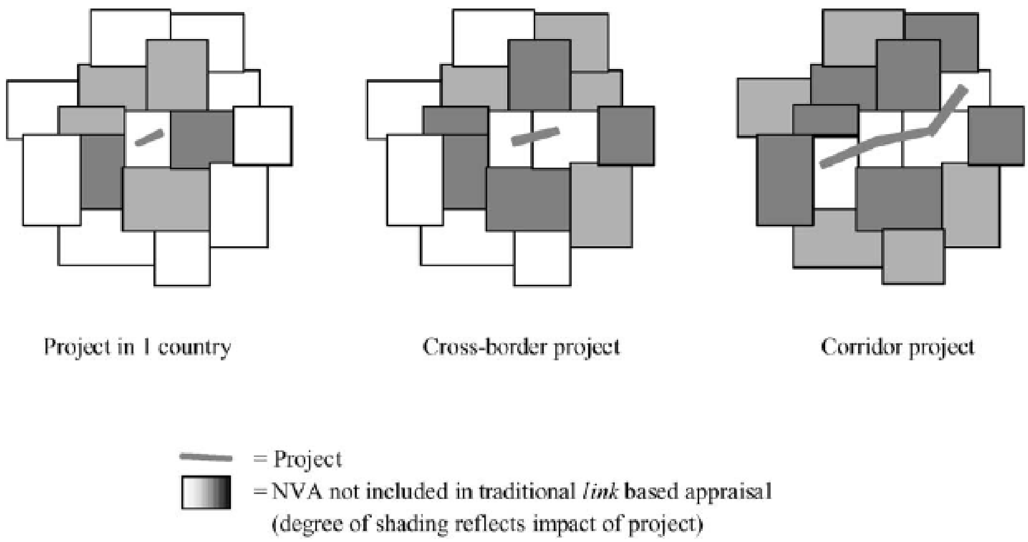

Figure I.2. Spillovers produced by different infrastructure projects (the rectangles represent regions or countries).
Source: Van Exel et al., 2002.

Aggregate methods consider all the capital stock in transport infrastructure in the neighbouring regions, regardless of whether that stock is used or not in commercial relations. Some infrastructures are of both national and international importance, and are therefore used in multiple commercial relations and generate significant spillover effects, whereas others are only used for local relations and generate fewer spillovers and more internal benefits.

It is also evident that high-capacity infrastructure have a much greater weight in commercial relations than local roads. Considering the greater contribution of high-capacity roads to commercial flows, some studies have opted to include only stock of this kind of road in their models (Crescenzi and Rodriguez-Pose, 2008). But this procedure may undervalue spillovers from transport infrastructure, particularly in regions which are less well-endowed with high-capacity roads.

Another drawback of this method lies in the concept of proximity itself, as by selecting only the adjacent regions, the infrastructure from other more distant regions may be overlooked while the infrastructure in neighbouring regions may be overvalued. But if, in order to overcome this limitation, the infrastructure stock in neighbouring regions (adjacent or not) is weighted according to interregional commercial flows (Cantos et al, 2005), then this also ignores the fact that many infrastructure in nearby regions (and particularly in neighbouring regions) are used to conduct business with third regions, and this business is not taken into account in the weighting.

With regards to transport infrastructure, the aggregate methods used to measure spillovers are not capable of correctly considering their network properties, which accessibility indicators are able to do. Accessibility indicators and Geographic Information Systems allow the representation of the behaviour of the transport networks and can thus reveal where and with what intensity the spillover effects occur.

As well as simulating the behaviour of transport networks, accessibility indicators make it possible to represent the functional relationships between activity centres. Using the component for spatial distribution of economic activities, these indicators attribute a greater weight to the relations established with the main economic centres. They can also include as many regions as considered necessary, as the weight of the relations between economic centres will decrease with distance.

An analysis of spillovers will also contribute valuable information on cohesion. In transport planning it is generally accepted that investment in infrastructure in peripheral/poorer regions will promote cohesion (from the point of view of both accessibility and the convergence of incomes), as the effects of these investments are concentrated in the receiving regions. However this perspective does not take into account the fact that spillovers may produce a perverse effect, as a considerable proportion of the desired effects is exported in the form of spillovers from the peripheral/poorer regions to the central/richer regions, thus diluting the possible cohesive impacts of the investment. Investing in regions with low income levels can produce abundant spillovers towards more developed regions which use these new infrastructure in their exports, particularly when, due to their location, the regions receiving the investments channel much of the interregional traffic.

In summary, methods which use public capital stock to quantify spillovers are incapable of simulating the real behaviour of transport networks, and their scope is thus limited. The analysis of spillover effects using aggregate methods such as production functions makes it impossible to distinguish the contribution of the different types of transport infrastructure. The use of accessibility indicators and GIS to measure spillovers represents an advance in the methodology for assessing transport infrastructure plans and projects. This methodology is designed to shed light on the spillover effect caused by each infrastructure or by the set of infrastructure as a whole contemplated in a particular plan. The study of the spillover effect makes it possible to determine the main beneficiaries of the new transport infrastructure. In some cases the infrastructures will have a clear internal benefit for the region where they are built, but a large part of the benefit may also go towards other regions, a fact which must be considered in cohesion analyses. Spillover analysis contributes relevant information, and highlights the fact that although some of the costs of the infrastructure are supported by the local inhabitants (pollution, noise, barrier effect, land consumption…) many of the benefits are enjoyed by the inhabitants of other regions.

1.4 SOURCES AND METHODOLOGY

1.4.1 Sources

The methodology for assessing the spillover effects of transport infrastructure is based on accessibility indicators, and developed using the GIS potentialities for network analysis and presentation of results in.

Implementing a transport model on a vector-based GIS requires considering the transport network and its relations. A network is a system of nodes connected by different arcs. The nodes represent the points of decision on the network, where the journey may begin, end, or branch. In multimodal networks, a node may also represent a point of mode transfer, where the individual changes from one mode of transport to another. The arcs represent a connection between one node and another; they may have an explicit direction of movement, and they should have some variable to describe the cost or impedance involved in their travel (for example, length, time, generalized transport costs, etc.). An arc may also have other measures associated to it, such as the volume of traffic flow (average daily traffic intensity, or capacity in the case of roads).

In transport studies it is usual to divide the study area into different transport zones, whose centroid represents the origin and/or destination of travel. This procedure is used to reduce the size of the distance matrices and consists of defining zones which are generally smaller in denser areas and larger in areas with less population density. The transport zones are usually connected to a network by means of one or several connectors, artificial elements with an associated impedance which represents the average distance which must be travelled on local roads in the area until the connection with the network. The transport zones usually have information which represents their socio-economic weight, such as population, employment or GDP.

The network and the transport zones are the two basic elements used to calculate the accessibility indicators. The transport zones represent the spatial organisation of the economic activities and the network enable measurement of the cost required to link them. In the various articles presented here, the methodology for measuring spillover effects has been applied to different spatial contexts and to a range of transport planning approaches, and thus uses various zones and networks created from different information sources. These are described below.

The first three articles measure the regional effects resulting from the current Spanish transport master Plan (PEIT). The plan has a projected duration of 15 years (2005-2020) and proposes considerable investments in all modes of transport in Spain (Ministerio de Fomento, 2005). This thesis focuses mainly on the investment actions scheduled for road transport.

These articles analyse the changes in accessibility, spillovers and the effects on cohesion resulting from the new roads. We have therefore used a simplified road network formed by 2195 arcs with information on the type of road (high-capacity roads, national roads and other roads), segment speed, and travel time. The following time-frame is considered: 2005 (without the plan) and 2020 (with the plan). The network covers all of peninsular Spain plus Portugal and the French regions of Aquitaine, Midi-Pyrénées and Languedoc-Rousellon. These non-Spanish territories are included in order to avoid the border effect on the accessibility results and to consider the effect of actions in the plan which are specifically conceived to improve cross-border road flows between Spain and its two neighbouring countries.

The study area was divided into 815 transport zones, each containing information on their population, which was the variable selected to represent their socio-economic importance. This variable is available at the municipal level, and can thus be easily added for each transport zone and projected with relative ease. The population information was obtained from the respective national statistics institutes (INE –Spain; INE –Portugal; INSEE –France). The population was then projected to the year 2020, the final year of the PEIT. This was done based on a study of population growth trends in the three countries, using a linear estimation model and considering, in the case of Spain, provincial population upper limits from an official projection drawn up by the INE.

In the specific case of article 2, the spillovers resulting from the new infrastructure are crossed with per capita income for each autonomous region in order to assess the impact of the spillovers on regional cohesion. The data refer to GDP per capita for 2005 according to the INE.

Article 3 focuses on the influence of the parameter representing friction of distance on the results of the potential and spillover model. This parameter, also known as the distance exponent, significantly influences the gravity models, and this study therefore tests the sensitivity at different values of the distance exponent. In order to calibrate the real value of the exponent, we used information on the commercial flows between provincial capitals obtained from the C-interreg database (Llano C. et al., 2008 y Llano C. et al., 2010), which provides information on the flows of goods and services between the various autonomous regions and provinces for the years 1995 and 2005. This specifies the geographic origin and destination of the commercial flows, and distinguishes 16 production sectors and four modes of transport. It also provides the option of obtaining the flow in euros or in tons. This case used both, and considered the total commerce in the 16 production sectors, transported by road.

Article 4 applies the spillover methodology to the study of the effects of possible road pricing in Spain. The objectives of the study required the use of a more detailed transport network in order to simulate the possible changes of route which might occur once a policy of this type was in effect. The network covers the whole of the study area, formed by Spain, Portugal and the French regions of Aquitaine, Midi-Pyrénées and Languedoc-Rousellon. This network was used in a traffic simulation model and therefore contains information on floating vehicle travel speeds, travel times and average daily traffic intensities (ADTI), as well as data on the capacity and the slope of the arcs. The floating vehicle speed and the ADTI were obtained from the traffic maps of the Ministry of Public Works (Ministerio de Fomento, 2005).

The origins and destinations zones correspond to the same zoning as the previous studies, formed by 815 transport zones. Accessibility impacts and spillover effects were measured for a series of pricing scenarios, differentiated by the type of road and vehicle (light, heavy) to which the tolls were applied, as well as by their economic value.

To measure accessibility under pricing conditions requires considering the impedance in terms of generalized transport costs, which in turn is the result of quantifying travel time and vehicle operating costs (fuel, maintenance, tolls, etc.) in monetary terms. These values, and the representative tolls in each scenario, were estimated within the framework of the META project (Di Ciommo, F., 2010 a y b), whose primary aim was to study of the impact of different pricing systems for light and heavy vehicles on the Spanish intercity road network.

Finally, the fifth article represents the application of the spillover methodology to the calculation of the European added value of cross-border projects. The case study selected was Project no. 25, one of the priority projects in the TEN-T programme, which involves the construction of a motorway linking four countries: Poland, Czech Republic, Austria and Slovakia. A network was used covering a large part of Europe and containing 377,797 arcs, and including main roads and ferry connections with islands. Each arc has information on the type of road, free-flow speed, length, travel time and penalties for waiting time when there is a change of mode (road – ferry). The NUTS 3 are taken as the transport zones which generate and attract journeys, and their GDP is used as the variable representing the economic importance of each one. Commercial flows (in tons) between the NUTS 2 were used to calibrate the distance exponent used in the model of economic potential. All the data used in the study were provided by the TRANS-TOOLS project developed in the IPTS (Institute for Prospective Technological Studies, Joint Research Centre of the European Commission), which implements a European transport model capable of predicting and testing different socio-economic scenarios and political strategies.

1.4.2 Methodology

The first step in any doctoral thesis after selecting the central theme of the study is to conduct a thorough review of the existing bibliography in order to establish the theoretical and methodological basis to support the subsequent phases of the research. The approach and development of the methodology proposed here were reached after reviewing the main studies on accessibility analyses, the influence of infrastructure on regional development and the measurement of the spillovers resulting from transport infrastructure. The bibliographic review revealed the main limitations of the studies on spillovers based on econometric techniques, and highlighted the valuable contribution offered by accessibility analyses and Geographic Information Systems to the study of spillovers.

This compilation of the main studies on accessibility analyses allowed us to establish and categorise the most relevant indicators (Section 1.3.3), and to select the accessibility indicator to be used in the methodology for assessing spillover effects. This process does not simply involve highlighting the best indicator, as different indicators offer complimentary information. The aim is rather to offer the possibility of accessing the data provided by these indicators and to weigh up the advantages and drawbacks of their application according to the objectives of the study. The following criteria were considered in the selection of the indicator for measuring spillover effects (based on Tillema, T., 2007):

- Realism of the results
- Use of a locational approach
- Low data requirement
- Ease of calculation
- Easy transmission and interpretation of results

The criterion of realism of results concerns the theoretical basis of the indicators. In this case the generation of spillovers is analysed from the standpoint of access to the markets, which requires a gravity type of indicator which reflects the utility of the infrastructure in relation to the available opportunities (potential markets).

The second criterion regarding the use of a locational approach refers to the fact that the results must represent the characteristics of territories and not of individuals. The spillover methodologies will be applied considering the impacts produced by a region's infrastructure on the accessibility of other regions. Accessibility will thus be measured from the territorial point of view and will not require analysis on individual scale.

The decision to use a locational approach determines the two following selection criteria, namely data requirements and ease of calculation. The selection of study areas which can cover one or more countries may demand enormous quantities of data – which are not always available on such a scale–, and require time to process the results, thus leading to greater difficulties in the calculations. The choice of indicator is therefore determined by the ease of obtaining information sources and by the time and the means available for processing them.

Finally, consideration was given to the ease of transmitting and interpreting the results, in order to ensure that both experts and non-experts can understand and use the findings in their transport planning processes.

Accessibility indicators	Criteria				
	Realism of the results	**Locational approach**	**Low data requirement**	**Ease of calculation**	**Transmission and interpretation of results**
Infrastructure-based	-	+	+	+	+
Activity-based					
• Contour indicators	+/-	+	+	+	+
• Potential indicators	+	+	+	+	+/-
• Space-time	+	-	-	-	+/-
Utility-based	+	-	+/-	+/-	+/-

Table I.1 – Adaptation of various accessibility measures for measuring spillover effects

Source: adapted from Tillema, T. (2007)

Table 1 shows the adaptation of the various accessibility measures for the analysis of spillover effects based on the criteria described above. Infrastructure-based indicators have the advantage of being easy to calculate and interpret, requiring few data and enabling the use of a locational approach. However, the results are not sufficiently realistic, since they do not take into account the importance of economic activities, which is fundamental to the study of spillover.

Contour indicators require relatively few data and are easy to calculate and interpret. However, their results are not sufficiently realistic as they use an all-or-nothing function (inside or outside the established contour) rather than a *distance decay* function. When sizes are equal, they attribute the same weight to all the economic centres within a particular distance, and do not consider at all any centres which lie beyond that distance. Contour indicators do not therefore accurately reflect the behaviour of the flows, which tend to decrease progressively as the distance increases. The choice of the distance limit in these indicators is somewhat arbitrary and may cause the results to vary significantly (Tillema, T., 2007).

Potential indicators enable a locational approach to be used, require few data and are easy to calculate. In addition they provide realistic results as their formulation includes a gravity component which attributes greater weight to closer relations, thus offering a more accurate representation of the real behaviour of the flows. Moreover, the parameter known as *distance decay* exponent can be used to simulate the greater or lesser resistance to distance: the higher the value of the exponent, the more resistance to distance, and the greater weight of relations over short distances. This parameter can be calibrated with real data on mobility; however, values of between 1 and 2 are normally used when such information is unavailable. The main drawback of the potential indicator is that its results are sometimes difficult to interpret as the indicator is expressed in relatively unintelligible units (market potential units).

Space-time measures offer realistic results as they use the maximum possible degree of disaggregation, the individual. However these measures cannot be implemented on the scale of the analyses used here, as they require a large quantity of information on individual movements. Their focus is also more social than economic.

Finally utility-based measures offer realistic results; however, the empirical data they require are not always easy to obtain. The calculation process is rather more complex than with the potential indicator. In addition, the results for this type of indicator present problems in their interpretation.

A comparative analysis between the different accessibility indicators led to the conclusion that activity-based measures, and particularly the potential indicator, are the most suitable for the objectives proposed in this thesis.

Once the accessibility measures to be used have been selected, the next step is to implement the indicators in GIS. According to Zhu and Liu (2004), the integration of the accessibility analysis in GIS consists of six processes (Figure I.3): definition of the problem, data collection, selection and specification of measures, measurement of accessibility, and finally interpretation and evaluation.

The first phase consists of defining the accessibility problem to be analysed in a particular study area, identifying the data requirements, collecting and pre-processing the spatial information from various sources, and building the GIS database. The sources for the data and their pre-processing were described in section 1.4.1. The GIS software selected to carry out most of the analyses was ArcGis®. This program includes the network analysis routines necessary to calculate the accessibility indicators as well as the cartographic tools for representing the results.

The second phase involves selecting and specifying the measures to be used. The measures are selected according to the criteria defined above, and specified, for example, by selecting the spatial units to represent the origins and destinations (census tracts, municipalities, economic centres, etc.), defining the variables which represent the attractiveness of the destinations, and other relevant variables for measuring accessibility.

The process for measuring impedance involves using spatial and/or network analyses to determine the distance between each pair of centres which represent the origin and destination of the journeys. Impedance is measured through the transport network, considering variables such as time or generalised transport costs, and provides the origin-destination matrices which will serve as a basis for calculating the accessibility indicator. Accessibility is calculated using indicators to characterise the accessibility in the study area.

Finally, the last phase consists of visualising, interpreting and evaluating the results obtained.

Accessibility analyses carried out in the GIS must allow the spillover effects to be measured. This involves using a procedure similar to the analysis of changes produced by a transport plan, where the usual method is to compare the *ex-ante* scenario, which represents the infrastructure before the start of the actions, with the *ex-post* scenario once the plan has been finalised. In this comparison the variable for the attractiveness of the destinations in the accessibility indicator is usually maintained fixed in order to isolate the effect produced by the infrastructure change. The comparison of both scenarios shows the impacts in accessibility due to the plan.

The methodology which measures the spillover effects also follows a similar procedure, although in this case the scenarios to compare are the ex-post scenario, which simulates the finalisation of all the changes in the transport network, and ex-post except in one study region, where the transport network remains unchanged (ex-ante only for this region).

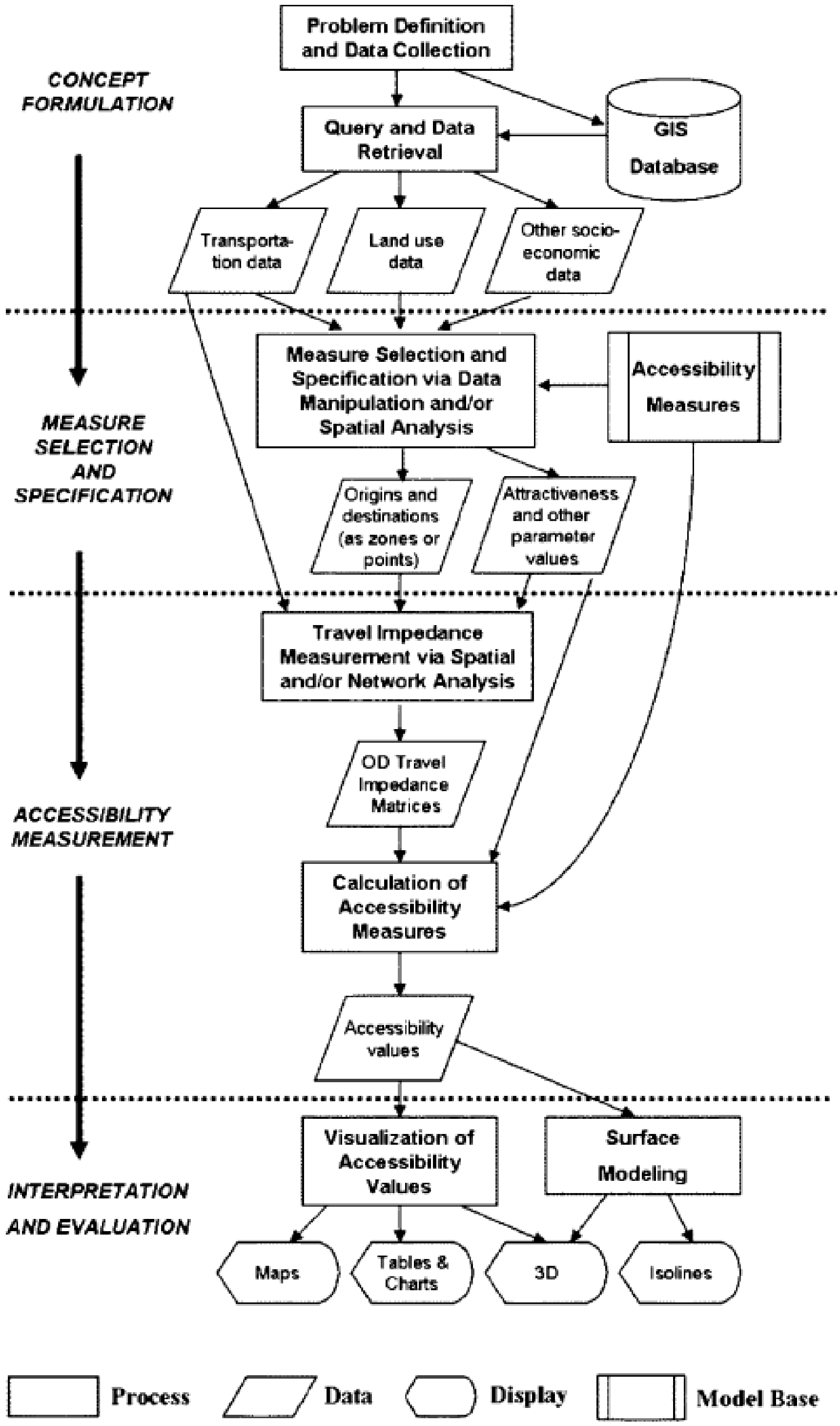

Figure I.3. Integration of accessibility analyses in a GIS.

Source: Liu (2002)

The comparison between both scenarios indicates the effects (internal and spillovers) of the investments made in this region. The analysis is repeated for each region subject to actions in the transport system. In all these scenarios the attractiveness variable (population in articles 1, 2, 3 and 4 and GDP in article 5) remains fixed in order to measure the "pure" effect of the change produced by the transport infrastructure.

The spatial unit delimitation is a fundamental aspect for the measurement of spillovers due to the fact that, as their definition indicates, these effects are generated by one region's transport infrastructure on the other regions. The choice of these spatial units depends on the territorial context used in the analysis, and the availability of data for the level of spatial disaggregation desired. This thesis considers the autonomous regions as the spatial units when Spain is the study area and the NUTS 3 when Europe is the study area. These units will be used to build the scenarios mentioned above. The results will be obtained at the transport zone level, although they will subsequently be aggregated to the regional level.

The spillover methodology is applied to different case studies. All of these studies first include the spatial patterns of the spillovers, both through a visual analysis of maps and by using spillover export and import matrices and descriptive statistics (analysing central and dispersion measures, the latter of which is particularly relevant for cohesion analyses). All the studies therefore include an analysis of the factors determining the spatial scope and intensity of the spillover effects, related in each case to the characteristics of the existing network, the spatial distribution of economic opportunities and the particular features of the transport infrastructure actions.

1.5 STRUCTURE OF THE THESIS

This thesis is presented in article format. It is therefore structured into three main parts:

1. A general introduction, which sets out the motivations for the thesis, its hypotheses and objectives, theoretical and methodological bases, data sources and proposed methodology.

2. A central nucleus consisting of the five articles which comprise the thesis, all closely interrelated.

3. Some final conclusions and future lines of research.

The central part of the thesis includes the five articles which constitute its primary contribution. At the start there is a summary of each article, indicating the research projects to which they belong, as well as the communications presented at congresses at which the works were discussed in their intermediate stages. Each article has as its central theme the proposal of a methodology to measure the spillover effects of transport infrastructure using accessibility indicators and GIS (Figure I.4).

The first article offers a methodological improvement over the previous study started with the DEA (during the second year of the doctorate period) due to its use of the economic potential indicator, which gives more realistic results. As demonstrated in the section on theoretical and methodological bases, this indicator includes a gravity component which represents the behaviour of transport flows, as it gives a greater weight to relations established over short distances. The methodology is developed using the case study of the spillovers generated by the new motorways proposed in the PEIT. The results are presented in the form of maps and spillover export and import matrices, in both economic potential units and in monetary units.

The second article analyses the spillovers resulting from the investments in the new motorways planned in the PEIT from the standpoint of territorial cohesion. This is designed to address the question of who benefits most from the spillover effects. If these are diverted towards less accessible and more economically disadvantaged regions, the plan will be fulfilling one of the main objectives, namely to reduce disparities and increase territorial cohesion.

Article 3 analyses the sensitivity of the spillover effects considering the influence of the *distance decay* parameter on the results of the potential indicator and the spillover methodology. This is done by repeating the methodology using a different value for this parameter each time. This analysis provides an insight into the robustness of the methodology to changes in the value of the *distance decay*. At the end of the article the exponent's value is calibrated based on commercial flows between provinces, from both the point of view of mobility (goods flows in tons) and particularly from the perspective of access to the markets (commercial flows in euros).

So far the methodology has been applied only to the study of the spillovers resulting from the construction of new infrastructure; however it can also be applied to other transport planning problems such as the issue of road pricing. This is the subject of the fourth article, where the spillover methodology is applied to a series of hypothetical scenarios representing the implementation of pricing on the intercity road network in Spain. Once it becomes necessary to measure accessibility under road pricing conditions, the analysis of the spillover effects becomes very complex and requires the use of generalised transport costs as an impedance variable. This variable must include both positive (a reduction in congestion) and negative (payment of tolls) aspects resulting from a policy of this type. The balance between the positive and negative impacts will determine the sign of the spillover effects.

Finally, the fifth article develops a methodology to assess the European added value of cross-border projects by measuring changes in accessibility and spillovers. The resulting spillover effects are analysed at the level of each of the segments in the corridor. Project no. 25, one of the 30 priority projects defined by the EU within the framework of the TEN-T (trans-European transport networks), was selected as a case study. This project involves the construction of a motorway which links four countries: Poland, Czech Republic, Slovakia and Austria. These types of projects frequently encounter financing problems. National economic priorities dictate that the most profitable segments in the interior of the country are built first and the least profitable, usually located on the borders, are delayed indefinitely. However from the point of view of EU integration, these border segments are crucial for linking the countries in the

Union and thus to the construction of the single market. The spillover methodology offers the possibility of determining the European added value (EAV) of each segment, which will be higher where greater spillover effects are generated. The EAV measured in this way will serve as a useful tool for planners, particularly from the standpoint of assigning European funds, as it enables segments to be differentiated in terms of their national or European interest.

Finally, Chapter 3 presents the main conclusions to be drawn from the various articles included in this thesis. It also contains a series of future research lines, some of which are already underway.

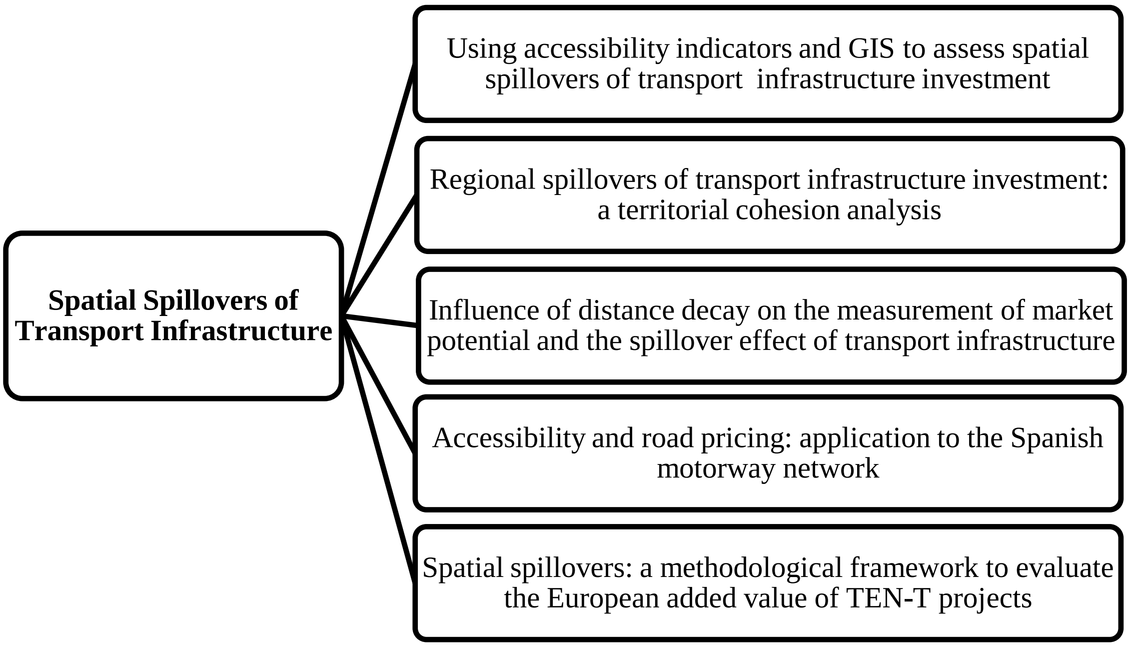

Figure I.4. General chart of the articles included in the thesis.

Source: Prepared by the author

ARTICLES

2. ARTICLES

This chapter presents the articles which comprise the main nucleus of this doctoral thesis.

A short summary of the main contributions is given before each article. These summaries highlight the relationship between the different articles and the progressive advances obtained in the development and application of the methodology.

The start of each summary features a brief description of the research projects to which these articles belong, and the congresses in which their preliminary results were presented for discussion.

2.1 USING ACCESSIBILITY INDICATORS IN A GIS TO ASSESS SPATIAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE INVESTMENT

Gutiérrez, J.; Condeço-Melhorado, A.; Martín, J. C. (2010): Using accessibility indicators in a GIS to assess spatial spillovers of transport infrastructure investment. ***Journal of Transport Geography****, Vol. 18, 1, pp. 141-152.* (JCR. Impact factor: 421)

The first article is part of the research project entitled "Assessment of the effects of transport infrastructure plans on mobility, territory and social economy" in the national R+D plan, financed by the Ministry of Education and Science's CICYT (Interministerial Commission for Science and Technology), with reference number TRA2004-04355. This project, coordinated by TRANSyT-UPM (the Transport Research Centre at the Madrid Polytechnic University) was developed between December 2004 and December 2007, with the participation of the University of Castile-La Mancha (UCLM), Seville University (US), Granada University (UG) and the Complutense University of Madrid (UCM).

The preliminary results of this work were presented at the 14th Pan-American Congress on Transit and Transport Engineering held in 2006 in Las Palmas de Gran Canaria (Condeço-Melhorado and Gutiérrez, J. 2006), at the 6th International Seminar of Systems Engineering, in Cozumel, México (Gutiérrez, J. and Condeço-Melhorado, 2006), and at the 6th Portuguese Geographical Congress which took place in Lisbon (Condeço-Melhorado and Gutiérrez, J. 2007).

This work measures the spillover effects resulting from the new motorways projected in the Spanish transport master plan (PEIT) in each autonomous region. The analysis is done using the market potential indicator. For each autonomous region, the scenario represented by the completion of the PEIT in the whole territory except in that particular region (where the road network remains unchanged) is compared with a scenario in which all the motorways in the PEIT are completed. The differences reflect the spillover effect of the actions planned in that region on all the other regions. The analysis is repeated for each autonomous region, thus giving a matrix of increase in accessibility, where the rows represent the exported improvements –due to the use of the future motorways in that region– and the columns the imported improvements –due to the use that the region makes of the infrastructure planned for the other regions. The diagonal cells represent the benefits that each region will obtain through the use of its own infrastructure.

The spillover matrix, in accessibility indicator units, is then used to redistribute the planned investment for each region based on the increments in accessibility and on the population which benefits from these improvements. This enables the creation of a euro matrix showing which part of the investment of the PEIT remains in the region for which it is intended, and which part is diverted to other regions through spillover effects.

The exported (rows) and imported (columns) investment flows are asymmetrical. Thus for example the Castile-La-Mancha region exports more investment to Andalusia than Andalusia imports from Castile-La Mancha. This is due to the fact that Andalusia uses Castile-La Mancha's infrastructure to access the Castile-La Mancha region itself, but also to connect with others such as Madrid. Castile-La Mancha, however, uses Andalusia's infrastructure primarily to reach cities in Andalusia.

A considerable part (a little over half) of the investment planned in the PEIT for each region is redistributed towards other regions in the form of spillovers. These spillovers depend on a series of factors which concern the characteristics of the road network and the localisation of the economic centres.

Journal of Transport Geography 18 (2010) 141–152

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment

Javier Gutiérrez [a,*], Ana Condeço-Melhorado [b], Juan Carlos Martín [c]

[a] Departamento de Geografía Humana, Facultad de Geografía e Historia, Universidad Complutense de Madrid, Calle Profesor Aranguren, s/n, 28040 Madrid, Spain
[b] Departamento de Geografía, Universidad de Alcalá, Calle Colegios, 2., 28801 Alcalá de Henares, Spain
[c] Departamento de Análisis Económico Aplicado, Facultad de Ciencias Económicas y Empresariales, Campus Universitario de Tafira, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain

ARTICLE INFO

Keywords:
Spillover effects
Transport infrastructure investment
Accessibility
GIS
Transport planning

ABSTRACT

This paper proposes a methodology to measure spatial spillovers of transport infrastructure investment and to monetize them by distributing the costs of the infrastructures envisaged according to the regional distribution of the potential accessibility benefits. We use a transport master plan (the Spanish "Plan Estratégico de Infraestructuras y Transporte" 2005–2020, PEIT) as a case study for applying our methodology. In order to calculate and map regional spillovers, economic potential values are computed using network routines in a Geographic Information System (GIS) by comparing two scenarios: firstly, the scenario PEIT 2020; and secondly the scenario which includes the improvements envisaged for the year 2020 in all the regions except the region whose spillover effects are being analyzed. The differences between these two scenarios represent the potential spatial spillover effects of this region on the rest of the regions. This procedure is repeated for each of the Spanish regions in order to calculate a matrix of inter-regional spillovers in economic potential units. In a second step, this matrix is monetized by distributing the costs of the investment in infrastructures envisaged in the region according to the regional distribution of the economic potential benefits. This inter-regional matrix of investments flows characterizes the "inner", "export", and "import" values of each of the regional road investments. Subtracting from the direct investment the exports to other regions and adding the imports from other regions, an estimation of the *real* investment of the plan in each region taking into account all the spillover effects is obtained. This value can be compared with the *direct* investment in the region, analyzing whether one region has more or less *direct* investment than *real*. The proposed methodology makes it transparent which regions benefit more from national transport investment irrespective of where the investment occurs. The spillover matrix can be a valid instrument, especially in federal states or in the case of transnational projects, in the field of regional economics because it offers very useful information for both planners and policy makers.

1. Introduction

Accessibility analyses are gaining momentum in the assessment of plans and projects of transport infrastructure in recent years. The improvement of accessibility, by itself, is one of the criteria considered in some of these evaluations. However, accessibility analyses may even go further, and permit researchers to evaluate other criteria as spatial cohesion (Schürman et al., 1997; López et al., 2008) or economic development (Rietveld and Nijkamp, 1993; Forslund and Johansson, 1995). Nevertheless, some of the possibilities of accessibility analyses in the assessment of infrastructure investment have hardly been explored (Halden, 2002; Geurs and Ritsema van Eck, 2003). We think that the study of the benefits that a country or region receives from infrastructure developments constructed in other countries or regions (spillover effects) is still in its infancy and can be one of the most paradigmatic examples that can be further explored. In this context, spatial or regional spillovers can be defined here as impacts of transport infrastructure investment in one region on the accessibility of other regions.

Accessibility is closely related to mobility, economic development, social welfare and environmental impacts. Therefore accessibility can be considered as a proxy of a set of related (economic, social, environmental) effects of transport infrastructure. By means of accessibility indicators it is possible to analyse the potential spatial interaction and the intensity of spillover effects. Other infrastructure investment produces spatial spillovers

* Corresponding author.
E-mail addresses: javiergutierrez@ghis.ucm.es (J. Gutiérrez), ana.condeco@alu.uah.es (A. Condeço), jcmartin@daea.ulpgc.es (J.C. Martín).

0966-6923/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jtrangeo.2008.12.003

too, but these effects are particularly relevant in the case of transport infrastructure investment due to the network effect (Laird et al., 2005).

The assessment of spillovers is relevant from the point of view of the financing of plans and projects of transport infrastructure. Sections constructed in a country can produce positive spillovers in other countries. If a cross-border project affects two countries, each country "exports" and "imports" benefits due to the spillovers. It seems logical to think that the country that has a negative balance should be compensated by the country that presents a positive balance (the Coasian approach). In the case of national transport plans, more realistic decisions can be made if spillovers among regions are considered. For countries like Spain, where it is frequent to have political bargaining conflicts among regions which fight for capturing more and more investments from the Spanish Central Government, it is important to study how the spillovers can affect the regional redistribution of transport investments. In fact, policy makers do need to know the amount of infrastructure investment in each region not only in terms of *direct* investment (how much money will be invested in each region), but also in terms of *real* investment (taking into account the regional spillovers).

This paper proposes a methodology to measure and monetize spatial spillovers of transport infrastructure investments using accessibility indicators. It analyzes spillover effects using accessibility indicators and network routines in a GIS. A transport master plan (the Spanish "Plan Estratégico de Infraestructuras y Transporte" 2005–2020, PEIT) is used as a case study for applying the proposed methodology. This case study is especially relevant, not only by its magnitude (32,105 millions Euros and 6129 km of new freeways), but also for the decentralized nature of Spanish governance. We analyze to what extent the foreseen improvements in the Spanish motorway network in a region produce accessibility gains in the rest of the Spanish regions. It seems clear that our proposal can also be applied in the assessment of cross-border projects.

The rest of the paper is structured as follows. Firstly, following this brief introduction, Section 2 presents the accessibility background and how it can be applied to measure the spillover effects generated after new transport infrastructure investment. Section 3 describes the building of the database in the GIS and the procedures used for the calculation of travel times and economic potential. Our methodology to measure and monetize the spillover effects of new transport infrastructure investment, using a definite Spanish transport master plan "PEIT" as a case study, is presented in Section 4. And, finally Section 5 concludes.

2. Accessibility and spillover effects

2.1. Accessibility, economic development and social welfare

The term "accessibility" expresses the facility with which activities may be reached from a given location by using a certain transport system (Morris et al., 1978); or in other words, the opportunities available to individuals and companies to reach those places in which they carry out their activities (Linneker and Spence, 1992).

Accessibility is the main 'product' of a transport system. It determines the locational advantage of a region relative to all other regions and so is a major factor for the social and economic development of a region (Wegener and Bökemann, 1998). From the theoretical point of view, there is a well-known relationship between transport infrastructures, accessibility and regional development. Transport infrastructures support a whole variety of dependent economic activity and serve to integrate the economic system and facilitate its transactions on a geographical scale (Linneker and Spence, 1996). The improvement of infrastructures produces an increase in accessibility that positively affects the competitiveness of the economic system and favours the appearance of specialisation benefits and scale economies (Forslund and Johansson, 1995).

From a regional perspective, it can be argued that new transport infrastructure investment increases the regional accessibility, and as a consequence better conditions are obtained which favour local firms regarding their level of productive efficiency. New firms are also created in the region because there are new economic opportunities (Banister and Berechman, 2003). In fact, regions with high levels of accessibility to the locations of input materials and markets tend to be more productive and competitive than peripheral and remote regions (Vickerman et al., 1999).

Transport infrastructure can be considered as one more input into the production process. Increasing the stock of infrastructure, like increasing any other stock of capital, should increase the rate of growth. This view underlies a large number of econometric exercises estimating aggregate production functions in which public capital enters as an input (Puga, 2002). The assumption behind these production functions is that regions with higher levels of infrastructure provision will have higher output levels and that in regions with cheap and abundant transport infrastructure more transport-intensive goods will be produced (Wegener and Bökemann, 1998). There are many examples of regional production functions including transport infrastructure indicators. But infrastructure endowment indicators used as an input in production functions suffer from the fact that they do not considered properly the utility of the network, but only the quantity of infrastructure (for example, kilometers of motorway). In order to respond to this criticism, infrastructure endowment indicators have been substituted by accessibility indicators in production functions (Forslund and Johansson, 1995; Wegener and Bökemann, 1998). In this way, improving accessibility implies an increase in the potential production.

It is well-known that accessibility (economic potential) is correlated with regional development. Keeble et al. (1988), for example, found a very marked economic potential disparity in levels of regional incomes per head within the European Community, so that regions with low economic potential values were characterized by low incomes. In the case of Spain economic potential and GDP per head at the regional level show a linear relationship with a correlation coefficient of 0.63 and a determination coefficient of 0.40. This suggests that Spanish regions with high accessibility tend to be more productive and developed. However this correlation may merely reflect historical agglomeration processes rather than causal relationships (Schürman et al., 1997). The impact of transport infrastructure on regional development has been difficult to verify empirically. There are not many satisfactory empirical investigations which determine clearly the role of accessibility as a mean to promote regional economic activity, so the literature is not conclusive regarding this issue, and uncertain and controversial results are frequent (Beuthe, 2002).

It is obvious that accessibility gains do not necessarily lead to economic development. Of course there are many factors influencing the regional development and accessibility to the markets is only one of them. It is well-known that a certain degree of transport infrastructure is a necessary condition to permit economic development, but the condition is not sufficient. The improvement of transport infrastructures can potentially promote regional economic development only in the presence of other market conditions or 'allocative externalities' (Beuthe, 2002; Banister and Berechman, 2003). These additional conditions include a favourable market environment, availability of funds, and supporting legal, organisational and institutional policies and processes. On the other side, the magnitude of the effect seems to depend strongly on the already existing level of accessibility (López, 2007). It is in regions with low transport infrastructure development, where transport networks do not exist or are very limited and there are important bottlenecks, that the strongest impacts of infrastructure investment on regional development have been observed (Rietveld and Nijkamp, 1993). However, in countries with an already highly developed transport infrastructure, further transport network improvements bring only marginal benefits (Vickerman et al., 1999).

Therefore, it is not straightforward to assess the effects on economic development of new transport investment and gains on accessibility. In fact, it is well-known that economic development depends on a myriad of different factors, such as, economic pulse or expectation, previous level of accessibility and overlapping and intrinsic characteristics of the project. However, the existence of the relationship is clear and it has been assumed for different research approaches. Governments of all the countries dedicate important budgets to invest in transport infrastructures with the confidence that better accessibility will provide an adequate framework for economic growth and better individual welfare of citizens. The negative statement has also been analyzed to study whether low level of transport investments affect economic growth. The empirical evidence shows that, in periods with inadequate level of transport investment, transport costs increase and accessibility is worsened as congestion and bottlenecks are frequent. For this reason, these periods are associated with poor economic growth or even economic recession. All this reinforces the new paradigm which recognizes that co-evolution, and not causality (Offner, 1992), better explains the relationship between transport investment and economic growth.

Accessibility approaches are gaining momentum in the assessment of plans and projects of transport infrastructure in recent years (López, 2007). In fact, many cost benefit analysis manuals are considering the necessity of studying the accessibility changes when new transport infrastructure investment is analyzed. Accessibility analyses can be used not only to assess the accessibility changes but also to study other important issues, such as, territorial cohesion and regional economic growth (production and employment). However, accessibility analyses offer a much broader panoply of possibilities. In fact, it is widely claimed that the potential of accessibility analysis for transport planning purposes is not fully exploited (Halden, 2002; Geurs and Ritsema van Eck, 2003). In this group, we can include the analysis of spillover effects of transport infrastructure investments and how these can be monetized, which is the aim of this paper.

2.2. The market or economic potential accessibility indicator

Accessibility indicators can be a valuable method to measure the benefits of population and firms at regional level after new transport infrastructure investment. One of the most popular indicators in accessibility studies is the economic (or market) potential. This indicator is a gravity-based measure which has been extensively used (see, for example, Harris (1954), Hansen (1959), Clark et al. (1969), Keeble et al. (1988), Bruinsma and Rietveld (1993), Linneker and Spence (1992), Spence and Linneker (1994), Dundon-Smith and Gibb (1994), Linneker and Spence (1996), Schürman et al. (1997), Gutiérrez (2001), López et al. (2008)). According to this model, the level of opportunity between a place i and a destination node j is positively related to the mass of the destination and inversely proportional to the distance or travel time between both nodes. Its classical mathematical expression is as follows:

$$P_i = \sum_{j=1}^{n} \frac{m_j}{t_{ij}^x} \qquad (1)$$

where, P_i is the economic (market) potential of node i, m_j is the mass (volume of activity) of the destination j, t_{ij} is the travel time by the minimum-time route in the network between node i and destination j, and x is a parameter that reflects the effect of the distance decay function.

In this paper, as in the majority of accessibility studies, the value of the parameter x is one. A value greater than one would overweight relations over short distances and would also increase the self-potential problem (Bruinsma and Rietveld, 1998; Gutiérrez, 2001).

Economic potential can be interpreted as the volume of economic activity to which a region has access, after the cost/time of covering the distance to that activity has been accounted for (Dundon-Smith and Gibb, 1994). The potential indicator gives an aggregate measure of a region's market area, and it can be seen that the economic potential diminishes as one move away from the centre (Vickerman et al., 1999). This feature has prompted an extensive use of the potential model for accessibility studies approached from an economic perspective (Bruinsma and Rietveld, 1993). The underlying assumption in the use of this model is that regions with better access to markets have a higher probability of being economically successful (Wegener and Bökemann, 1998).

2.3. Network and spillover effects

From a spatial perspective, network effects are a recognition that the improvement of a network element (arc or node) not only produce benefit effects in this element but also in many other elements of the network. Benefit measures require an understanding of networks behaviour. This is one of the advantages of using GIS; network effects can be analyzed because there are specific routines within the system that allow researchers to simulate the behaviour of the network. Using accessibility analyses and GIS, the network effects can be detected with a twofold consideration: identifying the geographical dimension of the effects of new transport infrastructure investment in those regions that are affected by these new infrastructures; and determining the grade or intensity of these effects.

Network effects produce important economic impacts on the transport system on both sides of transport markets: supply and demand (Laird et al., 2005). However, the economic effects are not only circumscribed to the transport system, but also to the rest of the economic sectors, as transport is an important input for most of them. It is evident that some scale and scope economies on transport supply and other positive externalities on transport demand can be fostered by the improvement of the transport system, and at the same time, these gains contribute, in general, to a better functioning of the economic system. Forslund and Johansson (1995) show how the reduction of interaction costs and better accessibility to other markets make it possible for firms in other sectors to reach the benefits of scale and specialization economics.

Spillover effects are narrowly linked to network effects. Accessibility analysis can also allow researchers to study spatial scope and intensity of spillover effects of transport infrastructure investments. Thus, they can understand whether the benefits experienced by one region are produced as a consequence of transport investments made in other regions (Pereira and Sagalés, 2003). These effects are especially relevant in the case of transport infrastructure plans and projects, because network effects cause spillovers in distant territories (Martín et al., 2007). Studies carried out to analyze the importance of infrastructures in productivity gains using production functions at a subnational scale (states, regions or metropolitan areas) obtain lower elasticities than studies at a national level (Cantos et al., 2005). This result shows that the infrastructures of a region have effects not only on the region itself, but also on other regions connected by a transport network (Hulten and Schwab, 1991).

Aschauer's work opened a debate which still continues about the role of public capital investment of the state on the productivity of the private capital (Aschauer, 1989a, b). He pointed out that infrastructure endowments produce spillover effects on other economic sectors and are a factor of enormous importance in explaining the evolution of economic growth. Some authors have analyzed the spillover effect from a spatial perspective (e.g., Mas et al. (1994), Holtz-Eaking and Schwartz (1995), Pereira and Sagalés (2003)), but there are only some exceptions in which the capabilities of GIS models have been employed in this context (Gutiérrez and Condeço, 2006; López et al., 2006). However, none of these previous studies has monetized the spillover effects obtained from the network analysis of a GIS model.

In order to analyse and quantify the regional spillover effects of transport infrastructure using production functions, some authors have made estimations extending the public capital stock to include that of geographically adjacent regions, as it was assumed that positive external effects would be of greater intensity in relation to the nearest regions (Cantos et al., 2005). Since the literature on economic growth alludes to the existence of spillovers between regions due to trade flows between them, Cantos et al. (2005) calculates the capital stock effectively used by a region as the sum of the region's own transport infrastructures plus a weighted sum of the capital in transport infrastructures in the rest of the regions. This second procedure presents some advantages because it takes into account the interaction among the regions, but it does not reflect adequately all the network effects produced by new transport investment.[1] However, accessibility analyses allow researchers to determine with precision the geographical distribution of the potential spillover effects. It is likely that some parts of a surrounding region do not experience any positive effect, and others experience important and intense spillover effects. Thus, the aggregation method employed in other studies may bias the results. GIS models are capable of storing very detailed disaggregate information on a set of small spatial units of the distribution of population, economic activity and other social or economic information susceptible of being included and analyzed in the study. In this way, it is possible to calculate the spatial spillovers in each of the municipalities in terms of accessibility improvements. Once we have calculated the accessibility gains on each municipality after the construction of new transport infrastructures in a region, the aggregation at different spatial structures (counties, provinces or regions) will be straightforward.

3. GIS database and accessibility calculations

3.1. Study area

The Spanish transport master plan "Plan Estratégico de Infraestructuras y Transporte 2005–2020 PEIT" covers a period of 16 years from 2005 to 2020. In relation to roads, it contemplates the new construction of 6,129 km of highways at a total cost of 32,105 millions of Euros in the whole territory of Spain with the exception of the Canary and Balearic Islands because these two Autonomous Regions are entirely responsible for their own roads. Thus, our research is focused on the analysis of the future spillover effects that will be produced after the new investment in roads and spatial effects in all of the Spanish peninsular regions (see Table 1 and Fig. 1).

Table 1
Kilometres and investments on highways envisaged in the Spanish transport master plan by autonomous regions.

Autonomous region	New highways (km)	Investments (million euros)	Population 2020
Andalusia	808	4782.2	8,612,345
Aragón	580	4069.2	1,379,747
Asturias	107	1314.8	1,033,180
Cantabria	64	534.0	637,361
Castilla-La Mancha	1279	5023.9	2,089,384
Castilla-León	1228	4851.4	2,453,287
Catalonia	456	2728.5	8,266,536
Extremadura	559	2275.4	1,080,251
Galicia	392	2234.9	2,790,901
La Rioja	43	214.8	375,206
Madrid	38	371.9	7,513,308
Murcia	197	1184.5	1,739,012
Navarra	172	1206.7	727,708
Vasc country	17	141.8	2,014,412
Valencia	189	1170.7	5,741,752
Total	6129	32104.9	46,454,390

Source: Spanish transport masterplan "Plan Estratégico de Infraestructuras y Transporte, PEIT, de España, 2005–2020" and own calculations.

It is well-known that the total area taken into account in an accessibility study is an important choice. If the spatial demarcation of the area of study coincides with the borders of the country, low accessibility values in cities located near borders are obtained (Bruinsma and Rietveld, 1998). For the accessibility of Galicia, for example, it is more important to include the North of Portugal than remote regions of Spain such Murcia (see Fig. 1). Thus, the accessibility calculations of the Spanish regions located near the borders correct this bias by considering Portugal and the South-Western French Regions (Aquitaine, Midi-Pyrénées y Languedoc-Rousellon).

3.2. Road network

We have based our accessibility analysis on a Geographic Information System (ArcGIS) which considers the main road network of the 15 Spanish Peninsular Regions, Portugal and the South-Western French Regions (Aquitaine, Midi-Pyrénées y Languedoc-Rousellon). Two different time horizons are considered: the years

Fig. 1. Regions of Peninsular Spain.

[1] In fact, the paper is not clear about whether the weights are fixed or dynamic according to the changes of commercial flows. If the weights are fixed then network effects are not considered on the new commercial interaction among regions. However, if they are dynamic, it is not clear what changes in commercial flows are due to the construction of new transport infrastructures.

2005 (ex-ante plan) and 2020 (ex-post plan), respectively. For each link of the network, information about the length, average speed (2005 and 2020) and travel time (2005 and 2020) was stored. Different type of roads and speed were considered in the study: 120 km per hour for toll highways, 110 km per hour for the rest of the highways, 90 km per hour for national roads, 80 km per hour for the rest of interurban roads and 50 km per hour for urban roads. Lower velocities were stored on sections affected by congestion near the most populated cities. A congestion effect has also been considered within the urban zones with more than 75,000 inhabitants (see Section 3.4).

3.3. Transport zones

The study area was divided into 815 transport zones with their respective centroids. This large number of zones is justified because:

1. It is necessary to consider in enough detail all the potential travel destinations. The large number of centroids (815) makes the indicator more realistic and precise than if other aggregated spatial units such as provinces (47) or regions (15) had been used.
2. It is necessary to correct the problem known as self-potential. The self-potential problem in the studies of accessibility has been previously discussed (Bruinsma and Rietveld, 1993; Frost and Spence, 1995), and it is related to the contribution of the internal accessibility of each zone with respect to the total accessibility. The self-potential can distort the total accessibility in highly populated areas or large zones. This problem can be serious when a transport national plan is analyzed, where the strategic relationships between regions should prevail over the local and urban relationships. Disaggregated and small transport zones, especially in metropolitan areas, help to estimate more accurately the internal time of each zone and to reduce the self-potential problem.

Transport zones in Spain were defined with the aggregation of the municipalities. 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:

1. *Zone size*. The size of the zones should be similar in order to make a better and easier estimation of internal travel times. Nevertheless, small urban zones or large rural zones are accepted.
2. *Zone shape*. Compact zones are preferred rather than irregular ones.
3. *Discontinuities*. The zones should be continuous.
4. *Natural barriers*. Valleys and mountains have been used to make the delimitation of zones more realistic.

In Portugal and France, a more pragmatic approach has been used. In both cases, the zonification is based in the administrative units of the respective countries (*Concelhos* in Portugal and the *Departments* in France).

The attractiveness of each zone is measured in the accessibility indicator using the population as a proxy of the importance of the economic activity.[2] We have taken the official projections for 2020 at the province level and then these projections were disaggregated at the municipal level using the trends of the last ten years in order to consider the different dynamics of the municipalities within the same province. Once the estimated population of each municipality for the year 2020 was obtained, the data of the different municipalities within the same zone were added in order to calculate the estimated population within the zone for the horizon year 2020. In each scenario (see Section 4.1), the forecasted population for the year 2020 was used in order to analyze the isolated effect of the transport infrastructure. It is clear that some economic activity can be promoted by the transport investment but this feedback effect is very complex to analyze and it is outside the scope of the paper.

3.4. Travel times and accessibility calculations

Network Analyst, a package extension included in ArcGIS, has been used to calculate minimal routes between the centroids of the 815 transport zones in order to obtain origin-destination travel time matrices. This process has been carried out for the 16 scenarios, 15 for each Autonomous Region and the scenario named 2020 which includes all the road investment foreseen in the Master Plan (see Section 4.1). Therefore, each matrix contains the travel times of more than half a million relationships ($815 \times 815 = 664{,}225$).

The internal travel time for each zone has been initially hypothesized in units of 10 min due to the small dimension of each zone. However, a congestion effect has also been considered within the urban zones with more than 75,000 inhabitants using the following correcting formula:

$$t_i = 3.4336 \quad \mathrm{Ln}(p_i) - 0.8476$$

where t_i is the internal time and p_i is the population of the zone i. This correcting formula is the result of an estimation obtained from a sample of Spanish cities. Finally, the internal time ranges from 10 min for rural zones to 28 min in the zone which represents the municipality of Madrid.

Total travel times between two centroids are calculated as the sum of the travel time through the network between the origin and the destination centroids and two penalty times (in origin and in destination, respectively) according to:

$$t_{ij} = t_i + tr_{ij} + t_j$$

where,

1. t_{ij} is the total travel time between the origin centroid i and the destination centroid j.
2. t_i is half of the internal time of the zone i.
3. tr_{ij} is the minimum travel time through the network between the centroid i and the centroid j.
4. t_j is half of the internal time of the zone j.

It can be seen that travel times are simply adjusted by the internal times of the respective zones. These penalties simulate the time spent using the local roads and streets in order to connect to the represented road network.

The implementation of the economic potential accessibility indicator in a GIS is a relatively easy task. After computing the minimum paths through the network between the 815 centroids in order to obtain travel time matrices, the accessibility value of each centroid was obtained throughout database operations. This procedure was repeated for each of the scenarios considered. Comparing accessibility values for the different scenarios of each region (see Section 4.1), spillovers for each centroid in economic potential units were calculated. These values (spillovers) were then interpolated using IDW (inverse distance weighted interpolation) raster analysis, a procedure that determines cell values in a grid using a

[2] Certainly, population is not the best proxy of the level of economic activity within each transport zone. However, there are not any official or reliable employment data at the level of municipalities in Spain. It is evident that the use of population or employment data to approximate the economic activity can affect the results of the analysis, but the main objective of this paper is the development of a methodology to calculate regional spillovers and the (re)distribution of transport investments and not the accuracy of the results.

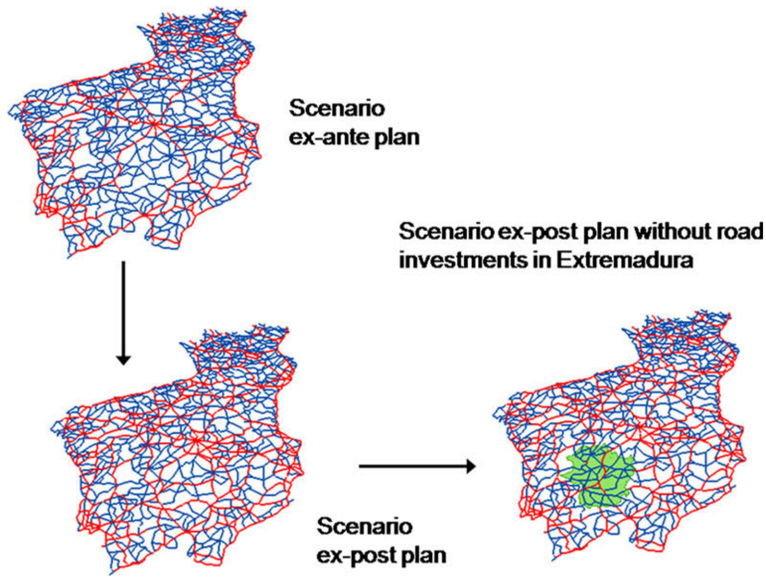

Fig. 2. Scenarios to measure spillover effects of Extremadura.

weighted average of the values of the nearest points (the centroids, in this case), taking as weights a function of the inverse of distance (see Philip and Watson, 1982). Following this procedure, maps such as the one represented in Fig. 3 can be produced. Fig. 3 shows the potential spillover effects that each region of Spain obtains as the consequence of the roads constructed in Castilla-La Mancha. Finally we perform overlays with each map of potential spillovers and the map of the Spanish municipalities in order to obtain the (interpolated) values of the potential spillovers in each municipality.

4. Methodology and results

4.1. Calculating spatial spillovers in economic potential units

In this section, we present our methodological proposal to measure the potential spatial spillovers through an accessibility analysis. We will test our methodology using as a case study the Spanish transport master plan "Plan Estratégico de Infraestructuras y Transporte, PEIT, de España, 2005–2020" and analyzing specifically the investment in motorways. In order to calculate and map spatial

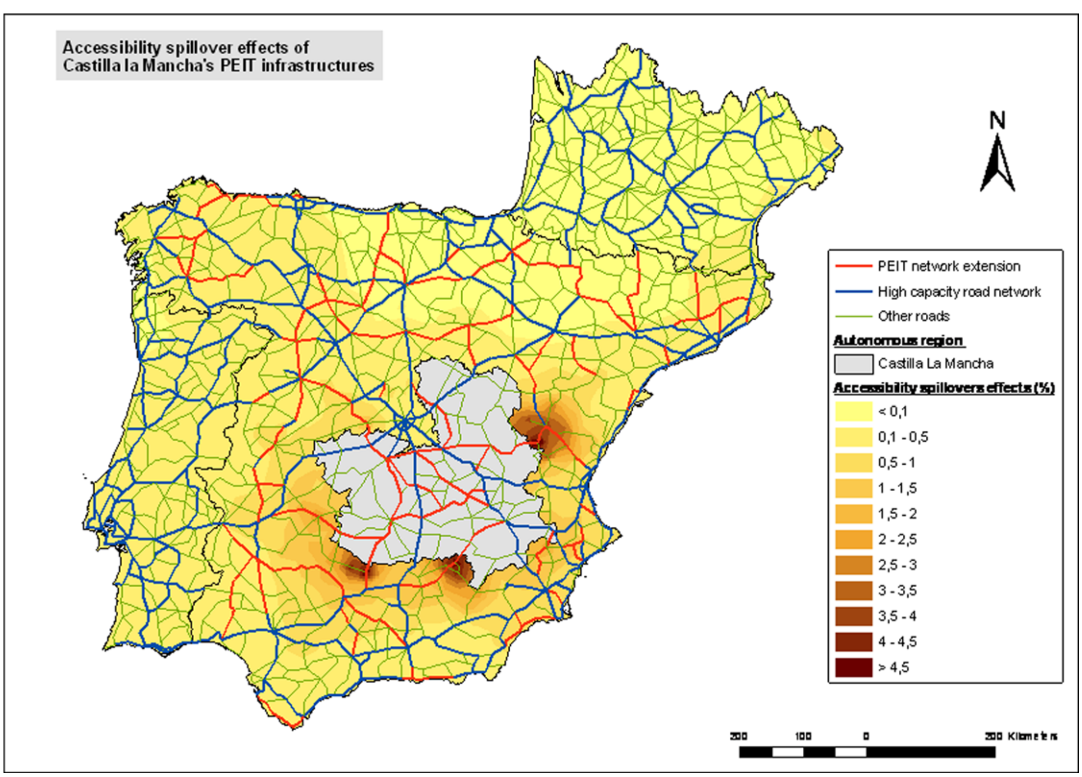

Fig. 3. Accessibility spillover effects of Castilla-La Mancha's PEIT motorways.

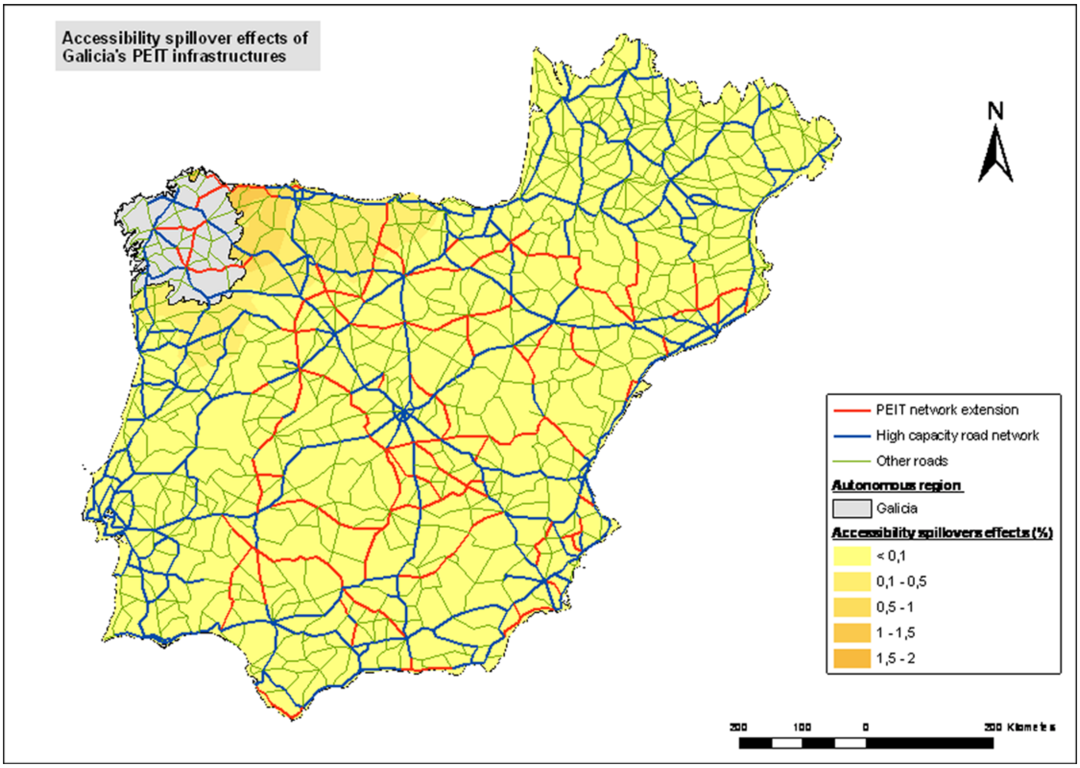

Fig. 4. Accessibility spillover effects of Galicia's PEIT motorways.

spillover effects of each region, accessibility values are computed by comparing scenarios: firstly, the scenario PEIT 2020; and secondly the scenario which includes the improvements envisaged for the year 2020 in all the regions except the region whose spillover effects are being analyzed. The differences between these two scenarios (PEIT 2020 and the do-nothing scenario in the region *i*) represent the spatial spillover effects of region *i* on the rest of the regions. This procedure is repeated for each of the Spanish regions to calculate a matrix of inter-regional spillover effects. In all the scenarios, the road network of Portugal and France is fixed and the plan of the European Commission for the year 2020 has been used.

Fig. 2 shows the two scenarios considered to measure the spillover effects of Extremadura, a region of Spain. It should be clear at this moment that we do not compare ex-ante and ex-post scenarios considering the investment of the transport master plan, but the scenarios ex-post and ex-post without considering the investment (new motorways) in the region under analysis (in the case of Fig. 2, Extremadura). Thus, the spillover effects of Extremadura over all the regions of Spain (including Extremadura) can be measured. This process is repeated iteratively for each of the regions of Spain[3], using the procedures described in Section 3.4.

Potential spillovers are measured in the units of the accessibility indicator used in the analysis (in our case economic potential gains). Those Spanish regions located in the centre of the Iberian Peninsula and others which are very large, produce important spillover effects. However, other peripheral regions produce negligible and insignificant spillover effects. Castilla-La Mancha (Fig. 3) is an example of a region of the first set, and Galicia (Fig. 4) of the second one. For the sake of exposition and space, we only present these two maps which are really representative of the extreme effects that can be observed in the regions of Spain regarding the spillover effects produced by the road investment of the Spanish master plan.

Fig. 3 shows how the distribution of spatial spillovers is not uniform within the same region. As spillovers were calculated for each of all the municipalities of Spain (see Section 3.4), a regional aggregation procedure is needed. Thus, the regional aggregate value of spillover effects in region *j* from the investment made in region *i* (in economic potential units) is obtained by a weighted average of the municipalities of the region *j* according to the population as follows:

$$S_{ij} = \frac{\sum_k s_{kij} p_{kj}}{\sum_k p_{kj}}$$

where:

S_{ij} are the average spillover effects (gains in economic potential) in the region *j* from the investment on region *i*,

s_{kij} are the spillover effects in each *k*-th municipality within the region *j* from the investment made in region *i,* and

p_{kj} is the population of each *k*-th municipality within the region *j*.

Of course, there is an important part which is retained by the region itself which cannot be considered as spillover effects. These will be referred as inner accessibility benefits, and the rest of the benefits which can be considered pure spillover effects of region *i* over the rest of the regions will be referred to as exports. Thus, it is possible to analyze which part of the accessibility gains is retained by the region (inner gains) and which is exported to other regions (pure spillover effects) (Table 2). We can see, for example, the accessibility gains accrued by the construction of the motorways in Castilla-La Mancha. Of course, as it can be expected the

[3] Our approach differs significantly from the one that has been previously used in transport planning, which compares two simple scenarios with and without the project, or the scenarios with and without a plan (see, for example, Linneker and Spence (1996) or Gutiérrez and Urbano, 1996). A different approach is also adopted when the researchers are interested in analyzing the vulnerability of the network. In this case, a link is erased from the network in order to analyze the increase in generalised travel costs as a measure of vulnerability (Cova and Conger, 2004; Husdal, 2006; Jenelius et al., 2006).

Table 2
Spillover matrix (in economic potential units).

To From	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castilla-León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Basque Country	Valencia	Total
Andalusia	4271	94	195	162	1051	354	135	2871	197	144	371	941	105	137	520	11548
Aragón	196	7773	419	902	796	608	1479	310	156	2296	809	958	4705	2350	2189	25946
Asturias	1	9	1285	353	3	29	6	2	838	17	4	1	27	181	2	2758
Cantabria	22	3	114	2996	44	248	0	54	8	11	67	18	1	79	12	3677
Castilla-La Mancha	1317	817	344	119	9490	754	473	1653	271	192	1175	2554	149	115	2164	21587
Castilla y León	429	2945	2079	4921	1280	7957	1379	1601	1284	5505	1792	327	4961	1363	393	38216
Catalonia	101	1355	135	216	294	187	4494	183	71	337	413	337	583	358	628	9692
Extremadura	2311	58	624	547	788	1017	19	7261	510	368	300	361	158	435	329	15086
Galicia	9	22	1292	400	25	324	12	27	2475	115	34	13	96	220	13	5077
La Rioja	6	85	40	26	3	291	29	31	47	1470	7	1	664	23	1	2724
Madrid	4	23	13	19	230	62	8	59	9	2	27	19	0	12	24	511
Murcia	602	220	10	11	228	18	300	31	8	72	35	5180	131	38	763	7647
Navarra	18	287	218	415	67	173	274	28	34	3339	86	34	4248	937	101	10259
Basque country	11	16	0	1	17	109	0	27	16	153	42	4	74	354	5	829
Valencia	29	1143	51	156	281	114	203	44	27	586	131	534	595	354	3885	8133
Total	9327	14850	6819	11244	14597	12245	8811	14182	5951	14607	5293	11282	16497	6956	11029	163690

Table 3
Monetized spillover matrix (millions Euros): investment flows between regions.

To From	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castilla y León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Vasc country	Valencia	Direct investments
Andalusia	3333.3	11.7	17.9	8.9	200.9	78.1	101.4	277.1	48.5	4.7	251.2	146.2	6.9	26.3	269.3	4782.2
Aragón	116.8	735.3	29.5	37.9	116.1	102.3	848.5	22.8	29.3	56.5	416.9	113.5	235.6	342.9	865.3	4069.2
Asturias	3.1	3.9	390.5	64.1	2.0	21.2	15.9	0.7	679.6	1.8	8.4	0.6	5.9	114.4	2.8	1314.8
Cantabria	27.1	0.6	16.8	264.5	13.5	87.7	0.3	8.4	3.1	0.6	72.5	4.6	0.1	24.2	10.0	534.0
Castilla-La Mancha	849.4	83.8	26.2	5.4	1498.8	137.5	293.9	131.8	55.0	5.1	656.4	327.8	8.1	18.2	926.5	5023.9
Castilla y León	235.6	256.8	134.7	190.5	172.0	1234.4	729.0	108.6	222.0	125.0	851.9	35.7	228.9	183.3	143.1	4851.4
Catalonia	47.1	100.6	7.4	7.1	33.6	24.6	2023.2	10.6	10.5	6.5	167.3	31.3	22.9	41.0	194.7	2728.5
Extremadura	1124.5	4.4	35.8	18.8	93.9	140.0	9.1	437.0	78.3	7.4	126.6	35.0	6.5	51.9	106.2	2275.4
Galicia	16.7	6.5	285.8	52.9	11.3	171.5	21.0	6.3	1460.9	8.9	55.7	4.8	15.1	101.1	16.6	2234.9
La Rioja	4.3	10.2	3.6	1.4	0.6	62.1	21.0	2.9	11.1	45.8	4.8	0.1	42.1	4.3	0.7	214.8
Madrid	10.5	9.1	4.0	3.3	140.8	44.0	18.7	18.3	6.8	0.2	59.0	9.5	0.0	7.0	40.6	371.9
Murcia	275.6	16.0	0.5	0.4	25.6	2.3	132.4	1.8	1.2	1.4	13.9	472.2	5.1	4.2	232.1	1184.5
Navarra	16.6	41.2	23.3	26.4	14.7	44.3	238.3	3.1	9.8	124.8	67.3	6.1	322.8	207.5	60.3	1206.7
Vasc country	7.7	1.9	0.0	0.1	2.9	22.3	0.2	2.5	3.6	4.6	26.0	0.5	4.5	62.7	2.3	141.8
Valencia	9.6	60.8	2.0	3.7	23.1	10.8	65.4	1.8	2.8	8.1	38.0	35.6	16.7	29.1	863.3	1170.7
Real investments	6077.9	1342.7	978.0	685.2	2349.6	2183.2	4518.3	1033.6	2622.4	401.5	2815.9	1223.6	921.1	1218.2	3733.6	32104.8

greatest economic potential gains correspond to Castilla-La Mancha itself (inner accessibility benefits) (9,490 economic potential units). However, there are also significant accessibility benefits in other nearby regions, such as Murcia (2,554), Valencia (2,164). Extremadura (1,663) and Andalusia (1,317) (see also Fig. 3).

As it can be seen, the regional distribution of spillover effects is clearly asymmetric. For example, the foreseen investment in Castilla-La Mancha will increase by 1,317 units the economic potential in Andalusia, however the economic potential in Castilla-La Mancha is only increased by the road investment made in Andalusia by 1,051 units (Table 2).

4.2. The redistribution of transport investments taking into account potential regional spillovers

So far the analysis has been focused on economic potential gains. In this section, a further step will be undertaken considering how these spillovers, in terms of accessibility gains, can be used to obtain a (re)distribution of transport investments among regions.[4] As we know the total investments in Euros of the region under analysis (Table 1), we can distribute this quantity according to the spillover effects (Table 2) and the total population of each of the regions (potential beneficiaries of this spillover effects) (Table 1) as follows:

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

where:

M_{ij} is the investment that region j imports from the direct investments in region i,

I_i is total investment (in Euros) in region i,

S_{ij} are the average spillover effects (gains in economic potential) in the region j from the investment in region i and

P_j is the population of the region j who benefit from the direct investments in region i.

This procedure provides a monetized matrix of *retained*, *exported* and *imported* investment (Table 3). In each of the rows, the figures of *inner* and *export* values of the region i are presented[5], and in each of the columns, *inner* and *import* values of the region j are shown. It can be seen, that the inter-regional matrix of investments flows is asymmetric too, implying that import and export values are not equal. For example, Andalusia imports more from Castilla-La Mancha (849.4 million Euros) than Castilla-La Mancha imports from Andalusia (200.9). The gap is accentuated because the population plays an important role in the calculation of these monetized values. In fact, Andalusia is a region with more population than Castilla-La Mancha (see Table 1), so more potential beneficiaries exist in the region.[6] It is evident that the row sum is equal to the *direct* investment on each region according to the Spanish master plan, and the column sum is equal to the *real* investment taking into account the spillovers. In other words, the real investment of one region is the estimated direct investment minus the exported investment plus the imported investment (or equivalently to retained investment plus imports).

Table 4
Real and direct investment (million Euros).

	Direct investments	Real investments	Difference
Andalusia	4782.2	6077.9	1295.7
Aragón	4069.2	1342.7	−2726.4
Asturias	1314.8	978.0	−336.8
Cantabria	534.0	685.2	151.2
Castilla la Mancha	5023.9	2349.6	−2674.3
Castilla y León	4851.4	2183.2	−2668.3
Catalonia	2728.5	4518.3	1789.8
Extremadura	2275.4	1033.6	−1241.8
Galicia	2234.9	2622.4	387.5
La Rioja	214.8	401.5	186.6
Madrid	371.9	2815.9	2444.1
Murcia	1184.5	1223.6	39.0
Navarra	1206.7	921.1	−285.6
Vasc country	141.8	1218.2	1076.3
Valencia	1170.7	3733.6	2562.9

Table 5
Motorway infrastructure investment exported.

	Euros millions	Percentage over direct investments
Andalusia	1448.9	30.3
Aragón	3333.9	81.9
Asturias	924.3	70.3
Cantabria	269.5	50.5
Castilla-La Mancha	3525.1	70.2
Castilla y León	3617.1	74.6
Catalonia	705.3	25.8
Extremadura	1838.4	80.8
Galicia	774.1	34.6
La Rioja	169.0	78.7
Madrid	312.9	84.1
Murcia	712.3	60.1
Navarra	883.9	73.2
Vasc country	79.1	55.8
Valencia	307.4	26.3
Total	18901.1	58.9

Table 5 compares *direct* and *real* investment in each of the regions. It can be seen, for example, that Andalusia receives a real investment (6077.9 million Euros) greater than it would have been in terms of the value of direct investment (4782.2). This region is an important beneficiary of the investment on other regions of Spain (it imports more that exports). However, for other regions the picture is just the opposite one, its direct investment over estimates the real investment in the region. This is the case of central regions of Spain where through transit traffic is frequent (for example, Castilla y León or Castilla-La Mancha) and transport investments tend to benefit the nearby regions more (see Table 4).

It is well-known that transport master plans can help to obtaining more regional integration among the territories of a nation. From the pure spillovers (export and import values), relevant information can be extracted regarding the calculation of the integration added value as it was proposed by López et al. (2006) using only non-monetized accessibility indicators. Thus, territorial integration is promoted when large values of the monetized pure spillovers are to be expected. So the contribution of the PEIT investments on motorways in each Spanish region to territorial integration can be measured as the proportion of the investment which is finally exported to other regions as the consequence of spatial spillover effects (Table 5). It can be seen, for example, that Andalusia exports spillovers equivalent to the 30.3% of the total direct investment. However, this figure accounts for the 70.2% in the

[4] It is outside the scope of this paper to combine our results with those obtained from econometric methods in order to monetize economic benefits.

[5] The elements on the diagonal of the matrix are the "inner" or "retained" investment of each region.

[6] It is worth mentioning here that the economic potential accessibility index was calculated using the number of inhabitants in the destination zone, while the monetization process considers the population that can be benefited from a better access. Therefore, the asymmetry gaps differ in both matrices (non-monetized and monetized spillover matrices). Populated regions tend to "benefit" from the monetization process, since potential beneficiaries are considered as a weight. This procedure to monetize the spillover effects is consistent with the new economic geography theory, that suggests that when transport infrastructures are improved, in the first stage the core (more populated) regions will benefit most, and only in a later stage will peripheral (less populated) regions start to benefit (Krugman, 1991; Bruinsma and Rietveld, 1998; Puga, 2002).

Table 6
Motorway infrastructure investment imported.

	Euros millions	Percentage over real investments
Andalusia	2744.6	45.2
Aragón	607.4	45.2
Asturias	587.5	60.1
Cantabria	420.7	61.4
Castilla-La Mancha	850.8	36.2
Castilla y León	948.8	43.5
Catalonia	2495.1	55.2
Extremadura	596.6	57.7
Galicia	1161.5	44.3
La Rioja	355.6	88.6
Madrid	2757.0	97.9
Murcia	751.3	61.4
Navarra	598.3	65.0
Vasc country	1155.4	94.9
Valencia	2870.4	76.9
Total	18901.1	58.9

case of Castilla-La Mancha. Two main conclusions can be drawn from the data in Table 5. The first one is that the magnitude of the spillover effects varies significantly according to regions, from 26.3% in Valencia to 84.1% in Madrid. The second idea is that spillovers are really important and should not be neglected in this type of analysis. In fact it can be seen that overall 58.9% of the total investment in motorways of the Spanish transport master plan PEIT would be exported to other regions. These results are consistent with those obtained by Pereira and Sagalés (2003). In this case, they evaluated the impact of public capital formation on private input in Spain using vector auto regressive (VAR) models, and they found that the measure of the spillovers – 57.1% of the aggregate effect – was comparable, in fact slightly greater, than the direct effects of public capital invested in the region.

Table 6 shows the counterpart of Table 5, that is, the spillover effects from the perspective of imports are now analyzed. It can be seen how the figures obtained differ significantly from those presented in Table 5. Castilla y León, for example, exports investments equivalent to the 74.6% of the direct investment (Table 5), but it imports a figure equivalent to only the 43.5% of the real investment (Table 6).

As we have seen, the monetization procedure described in this section consists of distributing the costs of the investment in envisaged infrastructures according to the regional distribution of the potential accessibility benefits in order to obtain an inter-regional investments flow matrix. It offers interesting information for the regions, since they usually know the value of the (direct) investment they will receive, but not the value of the (real) investment taking into account all the accessibility spillovers. It is clear that this methodology could be used to re-distribute transport investments, but not economic benefits. If a realistic estimate of the regional benefits in absolute terms is wanted, other economic evaluation methods can be used in a complementary way.

5. Conclusions

This paper has considered how different approaches have been used to measure regional spillover effects and proposes a new methodological approach which complements more traditional methods and overcomes the lack of sensitivity of previous studies regarding the network effects. Our methodology is based on GIS and accessibility indicators, and takes into account two scenarios: ex-post without considering the investment in region *i* and ex-post considering all the investment. It can be applied to different accessibility concepts, such as an economic potential indicator.

To test our methodology we used the Spanish "Plan Estratégico de Infraestructuras y Transporte" 2005–2020, PEIT. Following an iterative procedure we measured the regional spillover effects and (re)distributed the investment in the Plan according to accessibility spillovers in order to build an inter-regional matrix of investments flows. The "real" investment of one region is the "direct" investment plus the imported investment minus the exported investment. We observed different regional behaviour, namely there are some regions which export more than they import and others that import more than they export. Overall, 59% of the direct investment is exported (spillover effects). This figure should be taken into account when some analyses are only based on the total economic investment in each region. This type of analysis is certainly short sighted because an important characteristic of new transport investment, the spillover effects, is totally neglected. The results of such analysis can produce poor, inconsistent and biased measures of the regional effects of the transport plans.

Our methodology extends the state of the art because it takes into account the network effects, and the spillover effects are evaluated territorially analyzing the potential beneficiaries. From our results, it can be concluded that the spatial distribution of spillover effects is influenced principally by the following factors:

1. As distance increases the spillover effects tend to be diluted. This is a consequence of the use of the gravity model to measure the economic potential accessibility index. As it can be seen in the Figs. 3 and 4, the neighbouring regions are the ones which benefit more from the road investment in a particular region.
2. However, the new road investment does not produce homogenous results in the neighbouring regions, since the direction of the new links distorts the effect of the distance (Figs. 3 and 4). For example, if the new investments affect a section of a corridor North–South, the regions to the North and South of the section are better off than the regions located in the West and East.
3. Spillover effects (as a percentage of the direct investment) are more important in the regions located in the centre than in the periphery of the Spanish Iberian Peninsula because the interurban crossing traffic between the rest of the regions is more affected (see Table 5). For example, Castilla-La Mancha produces more spillovers than Galicia because the roads in Castilla-La Mancha are more heavily used in all the inter-regional interaction than the roads in Galicia which are mainly used for the traffic generated or attracted in the region.
4. The total number of kilometres of envisaged roadways has also an important influence on the expected exports of the regions. In Madrid and the Basque Country, the new investments are small, and for that reason the exported investments of these regions are also low (Table 5). Therefore, it is evident that for these regions most of the real investment is due to imports (97.9 and 94.9 percent, respectively) and not to retained investment (Table 6).
5. Large regions (as Castilla-León o Castilla-La Mancha) tend to generate more spillover effects in absolute terms because the large amount of km envisaged in the plan.
6. The location of the new highways within the region does matter too. Since changes in accessibility tend to be higher over short distances, as a consequence of the gravity-based formulation, spillover effects are more significant when the location of the improved road is near the border with other regions.
7. Since highly populated regions have more potential beneficiaries (population), they tend to retain more of the direct investment and to import more investment from other regions (pure spillover effects).
8. Of course local factors are also relevant in order to explain the spatial distribution of the spillover effects. Thus, for example, the investments envisaged in Madrid (only 17 km of highways) correspond to a section of the new direct link between Toledo (Castilla-La Mancha) and Ávila (Castilla y León) which will avoid

crossing through Madrid. Therefore, this new link hardly benefits Madrid and the spillover effects represent 84.1% of the direct investment.

As has been previously discussed, the procedure to monetize spillovers has been undertaken allocating the total investment of the plan according to the economic potential gains accrued to each Autonomous Region direct investment. However, it would be straightforward to implement an estimation of these spillover effects in economic terms if the information obtained by a traditional cost benefit analysis is available. Thus, our approach can be considered an adequate complementary methodology which could guide planners and policy makers in order to quantify the spillovers of new transport investment in economic terms.

It is worth noting here that the extension and intensity of the spatial spillover effects is clearly influenced by the exponent assigned to the distance in the formula of the economic potential indicator. The exponent should not necessarily reflect the intensity of the interaction of future mobility (if this is the case, the exponent could be changed according to some estimation of a demand model), but its economic potential. The economic potential is still a subtle concept which is more linked to the economic interaction of the agents and it is difficult to measure it empirically. Economic potential is certainly related to mobility, but it is as also a broader concept because long distance interaction between regions has also a very important strategic value. An area of future promising research is to test the robustness of spillover effects with respect to this impedance value (exponent of distance).

Finally, an area of future research is to know how our methodology deals with the whole question of financing a national transport system, or even better a transnational one. We think that most researchers reach the conclusion that taxing and dedicating taxes are probably not the total or best solution, if any part of the solution. Our method can be used in order to find a new assignment of the total costs of the investment among regions, when planners try realistically to finance new transport infrastructure systems or renew some of the obsolete ones over the medium or long term. At the same time, when you look at an issue such as the national transport system, it is evident and should be recognized that one of its purposes is to tie together some parts of countries with low population densities. The maintenance of connectivity to all of the territories of a nation is normally a statutory condition.

Acknowledgements

This research has been financed by the Projects "Evaluación de los efectos de Planes de Infraestructuras de Transporte sobre la movilidad, el territorio y la socioeconomía" (Ministerio de Ciencia y Tecnología) and "META" (CEDEX, Ministerio de Fomento). We also want to express our gratitude to the editor and two anonymous referees for their comments and suggestions which have helped us to improve the paper.

References

Aschauer, D.A., 1989a. Is public expenditure productive? Journal of Monetary Economics 23, 177–200.
Aschauer, D., 1989b. Does public capital crowd out private capital? Journal of Monetary Economics 24 (2), 171–188.
Banister, D., Berechman, Y., 2003. The economic development effects of transport investment. In: Pearman, A., Mackie, P., Nellthorp, J. (Eds.), Transport Projects, Programmes and Policies: Evaluation Needs and Capabilities. Ashgate, Aldershot.
Beuthe, M., 2002. Transport evaluation methods: from cost-benefit analysis to multicriteria analysis and the decision framework. In: Giorgi, L., Pearman, A. (Eds.), Project and Policy Evaluation in Transport. Ashgate, Aldershot.
Bruinsma, F., Rietveld, P., 1993. Urban agglomerations in European infrastructure networks. Urban Studies 30, 919–934.
Bruinsma, F.R., Rietveld, P., 1998. The accessibility of European cities: theoretical framework and comparison approaches. Environment and Planning A 30, 449–521.
Cantos, P., Gumbau-Albert, M., Maudos, J., 2005. Transport infrastructures, spillover effects and regional growth: evidence of the Spanish case. Transport Reviews 25 (1), 25–50.
Clark, C., Wilson, F., Bradley, 1969. Industrial location and economic potential in Western Europe. Regional Studies 3 (2), 197–212.
Cova, T.J., Conger, S., 2004. Transportation hazards. In: Kutz, M. (Ed.), Handbook of Transportation Engineering. McGraw Hill, New York, pp. 17.1–17.24.
Dundon-Smith, D.M., Gibb, R.A., 1994. The Channel Tunnel and regional economic development. Journal of Transport Geography 2 (3), 178–189.
Forslund, U.M., Johansson, B., 1995. Assessing road investment: accessibility changes, cost benefit and production effects. The Annals of Regional Science 29, 155–174.
Frost, M.E., Spence, N.A., 1995. The rediscovery of accessibility and economic potential: the critical issue of self-potential. Environment and Planning A 27, 1833–1848.
Geurs, K., Ritsema van Eck, J.R., 2003. Evaluation of accessibility impacts of land-use scenarios: the implications of job competition, land-use, and infrastructure developments for the Netherlands. Environment and Planning B: Planning and Design 30, 69–87.
Gutiérrez, J., 2001. Location, economic potential and daily accessibility: an analysis of the accessibility impact of the high-speed line Madrid-Barcelona-French border. Journal of Transport Geography 9 (4), 229–242.
Gutiérrez, J., Urbano, P., 1996. Accessibility in the European Union: the impact of the trans-European road network. Journal of Transport Geography 4 (1), 15–26.
Gutiérrez, J., Condeço, A., 2006. Medición de efectos de desbordamiento de las infraestructuras de transporte a través de indicadores de accesibilidad. Las Palmas, PANAM XIV - XIV Congreso Panamericano de Ingeniería de Tráfico y Transporte.
Halden, D., 2002. Using accessibility measures to integrate land use and transport policy in Edinburgh and the Lothians. Transport Policy 9 (4), 313–324.
Hansen, W.G., 1959. How accessibility shapes land-use. Journal of the American Institute of Planners 25 (2), 73–76.
Harris, C.D., 1954. The market as a factor in the localisation of industry in the United States. Annals of the Association of American Geographers 44, 315–348.
Holtz-Eaking, D., Schwartz, A.E., 1995. Spatial productivity spillovers from public infrastructures: evidence from state highways. International Tax and Public Finance 2, 459–468.
Hulten, C.R., Schwab, R.M., 1991. Public capital formation and the growth of regional manufacturing industries. National Tax Journal 44, 121–134.
Husdal, J., 2006. Transport network vulnerability – which terminology and metrics should we use? Paper presented at the NECTAR Cluster 1 Seminar, Molde, Norway, 12–13 May 2006.
Jenelius, E., Petersen, T., Mattson, L.-G., 2006. Importance and exposure in road network vulnerability analysis. Transportation Research Part A 40, 537–560.
Keeble, D., Offord, J., Walker, S., 1988. Peripheral regions in a community of twelve. Office for Official Publications of the European Communities, Brussels/Luxembourg.
Krugman, P., 1991. Geography and trade. MIT Press, Cambridge MA.
Laird, J., Nellthorp, J., Mackie, P., 2005. Network effects and total economic impact in transport appraisal. Transport Policy 12, 537–544.
Linneker, B., Spence, N.A., 1992. Accessibility measures compared in an analysis of the impact of the M25 London orbital motorway on Britain. Environment and Planning A 24, 1137–1154.
Linneker, B., Spence, N., 1996. Road transport infrastructure and regional economic development. The regional development effects of the M25 London orbital motorway. Journal of Transport Geography 4 (2), 77–92.
López, E., 2007. Assessment of Transport Infrastructure Plans: a strategic approach integrating environmental, efficiency and cohesion aspects. Madrid, Universidad Politécnica de Madrid, Thesis Doctoral.
López, E., Mancebo, S., Ortega, E., Monzón, A., 2006. El cálculo del valor europeo añadido mediante la utilización de indicadores de accesibilidad: aplicación a la evaluación de Planes de Infraestructura de Transporte.XIV Congreso Panamericano de Ingeniería Tránsito y Transporte. Las Palmas de Gran Canaria.
López, E., Gutiérrez, J., Gómez, G., 2008. Measuring regional cohesion effects of large-scale transport infrastructure investment: an accessibility approach. European Planning Studies 16 (2), 277–301.
Martín, J.C., Gutiérrez, J., Román, C., 2007. Accessibility impacts of European TENs railway network. In: Van Geenhuizen, M., Reggiani, A., Rietveld, P. (Eds.), Policy Analysis for Transport Networks. Ashgate, Aldershot, pp. 189–213.
Mas, M., Maudos, J., Pérez, F., Uriel, E., 1994. Capital público y productividad en las regiones españolas. Moneda y Crédito 198, 163–193.
Morris, J.M., Dumble, P.L., Wigan, M.R., 1978. Accessibility indicators for transport planning. Transportation Research A 13, 91–109.
Offner, J.M., 1992. Les effects structurants du transport: mythe politique, mystification scientifique. L'espace géographique 3, 233–242.
Pereira, M.A., Sagalés, O.R., 2003. Spillover effects of public capital formation: evidence from the Spanish regions. Journal of Urban Economics 53, 238–256.
Philip, G.M., Watson, D.F., 1982. A precise method for determining contoured surfaces. Australian Petroleum Exploration Association Journal 22, 205–212.

Puga, D., 2002. European regional policies in light of recent location theories. Journal of Economic Geography 2, 373–406.
Rietveld, P., Nijkamp, P., 1993. Transport and regional development. In: Polak, J., Heertje, A. (Eds.), European Transport Economics, European Conference of Ministers of Transport (ECMT). Blackwell Publishers, Oxford.
Schürman, C., Spiekermann, K., Wegener, M., 1997. Accessibility indicators. Berichte aus dem Institut für Raumplanung, 39, IRPUD, Dortmund.
Spence, N., Linneker, B., 1994. Evolution of the motorway network and changing levels of accessibility in Great Britain. Journal of Transport Geography 2 (4), 247–264.
Vickerman, R.W., Spiekermann, K., Wegener, M., 1999. Accessibility and economic development in Europe. Regional Studies 33 (1), 1–15.
Wegener, M., Bökemann, D., 1998. The SASI Model: Model Structure. Institut für Raumplanung, Universität Dortmund.

2.2 REGIONAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE INVESTMENT: A TERRITORIAL COHESION ANALYSIS

Condeço-Melhorado, A., Martín, J.C. y Gutiérrez, J. (in press): Regional spillovers of transport infrastructure investment: a territorial cohesion analysis. ***European Journal of Transport and Infrastructure Research.*** (JCR. Impact factor not yet available).

This article was developed as part of the META project (described below), within the framework of the TRANSPORTRADE network. The TRANSPORTRADE research network (spatial modelling applied to the movement of goods and people in the international sphere and on the Spanish regional level, S2007-HUM-0467) is financed by the IV PRICIT of the Madrid Regional Government. Its primary aim is to develop a multidisciplinary research network to study the effects of infrastructure and transport networks on economic activity, both at the interregional and international level, with particular emphasis on the mobility of goods and people. The network integrates the Department of Economic Analysis at the UAM, the L.R. Klein Institute at the UAM, Transyt at the UPM, the Department of Human Geography at the UCM, as well as international researchers of note in the subjects of economy, transport engineering, geography and environment sciences. Transportrade’s scientific programme involves developing different lines of research which address the problems of transport and its socio-economic effects using complementary methodologies. One of these lines of research is the interrelation between economic development and factors such as accessibility and territorial cohesion. The present article lies within this area of research, as it contains an innovative proposal for analysing territorial cohesion through the measurement of spillover effects.

A preliminary version of this work was presented in the NECTAR Cluster 6 (Accessibility) seminar held in 2008 in Las Palmas de Gran Canaria (Gutiérrez, J. et al., 2008).

The concept of territorial cohesion has today moved to centre stage in studies and territorial policies, particularly due to the importance it has been accorded by the EU since the Treaty of Amsterdam in 1997. Various reports (CEC, 2001; CEC, 2004, CEC, 2008), as well as the Treaty of Lisbon, have ratified territorial cohesion as being one of the underlying objectives that must be achieved in order to ensure the correct functioning of the Union.

According to the third report on Economic and Social Cohesion (CEC, 2004, pp. 27), the aim of territorial cohesion is to attain a more evenly balanced pattern of development in order to reduce existing disparities and avoid territorial imbalances. One of the key aspects of territorial cohesion is to guarantee good accessibility to the centres of economic activity and to services of general economic interest. Certain authors therefore use accessibility indicators to study territorial cohesion (Schürmann et al., 1997; Martín et al., 2004; López, et al. 2008).

The present article aims to further the methodology for assessing transport plans and their effects on territorial cohesion, using the new motorways planned in the PEIT as a case study. One of the objectives of this plan is precisely to reduce territorial disparities in the issue of accessibility. The investments dedicated by the PEIT to each autonomous region will generate spillovers, which imply that the general balance of accessibility between the regions will be significantly influenced by accessibility exports and imports deriving from the spillover effects.

To measure the effect of the plan on cohesion, the distribution of accessibility is analysed before and after the plan, using a set of inequality indicators (Gini coefficient, Theil or Variation's coefficient). The results show that the completion of the roads planned in the PEIT will decrease the existing accessibility disparities between regions, thereby meeting one of the primary objectives of the PEIT, namely that of improving cohesion.

An analysis is also made of the partial scenarios simulating the completion of the PEIT in the whole of Spain, except for the study region, which retains the same situation as prior to the plan. This reveals that the non-construction of the infrastructure in most of the autonomous regions will produce an increased imbalance, whereas in regions which have a greater market potential, the effect will be the reverse. This general trend is moderated by several factors, such as the nature of the planned investments. Thus for example, the construction or not of the infrastructure planned for Madrid does not alter cohesion values due to the fact that the PEIT contemplates minimal investments in this autonomous region.

Territorial cohesion is also analysed using an original approach in which the direction of the spillover effects is classified into either regressive or progressive. Regressive effects (upstream effects) are spillovers generated by a less accessible region benefiting more accessible regions; and progressive effects (downstream effects) are when the spillovers go in the opposite direction. Generally speaking, regressive effects are considered to be negative from the standpoint of territorial cohesion, as they represent benefits for the central regions deriving from the construction of infrastructure in peripheral regions, thereby heightening the contrast between more and less accessible regions. The results show the predominance of progressive effects over regressive effects, which is consistent with the results obtained previously with dispersion indicators.

Universidad de Las Palmas de Gran Canaria
Grupo de Investigación ITyT
Facultad de CC. Económicas y Empresariales
Campus Universitario de Tafira
35017 Las Palmas de Gran Canaria

Juan Carlos Martín Hernández, provisto de D.N.I. nº 05380316H y en calidad de co-editor del número especial "What can we learn from Accessibility Modelling?" que se publicará en el verano del 2011 en la revista European Journal of Transport and Infrastructure Research que edita la Universidad Técnica de Delft y con ISSN 1567-7141,

CERTIFICA QUE

El artículo "Does Spain's transport master plan 2005-20 promote regional cohesion?", escrito conjuntamente por Javier Gutiérrez, Ana Condeço y Juan Carlos Martín, ha sido aceptado para la publicación en el número especial citado con anterioridad.

Y para que así conste, a los efectos oportunos, firmo el presente a 24 de enero de 2011

Juan Carlos Martín Hernández

(: +34 928 458189 Fax: +34 928 458183 : : jcmartin@daea.ulpgc.es

Regional Spillovers of Transport Infrastructure Investment: A Territorial Cohesion Analysis

Ana Condeço-Melhorado[(a)]

Juan Carlos Martín[(b)]

Javier Gutiérrez[(c)]

(a) Departamento de Geografía Universidad de Alcalá Calle Colegios, 2. 28801 Alcalá de Henares (Spain) ana.condeco@alu.uah.es
(b) Departamento de Análisis Económico Aplicado Facultad de Ciencias Económicas y Empresariales Campus Universitario de Tafira Universidad de Las Palmas de Gran Canaria 35017 Las Palmas de Gran Canaria (Spain) jcmartin@daea.ulpgc.es
(c) Departamento de Geografía Humana Facultad de Geografía e Historia Universidad Complutense de Madrid Calle Profesor Aranguren, s/n 28040 Madrid (Spain) javiergutierrez@ghis.ucm.es

Abstract

Territorial cohesion is a routine part of the job of spatial planners. However, it has not always been measured using a valid and solid methodology. This paper addresses conceptually how regional spillovers of transport investments of the Spanish master plan (''Plan Estratégico de Infraestructuras y Transporte'' 2005–2020) affect territorial cohesion. Different periods undergo analysis using the ''extraction method''. We calculate regional spillovers by accessibility gains measured in economic potential units (gravitational method using GDPs for each centroid under analysis). Two different typologies of regional spillovers are given, according to the direction of the effects: upstream and downstream. We conclude that the 'Plan Estratégico' favours territorial cohesion of Spain, but the degree of territorial cohesion produced by each region is not uniform. The end of the paper raises a number of suggestions for further research on the interaction of regional spillovers with territorial cohesion.

Keywords: Regional spillovers; transport infrastructure; accessibility; territorial cohesion; Spain

1. Introduction

The European Commission (EC) has, since its inception in 1957, devoted much discussion to the future of the European Union's cohesion policies (CEC, 2004, CEC, 1998). In fact, the European Cohesion Forum, held by the Commission on 21 and 22 May 2001, concluded that cohesion must not be a matter for structural policy alone, and other European Union organisations - in particular those for agriculture, rural development, the environment and transport - must make policies that more effectively contribute to it. Among the policies named to play that role are the European Common Transport and the Trans-European Transport Network (TEN-T). The TEN-T Policy aims to provide the infrastructure for smooth functioning of the internal market and achievement of the objectives of the Lisbon Agenda on Growth and Jobs (CEC, 1998). It also sets out to help ensure accessibility to transport throughout the EU and to boost economic, social and territorial cohesion (CEC, 2009).

So far, the EU has invested €400 billion in a network that was established by decision of the European Parliament and the Council in 1996, and last amended in 2004. This investment has helped to complete a large number of projects of common interest, interconnecting national networks and overcoming technological barriers across national borders. . Articles 154-156 of the Treaty on European Union define TEN-T policy and its role in achieving the objectives of smooth functioning of the internal market. They include social and economic cohesion for the benefit of all its citizens, economic operators, and regional and local communities, inter alia by targeting EU action to promote interconnection and interoperability of national networks, and access to such networks.

All the national transport master plans in the EU follow these premises and, in principle, they are expected to promote regional cohesion at the national level. This in keeping with the view of policymakers and researchers, such as Nijkamp *et al.* (1990), who suggested that cohesion effects should be studied in any relevant integrated policy analysis. Because of existing policy, the treatment of cohesion effects of transport infrastructure investments tends to be even and common (Grant-Muller *et al.*, 2001).

Ex-ante cohesion effects of transport investments are difficult to analyse, because all transport investments in a region affect not only the internal boundaries of the region but other regions situated in the vicinity. These effects are usually termed 'regional spillover effects'. Regional spillovers are the main drivers of the cohesion policies in transport master plans, because some of the accessibility gains achieved by a region are consequences of regional transport investments made in others. In practice, some important benefits of transport investments of less developed regions could be reaped by the most developed regions of the country in the form of regional spillovers, leading to an increase in regional disparities.

In this paper we aim to analyse how regional spillovers of road transport investments in the Spanish transport master plan (Ministerio de Fomento [2004], ''Plan Estratégico de Infraestructuras y Transporte,'' 2005–2020; PEIT) can affect the territorial cohesion of Spain. Planners usually concentrate transport investments in those regions with less income, in order to promote territorial cohesion. However, this behaviour is myopic because new investments benefit both their own regions and neighbouring ones. For this reason, it is necessary to analyse how regional spillovers produced by transport investment affect territorial cohesion. The analysis of spillovers could help to disentangle the real investments of the transport master plan in each of the regions. To our knowledge, this exercise has not been performed in the past, so this paper expands the current state-of-the art, analysing how the objective of territorial cohesion is affected by the impact of regional spillovers from transport infrastructure investments.

2. Background

In this paper, the analysis of regional spillovers is conducted by looking at regional distribution of accessibility gains of each regional transport investment. We use geographic information system (GIS) technology, which can be considered a complementary tool to any conventional cost-benefit analysis. As stated earlier, it is well known that transport investments in a region affect the accessibility of the region itself and the rest of the regions considered in the study. This is especially true for some major motorways, which connect different regions of a country. Thus, if we have a motorway that connects two developed regions through a third, less developed one, then the investments in this third region could more intensely favour the two developed regions than the middle region. This critical issue has been scarcely studied and, as we will show, it is relevant in order to evaluate the transport master plans from the point of view of cohesion. The evaluation cannot only be based on the economic figures invested in the less developed regions of a territory, because part of these benefits are transferred to other regions and, as suggested earlier, positive cohesion effects of transport master plans can be blurred by spillovers. Thus, when we analyse the cohesion effects of any transport master plan, then regional spillovers play a determinant role: A plan will produce more cohesion when regional spillovers are harvested by the less developed regions (downstream effects). On the contrary, if regional spillovers are harvested by the developed regions (upstream effects), then cohesion will not be favoured.

Some earlier papers deal with the possible existence of regional spillover effects. Munnell (1992)[4] found that the elasticities of output with respect to public capital formation obtained with state-level data tend to be lower than those obtained with aggregate data, a finding she conjectured to be due to the existence of spillover effects. In studies of spillover effects, the methodologies and empirical results are usually based on the estimation of aggregated production functions (Boarnet, 1998; Holtz-Eakin and Schwartz, 1995; Cantos *et al.*, 2005). Pereira and Roca-Sagalés (2003) captured the spillover effects of public capital formation, estimating region-specific VAR models which include both public capital spent in the region itself and public capital spent outside the region. Thus, they estimated the marginal products for each region both for the public capital spent in the region itself and for the public capital located elsewhere (spillover effects of public capital). Their empirical results suggest that spillovers account for over half of the aggregate effects of public capital formation.

To date, the importance of spillover effects on regional cohesion has been elusive. We hypothesize that by using GIS technology to extract new regional features, our approach improves on the conventional ones that use more aggregate data, and for that reason are not particularly suitable to differentiate the intensity of spillover effects over all the regions of a country. In an earlier study, Ozbay, Ozmen-Ertekin and Berechman weighted investments according to two criteria: neighbouring regions that are closer and those that are farther away (Ozbay *et al.*, 2007). They concluded that the magnitude of regional spillovers to neighbouring counties is strongest near the investment location.

[4]Mas et al. (1996), Moreno et al. (1997) and Ezcurra et al. (2005), using panel data techniques, found possible indirect evidence of regional spillovers along the lines suggested by Munnell (1992).

Gutiérrez *et al.* (2010), using a different methodology - one based on the analysis of accessibility indicators - calculate matrices of investments flows among all the Spanish regions. These matrices serve to differentiate two important cases:

- upstream effects are regional spillovers which are transferred from less developed regions to developed regions;
- downstream effects are regional spillovers which are transferred from developed regions to less developed regions.

This matrix allows us to know how much of the direct investment in each region is transferred to other regions, and it is especially important to differentiate whether these transfers take an up- or downstream direction. Assessing these figures adequately can be crucial to determining whether the regional spillovers do favour territorial cohesion.

It is evident that underpinning this approach is the strong relationship between accessibility, on the one hand, and economic growth and development, on the other. Governments of all the EU countries dedicate important budgets to investing in transport infrastructures, confident that better accessibility will provide an adequate framework for economic growth and better welfare for individual citizens. Analogously to what has been previously cited regarding the imbricate relationship between public capital in special highways or transport infrastructure and economic growth and development, some studies have shown that accessibility and economic growth and development also have a strong direct relationship (Forslund and Johansson, 1995; Vickerman *et al.*, 1999; Ozbay *et al.*, 2003 and 2006).

2.1 Transport infrastructure, accessibility and economic growth

Transport infrastructure can be considered as one more input into the production process. Increasing the stock of infrastructure, like increasing any other stock of capital, should lead to an increase in the rate of economic growth. Underlying this view are a large number of econometric exercises that estimate aggregate production functions with public capital as an input (Puga, 2002). The assumption behind this production function is that regions that provide higher levels of infrastructure will have higher output levels, and that regions that provide cheap and abundant transport infrastructures will produce more transport-intensive goods (Wegener and Bökemann, 1998). There are many examples of regional production functions, including transport infrastructure indicators (see, for example, Aschauer, 1989; Munnell, 1992; Moomaw and Williams, 1991; Holtz-Eakin, 1994, Mamatzakis, 1999; Ozbay et al., 2007).

However, indicators of infrastructure endowment used as an input in production functions have been criticized because they are not a satisfactory measure of the utility of the network, rather only of the quantitative properties of the infrastructure (for example, kilometres of motorway). The interaction between regions and cities cannot be easily explained by these aggregate indicators without considering how cities are connected. Responding to this criticism, some researchers have substituted infrastructure endowment indicators with accessibility indicators in the analysis of production functions (Forslund and Johansson, 1995; Wegener and Bökemann, 1998; Ozbay et al., 2003 and 2006). In this view, improving accessibility implies an increase in potential production. Figure 1 shows the mechanisms that explain the relationship between accessibility and economic growth.

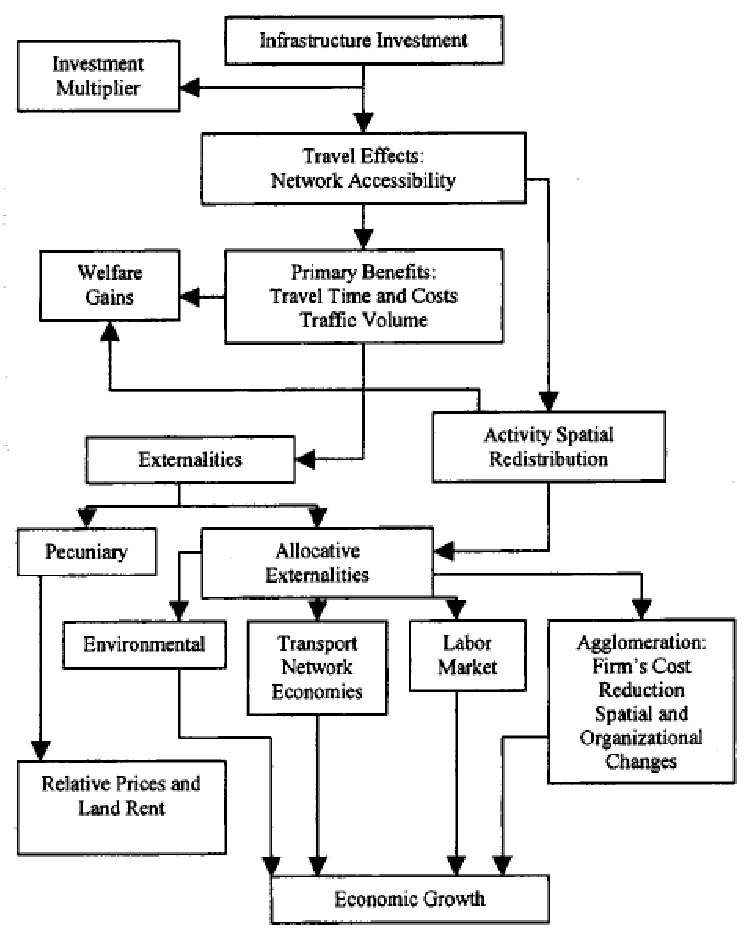

Figure 1. Framework representing the relationship between accessibility and economic growth (Banister and Berechman, 2000)

2.2 Transport infrastructure, regional spillovers and territorial cohesion

Spillover effects of transport infrastructure are understood as the benefits that one region experiences as the consequence of transport investments made in others (Pereira and Roca-Sagalés, 2003). These effects are especially relevant in the case of transport infrastructure plans and projects because network effects spill over into distant regions (Martín *et al.*, 2007). Studies carried out on the importance of infrastructures in productivity gains using a subnational scale (states, regions or metropolitan areas) obtain lower elasticities for infrastructures than studies at a national level (the Munnell paradigm). The elasticity result shows that the infrastructures of a region affect not only on that region, but also other regions connected by a transport network (Hulten and Schwab, 1991).

A unified planned transport network is essential to achieving better integration of the subnational areas. Cohesion between these areas will remain a basic prerequisite in designing transport master plans to facilitate free movement of goods and people. In Spain, the Ministry of Development, in designing ‘the “PEIT”, recognized the necessity of reducing gaps in opportunity among all the regions and sought to give the outlying parts of the Spanish territory greater access to the central backbone of the nation (Madrid-Barcelona-Valencia). This plan is especially relevant, not only because of its magnitude (€32,105 million and 6129 km of new motorways), but also because of the decentralized nature of Spanish government.

’Territorial cohesion’ is an ambiguous term, and the concept is used distinctly in different fields. According to Davoudi, ‘‘such obscurities often occur when a term is translated from one language to another while leaving behind its wider systems of meaning. The notion of territorial cohesion, translated from the French original, Cohesion territoire, is a victim of such a process’’ (2005, p. 433). However, despite its ambiguity the concept generally has a positive connotation; thus ‘territorial cohesion’ has spread around rapidly and become a routine feature of spatial planning (Schön, 2005).

Faludi (2004) and Davoudi (2004) attempted to trace the origin of ‘territorial cohesion’, with the aim of providing a deeper understanding of the concept’s meanings and applications. They outlined some important and particular events as well as publications that have given it political notoriety. It is clear that territorial cohesion gained widespread use at the European level after its appearance in the proposed EU

Constitution, which states that ‘‘in order to promote its overall harmonious development, the Union shall develop and pursue its action leading to the strengthening of its economic, social and territorial cohesion. In particular, the Union shall aim at reducing disparities between the levels of development of the various regions and the backwardness of the least favoured regions’’. (Conference of the Representatives of the Governments of the Member States, 2004, Article 220).

The Third Cohesion Report was the first attempt to shed some light on and extend the concept of territorial cohesion beyond the borders of social and economic cohesion[5]. Until then, indicators of cohesion had been mainly related to equality and, to a smaller extent, disparities between regions. This was a narrow approach because territorial cohesion was only studied via certain socioeconomic variables at a certain administrative level (country, region or municipality). In this context, some cohesion reports illustrate that although cohesion in this narrow sense between the EU member states was increasing, the disparities between the regions were also growing.

Hamez (2005) concluded that it is important to define 'territorial cohesion' broadly to avoid reducing it to the analysis of the regions facing economic weaknesses or geographical limitations, such as islands, mountainous areas or peripheral zones. A broader version of the concept combines several dimensions, including (p. 401):

1. a multisectoral dimension: in terms of the promotion of not just economic, but also social and environmental, cohesion;
2. a territorial dimension: in terms of different spatial levels, from the EU to the local level, and concerning both disparities and access to services (see Third Cohesion Report);
3. a temporal dimension: in terms of a concern not just with present disparities but also the likely changing relative situation.

Territorial cohesion has been previously analysed in other studies using GIS technology. In most of the cases, the approach is based on the analysis of changes in the spatial distribution of accessibility values (e.g., Schürman *et al.*, 1997; Martín *et al.*,

---

[5] The concept of territorial cohesion extends beyond the notion of economic and social cohesion by both adding to and reinforcing it. In policy terms, the objective is to help achieve more balanced development by reducing existing disparities, preventing territorial imbalances and making both more coherent both sectoral policies which have a spatial impact and regional policy. The concern is also to improve territorial integration and encourage cooperation between regions (CEC, 2004).

2004; López *et al.*, 2008). The studies use different equality indices to analyse whether territorial cohesion (equity) is increased or not using two different scenarios: ex-ante – ie, before the construction of transport infrastructure; and ex-post – ie, after the construction of all transport investments. In this paper, we use a different approach: analysing the effects on cohesion by comparing regional spillovers. Therefore, the analysis described in this paper extends the state of the art in two different directions:

1. First, for each region examined, the accessibility regional changes caused by the new motorways investments are obtained for three different scenarios. Then accessibility indices are used to analyse the results, and those are compared. Thus, we will compare the scenario ex-ante, the scenario ex-post (PEIT) and the regional scenario which describes the PEIT without any investment in a specified region ("extraction method"). In this way, we can conclude whether the regional investments in each of the regions promote territorial cohesion.
2. Second, when analysing the matrix of regional spillovers, we consider whether these spillovers are part of the upstream set.

In summary, we have developed a method in which the focus has been placed on territorial cohesion instead of economic cohesion, overcoming the availability of data which has been cited as the major constraint when this type of study is carried out using GIS technology. This method satisfies the second and third characteristics proposed by Hamez.

3. An Accessibility Indicator Methodology to Calculate Regional Spillovers

In this section, some aspects of the methodology in which the calculus of regional spillovers is based will be briefly explained. (See Gutiérrez *et al.*, 2010 for further details.) Regional spillovers are calculated for the 'PEIT', which covers the period of 16 years, from 2005 to 2020, and allocates funds for the new construction of 6,129 km of motorways with a total cost of €32,105 million in the peninsular territory of Spain.

The GIS model includes the main road network of the 15 Spanish peninsular regions (Figure 2), Portugal and the South-Western French regions (Aquitaine, Midi-Pyrénées and Languedoc-Roussillon) for 17 different scenarios – 2005 (ex-ante plan), 2020 (ex-post plan) – and 15 scenarios for 2020 without considering regional investments in region *i*. Thus, regional spillovers from new motorway investments foreseen in the PEIT are calculated according to the net gains on accessibility (measured by economic potential[6]). The accessibility gains are obtained using the regional extraction method (Figure 3). The logic behind this procedure resembles the works that use the extraction method on the basis of an input-output table with multiple regions. In order to consider the isolated effects of a hypothetical region *i*, it is usual to extract the region under analysis from the multiple-region model (Dietzenbacher *et al.*, 1993).

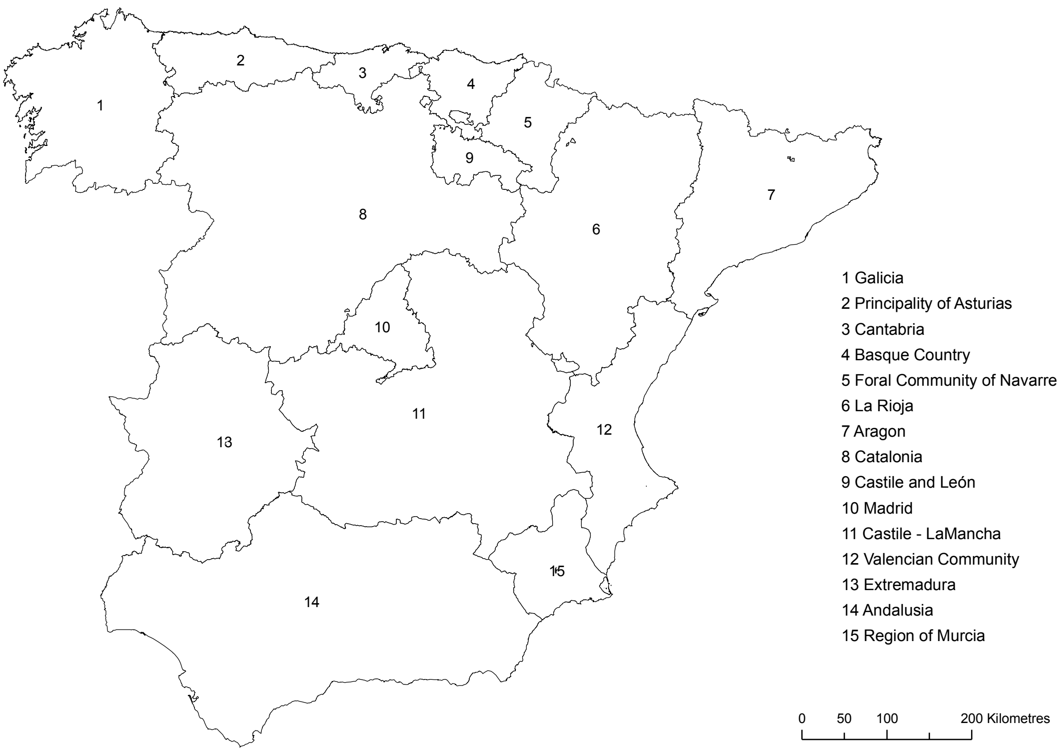

Figure 2. Study regions

[6] Economic potential can be interpreted as the volume of economic activity to which a region has access, after the cost and time of covering the distance to that activity has been accounted for (Dundon-Smith and Gibb, 1993).

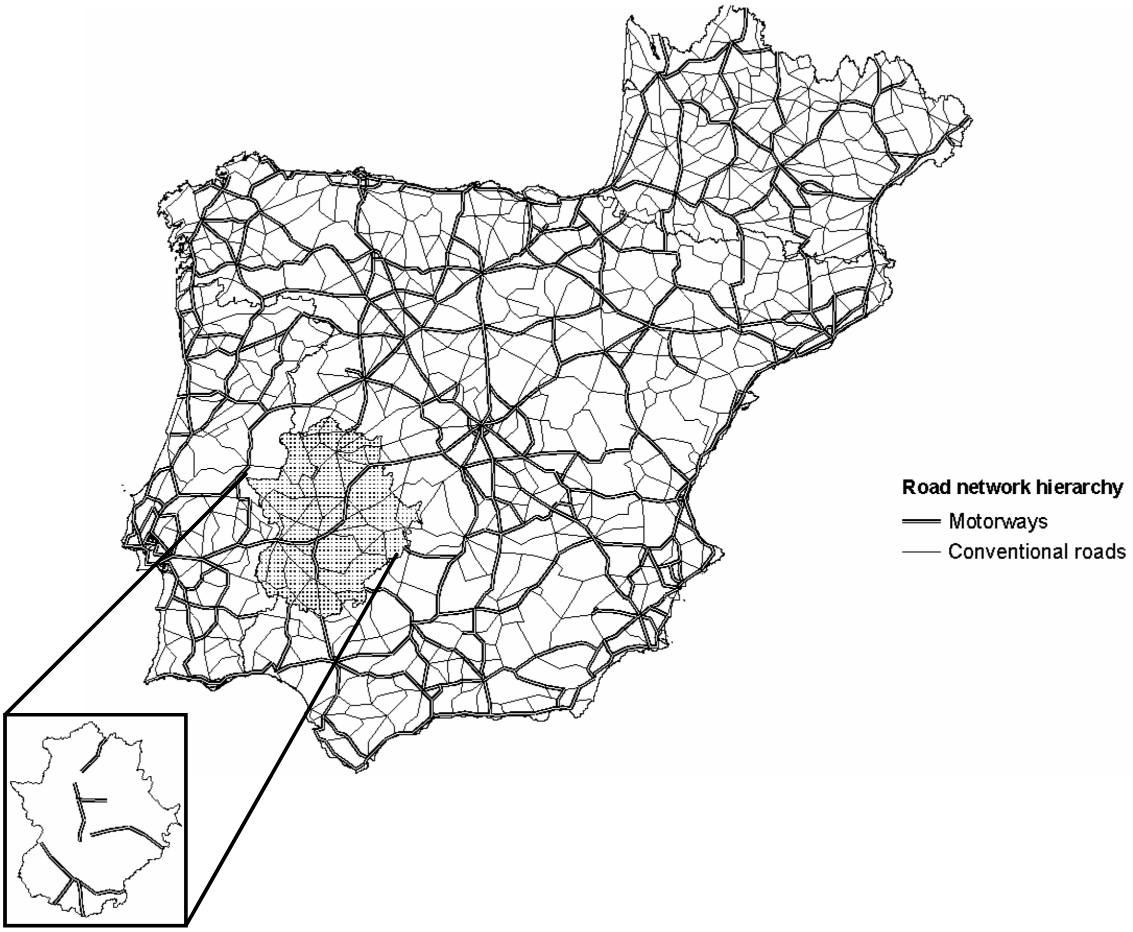

Figure 3. The regional extraction method (example of the extraction of the new motorways planned for Extremadura)

The difference in accessibility gains between the ex-post (PEIT) scenario and the scenario simulating the extraction method of region *i* gives a good approximation of the accessibility gains that these investments produce in all the regions of Spain. Part of these effects are absorbed for the region itself (inner effects), but the rest of the gains correspond to benefits exported to other regions in the form of regional spillovers.

For each of the 17 scenarios, the study area was divided into 815 transport zones with their respective centroids. This large number of zones was justified because accessibility indicators were more accurate and realistic than if other aggregated spatial units, such as provinces (47) or regions (15), had been used. Besides, it was necessary to correct the problem known as self-potential - which refers to how much the internal accessibility of each zone contributes to total accessibility - discussed in Bruinsma and Rietveld (1993) and Frost and Spence (1995). If not corrected, self-potential problems can bias the results of accessibility measures, most strongly in zones that are highly populated or have a large area.

Once the GIS model has been stored in a database, calculating the economic potential accessibility indicator is relatively straightforward. First, it is necessary to calculate the minimum paths through the network in order to determine the access time from each node to the different centroids included in the analysis, and then the accessibility indicator for each node can be obtained. Second, some results are interpolated using raster analysis (IDW - inverse distance weighted interpolation).

Thus, comparing the results obtained for the scenarios ex-post (all the investments foreseen in the PEIT) and each of the regional scenarios using the extraction method, it is possible to analyse all accessibility gains, differentiating which part is retained by the region itself (inner benefits) and which is exported to other regions (regional spillover effects) (Annex Table 1). We can see, for example, the regional spillovers measured in potential units produced by the construction of the motorways in Extremadura. As expected, the greatest economic potential gains correspond to the region itself, ie inner benefits (7261 economic potential units). However, there are also significant spillovers in other neighbouring regions, such as Andalusia (2311), Castilla y León (1017) and Castilla–La Mancha (788). The regional spillovers on farther regions of Spain are almost negligible, for example, Catalonia (19) and Aragón (58). Annex Table 1 also shows that the regional distribution of spillover effects is clearly asymmetric. For example, the foreseen investments in Andalusia increases the economic potential in Asturias by 195 units , whereas the road investments made in Asturias increases the economic potential in Andalusia by only 1 unit.

4. Regional Spillovers and Territorial Cohesion

This section analyses the results obtained by the aforementioned methodology from the perspective of territorial cohesion using inequality indices. Thus, a comparison between the regional scenarios with respect to both scenarios - ex-ante and ex-post - will be made in order to evaluate whether the motorway investments in each region contribute positively to the aim of territorial cohesion in Spain. This exercise belongs to the literature of territorial cohesion because the effects are measured by accessibility indices, extending the analysis beyond simple economic measures that do not take into account important regional spillovers.

We did not develop a specific methodology to quantify accessibility disparities. Rather, we calculated and compared different inequality measures frequently used in the income inequality literature (Cowell, 1995), using the following inequality indicators: Gini, Atkinson (0.5), Theil (0) and the coefficient of variation of the accessibility indicator that has been calculated in the previous section for all seventeen types of scenarios.

Table 1 presents the inequality accessibility indices. (Because the indices are well known, we are going to omit discussion of their basic characteristics and their mathematical representation.) These indices may be considered a policy tool for comparing the evolution of regional accessibility disparities in the different scenarios analysed. Their use will allow planners to discuss whether the impacts of the PEIT and individual regional investments serve to reduce or increase regional accessibility disparities. The reason to choose different inequality indicators for all the scenarios is twofold. First, it is well known that some inequality indices are quite sensitive to the presence of outliers in the distribution, so the analysis is more robust if we use different indices. Second, we study the economic potential differences associated with the different scenarios under analysis, in order to study the complexities of regional spillovers.

From table 1 we can conclude that regional cohesion will be achieved after the completion of the PEIT. It can be seen that all inequality indices are lower in the PEIT scenario. This result is consistent with the master plan, an objective of which is completion of the national interurban motorways in a way that makes more eastern and western links, favouring spatial interaction of the nodes without considering the hierarchy of Madrid. The Spanish national motorway system was based on the central location of the nation’s capital, and most links of the national motorway system pass through Madrid. However, PEIT was developed with the assumption that the grid of the existing centre-periphery axis would be completed. In summary, it can be concluded that PEIT’s overall performance on accessibility is very successful.

Scenarios (extraction method)	Gini	Atkinson (0.5)	Theil (0)	Coefficient of variation
Ex-ante (without plan)	0.0780	0.0057	0.0118	0.1601
Ex–post (PEIT 2020)	0.0764	0.0053	0.0110	0.1532
Andalusia	0.0774	0.0054	0.0112	0.1545
Aragón	0.0759	0.0053	0.0110	0.1537
Asturias	0.0769	0.0054	0.0111	0.1539
Cantabria	0.0768	0.0054	0.0111	0.1538
Castilla–La Mancha	0.0753	0.0052	0.0108	0.1524
Castilla y León	0.0772	0.0055	0.0113	0.1554
Catalonia	0.0756	0.0052	0.0108	0.1524
Extremadura	0.0781	0.0055	0.0113	0.1554
Galicia	0.0773	0.0054	0.0112	0.1544
La Rioja	0.0764	0.0053	0.0110	0.1534
Madrid	0.0764	0.0053	0.0110	0.1532
Murcia	0.0766	0.0053	0.0110	0.1536
Navarra	0.0767	0.0054	0.0110	0.1539
Basque Country	0.0765	0.0053	0.0110	0.1532
Valencia	0.0759	0.0053	0.0109	0.1531

Table 1. Accessibility inequality indices

Focusing on the partial scenarios for each region (the extraction method), the results show that regional cohesion for all the hypothetical scenarios is improved when the comparison is done with respect to the scenario of the PEIT without any investment in a specified region. In other words, if the investments of a particular region could not be foreseen, the regional cohesion would be improved independently from the rest of investments. However, this situation is not so uniform when the comparison is done with respect to the scenario of the complete PEIT. It is not surprising that extraction scenarios are better in terms of equity for these particular regions: Aragón, Castilla–La Mancha, Catalonia and Valencia (each of their individual figures is lower than the figure in the Ex–post [PEIT] row). It is clear that the PEIT investments favour the most accessible territories, with the exception of Madrid. The extraction of Madrid, the

Basque Country and La Rioja is almost negligible because the investment in these regions called for by the PEIT is really low.

5. Interaction of Regional Spillovers and Territorial Cohesion

The results in Section 4 allow policymakers and planners to evaluate globally the effects of each regional transport investment on territorial cohesion. However, the interaction between the individual regional spillovers and territorial cohesion is not well resolved. In this section, a further step is presented to analyse the individual behaviour of regional spillovers in terms of territorial cohesion. This analysis uses an innovative approach: studying individual regional spillovers according to their direction: upstream effects (when regional spillovers move towards less accessible regions – periphery to more accessible regions – core) and downstream effects (the opposite direction).

5.1 Regional Spillovers: Core and Periphery Effects

In this section, the direction of all the regional spillovers is analysed according to when the accessibility gains are produced in less accessible regions by investments in more accessible regions (downstream effects). The opposite direction is considered as the upstream effects, which are characterised by investments in less accessible regions which produce accessibility gains in more accessible regions. These regional spillovers can be named ‘periphery-core’ or ‘core-periphery’ effects. For these terms, the convention of location analysis has been followed, where the core consists of the most accessible regions in terms of economic potential, and the periphery consists of the complementary set. To differentiate the regional spillovers in these two categories, without loss of generality, we consider the downstream regional spillovers as positive because for territorial cohesion these values are preferred. Analogously, the values of upstream regional spillovers are considered negative. As we are only analysing the effects of regional spillovers on territorial cohesion, the values of the inner effects are changed to zero. Thus, Annex Table 2 shows the regional spillovers according to the direction of accessibility gains measured in potential units.

Table 3 shows that downstream effects (61.1%) are greater than upstream effects (38.9%). The average value and the asymmetry coefficient are also positive. Thus, we can conclude that regional spillover interaction points in the direction of territorial cohesion. This conclusion is similar to the one previously obtained in the literature. It is also coherent with the asymmetric behaviour of accessibility when this is studied by a gravity economic potential indicator (Figure 4). Bruinsma and Rietveld (1998) and Gutiérrez (2001) showed that when there is an improvement in the transport connection between two regions, the less accessible region is the one which is more favoured by this improvement as larger markets are closer to the latter region.

Average	106.2
Median	-0.1
Standard deviation	995.7
Coefficient of variation	937.7
Coefficient of asymmetry	2.3
Maximum	5505
Minimum	-3339
Downstream effects	61411.1 (61.1%)
Upstream Effects	-39113.7 (38.9%)

Table 3. Accessibility regional spillovers: Up- and downstream effects

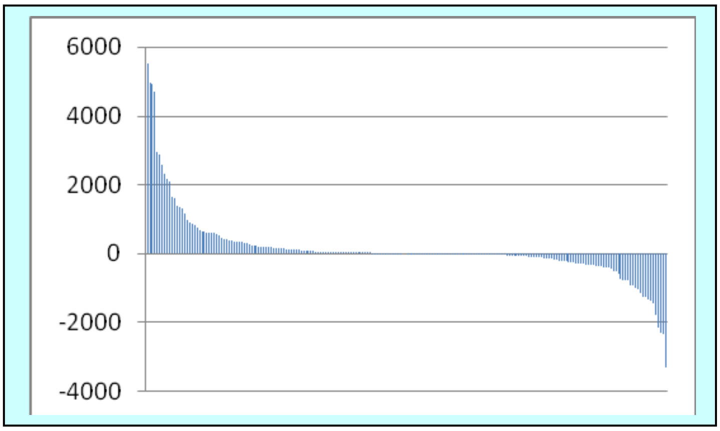

Figure 4. Distribution of accessibility regional spillovers: Up- and downstream effects

6. Summary and Conclusions

The notion of territorial cohesion was clearly established at the European level after its appearance in the proposed EU Constitution. In Spain, the PEIT recognized the necessity of reducing the gaps in opportunity among all the regions, bringing the outlying parts of the Spanish territory closer to the central backbone of the nation (Madrid-Barcelona-Valencia).

The Third Cohesion Report was the first attempt to shed some light on and extend the concept of territorial cohesion beyond the borders of social and economic cohesion. Hamez (2005) concluded that territorial cohesion studies should treat this concept broadly and should not be reduced to the analysis of the regions facing economic weaknesses or specific geographical limitations.

In this paper, we have used the suggestions proposed by Hamez in our extraction method in order to analyse the state of territorial cohesion in Spain after implementation of the transport master plan in 2020. We have studied how the interaction of regional spillovers affects territorial cohesion, measuring it by the gains in accessibility. Two characteristics of Hamez's recommendations are part of our methodology:

1. A territorial dimension (815 transport zones) has been used to measure both accessibility gains with respect to the status quo scenario - no plan - for 16 different scenarios (extraction method for each region and the whole plan) and to what extent the regional spillover is part of downstream effects.
2. A temporal dimension has been used out of concern not just with present disparities but also the likely changing relative situation. In this case, we have studied the temporal dimension, comparing the present situation (ex-ante without any investment of the plan), the likely changing relative situation produced by the whole transport master plan (ex-post scenario) and 15 individual regional situations without foreseen investments,.

To calculate regional spillovers derived from the PEIT 2005–2020, we employ the familiar extraction method to estimate region-specific spillovers, which are based on the comparison of the accessibility gains for all the scenarios listed in item 2 above. This approach allows us to estimate the marginal contribution for each region. Our empirical results, obtained from using a more general regional approach based on accessibility measures suggest, that regional spillovers account for a significant figure in all the cases.

The analysis of the partial scenarios for each region (the extraction method) has shown that regional cohesion for all the hypothetical scenarios is improved when the comparison is done with respect to the ex-ante scenario – no plan. If the investments in infrastructure could not be built in a particular region, regional cohesion would be improved by the rest of the investments. However, this situation is not so uniform when the comparison is done with respect to the scenario of the complete PEIT. It is not surprising that extraction scenarios favouring the most accessible territories are better in terms of equity for their respective regions..

We have shown that downstream effects (61.1%) are greater than upstream effects (38.9%). We also conclude that regional spillover interaction points in the direction of territorial cohesion. This conclusion is similar to the one which was obtained by the analysis of disparities on accessibility for all the different scenarios.

Although our results on regional spillovers are interesting in themselves, they may be used to show why previous literature has been so elusive, partly due to the difficulties behind models that treat regional spillovers as the effects of public capital with aggregated variables at the regional level. This literature has typically failed to affirm the importance of regional spillovers. This oversight is explained by the fact that past research has largely ignored or confounded spillover effects. Indeed we suggest that for future research, GIS technology can be used to overcome some of the difficulties of previous works, which are based on the lack of good and reliable data.

On a different level, promising future research on regional spillovers and territorial cohesion can address the role of the demarcation area, the size of transport areas and the parameter used in the impedance function of the gravitational model to explain robustness or differences of results.

Acknowledgements
This research has been financed by the META (CEDEX, Ministerio de Fomento) project and the TRANSPORTRADE (Comunidad de Madrid) project.

References

Aschauer, A.D. (1989). Is public expenditure productive? *Journal of Monetary Economics*, vol. 23, no. 2, pp. 177–200.

Banister, D. and Berechman, J. (2000). *Transport Investment and Economic Development*. University College Press, London.

Boarnet, M.G. (1998). Spillovers and the locational effects of public infrastructure. *Journal of Regional Science*, vol. 38, pp. 381–400.

Bruinsma, F.R. and Rietveld, P. (1993). Urban agglomerations in European infrastructure networks. *Urban Studies*, vol. 30, pp. 919–934.

Bruinsma, F.R. and Rietveld, P. (1998). The accessibility of European cities: theoretical framework and comparison approaches. *Environment and Planning A*, vol. 30, 449–521.

Cantos, P., Gumbau-Albert, M. and Maudos, J. (2005). Transport Infrastructures, Spillover Effects and Regional Growth: Evidence of the Spanish Case. *Transport Reviews*, vol. 25, no. 1, 25–50.

Commission of the European Communities (CEC) (1998). Communication from the Commission: Cohesion and Transport COM (1998) 806 final, Brussels.

Commission of the European Communities (CEC) (2004). *A new partnership for cohesion: convergence, competitiveness, cooperation: Third Report on Economic and Social Cohesion*. Luxembourg, Office for Official Publications of the European Communities: Brussels.

Commission of the European Communities (CEC) (2009). Green Paper. TEN-T: A policy review. Towards a better integrated transeuropean transport network at the service of the common transport policy. COM (2009) 44 final, Brussels.

Conference of the Representatives of the Governments of the Member States 2004 (2004). Treaty establishing a constitution of Europe (CIG 87/2/04): Brussels.

Cowell, F. (1995). *Measuring Inequality*. 2nd ed. London: Prentice-Hall.

Davoudi, S. (2004). Territorial cohesion: An agenda that is gaining momentum. *Town and Country Planning*, vol. 73, no. 7/8, 224–227.

Davoudi, S. (2005). Understanding territorial cohesion. *Planning Practice and Research*, vol. 20, no. 4, pp. 433–441.

Dietzenbacher, E., van der Linden, J.A. and Steenge, A.E. (1993). The regional extraction method: EC input-output comparisons. *Economic Systems Research*, vol. 5, no. 2, pp. 185–206.

Dundon-Smith, D.M. and Gibb, R.A. (1993). The regional impact of the Channel Tunnel: A return to potential analysis. *Geoforum*, vol. 24, no. 2, 183–192.

Ezcurra R., Gil, C., Pascual, P. and Rapun, M. (2005). Public capital, regional productivity and spatial spillovers. *Annals of Regional Science*, vol. 39, no. 3, pp. 471–494.

Faludi, A. (2004). Territorial cohesion: Old (French) wine in new bottles? *Urban Studies*, vol. 41, no. 7, pp. 1349–1365.

Forslund, U.M. and Johansson, B. (1995). Assessing road investments: accessibility changes, cost benefit and production effects. *The Annals of Regional Science*, vol. 29, pp. 155–174.

Frost, M.E. and Spence, N.A. (1995). The rediscovery of accessibility and economic potential: The critical issue of self-potential. *Environment and Planning A*, vol. 27, pp. 1833–1848.

Grant-Muller, S., Mackie, P., Nellthorp, J. and Pearman, A. (2001). Economic appraisal of European transport projects: The state-of-the-art revisited. *Transport Reviews*, vol. 21, no. 2, pp. 237–261.

Gutiérrez, J. (2001). Location, economic potential and daily accessibility: An analysis of the accessibility impact of the high-speed line Madrid-Barcelona-French border. *Journal of Transport Geography*, vol. 9, no. 4, 229–242.

Gutiérrez, J., Condeço, A. and Martín, J.C. (2010). Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. *Journal of Transport Geography*, vol. 18, no. 1, pp. 141–152.

Hamez, G. (2005). Territorial cohesion: How to operationalize and measure the concept? *Planning Theory and Practice*, vol. 6, no. 3, pp. 400–402.

Holtz-Eakin, D. (1994). Public sector capital and productivity puzzle. *Review of Economics and Statistics*, no. 76, pp. 12-21.

Holtz-Eakin, D. and Schwartz, A.E. (1995). Spatial productivity spillovers from public infrastructure: Evidence from state highways. *International Tax and Public Finance*, vol. 2, pp. 459–468.

Hulten, C.R. and Schwab, R.M. (1991). Public capital formation and the growth of regional manufacturing industries. *National Tax Journal*, vol. 44, pp. 121–134.

López, E., Gutiérrez Puebla, J. and Gómez, G. (2008): Measuring regional cohesion effects of large-scale transport infrastructure investments: An accessibility approach. *European Planning Studies*, vol. 16, no. 2, pp. 277–301.

Mamatzakis, E.C. (1999). Testing for long run relationship[[Au: Perhaps 'a long run relationship' or 'long run relationships'?]] between infrastructure and private capital productivity: A time series analysis for the Greek industry. *Applied Economics Letters*, vol. 6, pp. 243–246.

Martín, J. C., Gutiérrez, J. and Román, C. (2004). Data envelopment analysis (DEA) index to measure the accessibility impacts of new infrastructure investments: The case of the high-speed train corridor Madrid-Barcelona-French border. *Regional Studies*, vol. 38, no. 6, 697–712.

Martín, J.C., Gutiérrez, J. and Román, C. (2007). Accessibility impacts of European TENs railway network. In Van Geenhuizen, M., Reggiani, A. and Rietveld, P. (eds.), *Policy Analysis for Transport Networks*. Ashgate, Aldershot.

Mas, M., Maudós, J., Pérez, F. and Uriel, E. (1996). Infrastructures and productivity in the Spanish regions. *Regional Studies*, vol. 30, no. 7, 641–649.

Ministerio de Fomento (2004). *Plan Estratégico de Infraestructuras y Transporte 2005-2020*. Madrid, Ministerio de Fomento.

Moomaw, R.L. and Williams, M. (1991). Total factor productivity growth in manufacturing: Further evidence from the states. *Journal of Regional Science*, vol. 31, no. 1, pp. 17–34.

Moreno, R., Artís, M., López-Bazo, E. and Suriñach, J. (1997). Evidence on the complex link between infrastructure and regional growth. *International Journal of Development Planning Literature*, vol. 12, pp. 81–108.

Munnell, A.H. (1992). Policy watch: Infrastructure investment and economic growth. *Journal of Economic Perspectives*, vol. 6, no. 4, pp. 189–198.

Nijkamp, P., Rietveld, P. and Salomon, I. (1990). Barriers in spatial interactions and communications: A conceptual exploration. *The Annals of Regional Science*, vol. 24, no. 4, pp. 237–252

Ozbay, K., Ozmen-Ertekin, D. and Berechman, J. (2003). Empirical analysis of the relationship between accessibility and economic development. *Journal of Urban Planning and Development*, vol. 129, no. 2, 97–119.

Ozbay, K., Ozmen-Ertekin, D. and Berechman, J. (2006). Modeling and analysis of the link between accessibility and employment growth. *Journal of Transportation Engineering*, vol. 132, no. 5, pp. 385–393.

Ozbay, K, Ozmen-Ertekin, D. and Berechman, J. (2007). Contribution of transportation investments to county output. *Transport Policy*, vol. 14, pp. 317–329.

Pereira, M.A. and Roca-Sagalés, O. (2003). Spillover effects of public capital formation: Evidence from the Spanish regions. *Journal of Urban Economics*, vol. 53, pp. 238–256.

Puga, D. (2002). European regional policies in light of recent location theories. *Journal of Economic Geography*, vol. 2, pp. 373–406.

Schön, P. (2005). Territorial cohesion in Europe? *Planning Theory and Practice*, vol. 6, no. 3, pp. 389–400.

Schürman, C., Spiekermann, K. and Wegener, M. (1997). Accessibility indicators. Berichte aus dem Institut für Raumplanung vol. 39, IRPUD, Dortmund.

Vickerman, R.W., Spiekermann, K. and Wegener, M. (1999). Accessibility and economic development in Europe. *Regional Studies*, vol. 33, no. 1, 1–15.

Wegener, M. and Bökemann, D. (1998). The SASI model: Model structure. Institut für Raumplanung, Universität Dortmund. *Berichte aus dem Institut für Raumplanung*, vol. 40.
http://www.srf.tuwien.ac.at/Projekte/sasi/sasi.htm

Annex Table 1. Accessibility spillover matrix (in potential units)

From \ To	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castilla y León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Basque Country	Valencia	Produced benefits
Andalusia	4271	94	195	162	1051	354	135	2871	197	144	371	941	105	137	520	11549
Aragón	196	7773	419	902	796	608	1479	310	156	2296	809	958	4705	2350	2189	25947
Asturias	1	9	1285	353	3	29	6	2	838	17	4	1	27	181	2	2760
Cantabria	22	3	114	2996	44	248	0	54	8	11	67	18	1	79	12	3677
Castilla-La Mancha	1317	817	344	119	9490	754	473	1653	271	192	1175	2554	149	115	2164	21586
Castilla y León	429	2945	2079	4921	1280	7957	1379	1601	1284	5505	1792	327	4961	1363	393	38215
Catalonia	101	1355	135	216	294	187	4494	183	71	337	413	337	583	358	628	9691
Extremadura	2311	58	624	547	788	1017	19	7261	510	368	300	361	158	435	329	15087
Galicia	9	22	1292	400	25	324	12	27	2475	115	34	13	96	220	13	5077
La Rioja	6	85	40	26	3	291	29	31	47	1470	7	1	664	23	1	2724
Madrid	4	23	13	19	230	62	8	59	9	2	27	19	0	12	24	512
Murcia	602	220	10	11	228	18	300	31	8	72	35	5180	131	38	763	7647
Navarra	18	287	218	415	67	173	274	28	34	3339	86	34	4248	937	101	10259
Basque Country	11	16	0	1	17	109	0	27	16	153	42	4	74	354	5	829
Valencia	29	1143	51	156	281	114	203	44	27	586	131	534	595	354	3885	8133
Received benefits	9327	14852	6819	11243	14596	12247	8811	14183	5951	14607	5294	11282	16496	6958	11028	163693

Source: Gutiérrez *et al.*, 2010.

Annex Table 2. Accessibility spillover matrix (in potential units): Up and downstream effects

From \ To	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castilla y León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarra	Basque Country	Valencia
Andalusia	0	-94	195	-162	-1051	-354	-135	2871	197	-144	-371	-941	-105	-137	-520
Aragón	196	0	419	902	-796	-608	-1479	310	156	2296	-809	958	4705	-2350	-2189
Asturias	-1	-9	0	-353	-3	-29	-6	-2	838	-17	-4	-1	-27	-181	-2
Cantabria	22	-3	114	0	-44	-248	0	54	8	-11	-67	-18	-1	-79	-12
Castilla-La Mancha	1317	817	344	119	0	754	-473	1653	271	192	-1175	2554	149	115	2164
Castilla y León	429	2945	2079	4921	-1280	0	-1379	1601	1284	5505	-1792	327	4961	-1363	-393
Catalonia	101	1355	135	216	294	187	0	183	71	337	-413	337	583	358	628
Extremadura	-2311	-58	624	-547	-788	-1017	-19	0	510	-368	-300	-361	-158	-435	-329
Galicia	-9	-22	-1292	-400	-25	-324	-12	-27	0	-115	-34	-13	-96	-220	-13
La Rioja	6	-85	40	26	-3	-291	-29	31	47	0	-7	1	664	-23	-1
Madrid	4	23	13	19	230	62	8	59	9	2	0	19	0	12	24
Murcia	602	-220	10	11	-228	-18	-300	31	8	-72	-35	0	-131	-38	-763
Navarra	18	-287	218	415	-67	-173	-274	28	34	-3339	-86	34	0	-937	-101
Basque Country	11	16	0	1	-17	109	0	27	16	153	-42	4	74	0	-5
Valencia	29	1143	51	156	-281	114	-203	44	27	586	-131	534	595	354	0

Source: Own elaboration

2.3 INFLUENCE OF FRICTION OF DISTANCE IN MEASURING THE MARKET POTENTIAL AND THE SPATIAL SPILLOVERS OF TRANSPORT INFRASTRUCTURE

Condeço-Melhorado, A., Gutiérrez, J. y García-Palomares, J.C.: Influence of friction of distance in measuring the market potential and the spatial spillovers of transport infrastructure. Sent to ***The Annals of Regional Science***

This work was carried out as part of the HESTEPIT project (tool for the assessment of the social, territorial and economic effects of transport infrastructure plans. Assessment of the PEIT - TRA2007-63564), financed by the MICINN (national R+D plan). The primary objective of this project is to analyse the effects resulting from the construction of the infrastructure proposed in the PEIT on the territorial, economic and social system, as well as to develop an interactive tool to assess the long-term effects of transport infrastructure plans in Spain.

The preliminary results of the work were presented and discussed at the 55th Annual North American Conference of the Regional Science Association International. (NARSC) held in New York in 2008 (Condeço-Melhorado, et al., 2008d), and at the 12th Spanish American Conference on Geographic Information Systems in San José de Costa Rica in 2009 (Gutiérrez, et al., 2009).

The main aim of the work is to assess the sensitivity of the results obtained in measuring spillovers in relation to variations in the exponents representing the friction of distance in the market potential indicator. The results of this indicator can vary significantly depending on the value of the distance exponent used. High values for this parameter attribute greater weight to the relations over short distances and represent situations in which the friction of distance effect is high (transport costs significantly affect economic flows). Spillovers can thus be expected to decrease as the distant exponent increases.

The article analyses the impact of the PEIT on accessibility and spillovers. In the first place it assesses the effect of varying the exponent’s value on market potential. This is done by measuring accessibility in scenarios with and without the PEIT, using a different value of the exponent each time. A study of the accessibility after the PEIT reveals that an increase in the exponent’s value reduces regional economic potential due to the fact that transport costs have greater weight and the markets assume a more local character. However this reduction is not equal in all the autonomous regions. Regions with an important internal market (self-potential) undergo a lower reduction, thus leading to an increase in the differences between the central regions –which have more powerful internal markets–, and the peripheral regions. Another effect is that as the exponent's value increases, the changes in accessibility affect fewer territories, but become more intense near the new motorways, thus conferring greater benefits on the regions near this infrastructure.

As with market potential, spillovers decrease as the distance exponent increases. Sensitivity to the changes in the exponent was tested on spillover matrices in both potential and in monetary units. The results show that with higher exponents the internal benefits increase and spillovers are reduced. This reduction is greater in the more distant regions. However in the case of monetarised spillovers, the changes due to the use of different exponents are very mild compared to those observed in the spillover matrix in market potential units. This greater stability in the case of monetarised spillovers is primarily due to the methodology used for converting the spillovers into euros. The sum of the benefit retained and the exports for each region is always the same, although the distance exponent may change; whereas the market potential for each region varies drastically with an increase in the exponent. Moreover, the general trend of the spillover flows between regions tends to remain stable: the regions which benefit most remain the same, although the magnitude of the spillovers may vary.

The selection of the distance exponent is important and must be justified in accordance with the aims of the study. The value of the exponent was therefore calculated based on the data for interregional commerce in tons and in euros, obtaining values of 1.97 and 1.33 respectively. This difference is explained by the fact that in the economic space there are many low-value movements of goods over short distances, whereas high-value goods are moved over greater distances. In the study of the impact of transport infrastructure from the standpoint of goods mobility, the gravity models must be calibrated with data for tons transported; however from the perspective of access to the markets, it is indisputable that the most relevant calibration is obtained with monetary units.

INFLUENCE OF DISTANCE DECAY ON THE MEASUREMENT OF MARKET POTENTIAL AND THE SPILLOVER EFFECT OF TRANSPORT INFRASTRUCTURE

Ana Margarida Condeço-Melhorado[a]

Javier Gutiérrez [b]

Juan Carlos García-Palomares [c]

(a) Departamento de Geografía Universidad de Alcalá Calle Colegios, 2. 28801 Alcalá de Henares (Spain) ana.condeco@alu.uah.es

(b) Departamento de Geografía Humana Facultad de Geografía e Historia Universidad Complutense de Madrid Calle Profesor Aranguren, s/n 28040 Madrid (Spain) javiergutierrez@ghis.ucm.es

(c) Departamento de Geografía Humana Facultad de Geografía e Historia Universidad Complutense de Madrid Calle Profesor Aranguren, s/n 28040 Madrid (Spain), jcgarcia@ghis.ucm.es

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 envisaged in transport plans. However, the results of this indicator are influenced by the distance exponent value, representing the effect of distance decay on economic flows. This study analyses how variation in the distance exponent affects the results obtained, with respect to both the measurement of market potential and spatial spillovers. 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. Finally, 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; as predicted, a much higher exponent is obtained in the first case than in the second.

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

1. Introduction

In transport planning, accessibility analyses have gradually gained ground for assessing impacts associated with projects involving transportation (see, for example, Lineker and Spence, 1992a, 1992b; Dundon-Smith and Gibb, 1993; Gutiérrez and Urbano, 1996; Gutiérrez and Gómez, 1999; Halden, 2003; López et al., 2008). The advent of Geographical 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. 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.

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 the spatial spillover effect. This can be defined as the impact on a region of construction or infrastructural improvement carried out in other regions. These 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, which, as already mentioned, is highly sensitive to the distance exponent, is particularly appropriate for this. This study analyses the influence of the distance exponent on the results of the market potential analysis and the spillovers generated by transport infrastructure.

The study 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 economic potential indicator. Section 3 focuses on spatial spillovers and their measurement. Section 4 presents a methodology for analysing the spillover effect through accessibility indicators and GIS, while Section 5 shows the results of the sensitivity analysis and calibration of the distance exponent value, using data from commodity flows. The last section, Section 6, summarises the final considerations.

2. The market potential indicator and distance exponent.

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 (see, for example, Bruinsma and Rietveld, 1998; Muhammad et al., 2008). 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:

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

where P_i is the market or economic potential of the location *i*, *Mj* 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 (available opportunities) 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.)

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 (Haynes and Fotheringham, 1984). High values imply strong resistance to movement between one place and another, with 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 (such as building materials) are transported over short distances within small market areas; in contrast, when goods have a high value and low weight and volume (for example, electronic material) resistance to movement is reduced and, as a result, commercial relations are established over much greater distances, even worldwide. The transferability of different types of goods has for a long time been studied by calibrating the distance exponent from commodity flow data (see, for example, Black, 1972).

Where passenger transport is concerned, variation of the distance exponent depends on different factors (Geurs and Ritsema van Eck, 2001), 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 (Eldridge and Jones, 1991; Fotheringham, 1983).

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 and b) on the role of public capital in the productivity of private capital. Various studies (for example, Munell, 1990 and 1992; Mas et al., 1994; Pereira and 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 greater in analyses using data with lower levels of spatial disaggregation, which would be attributable to spatial spillovers, that is, to the spillover effect between regions. Thus, when the level of spatial disaggregation is reduced (larger sized spatial units), there is a increase in the magnitude of the coefficient associated with public capital (elasticity of the production function). 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 (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 (Laird Nellthorp and Mackie, 2005): 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, some authors include not only the infrastructure of a particular region but also that of adjacent regions, inasmuch as they are spaces that generate spatial spillovers (Mas et al., 1994). 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 the result of a comparison of the plan scenario that includes all motorways envisaged within the time frame of the plan with the plan scenario excluding those roads envisaged for the region under analysis, which would retain the road network that existed prior to the plan (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 (market potential). 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 to analyse input-output tables in order to know the effect of each region on the multi-regional model (Dietzenbacher, van der Linden and Steenge, 1993).

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.

4. Data and methodology

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. 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 transit time. Estimation of speed depends on the type of road: 120 km/h for toll motorways, 110 km/h for other motorways, 90 km/h for national roads, 80 km/h for secondary roads and 50 km/h for roads in urban areas. 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 its islands (the Balearics and the Canaries). 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.

The criteria followed in this process entailed the creation of compact zones of uniform size which respected natural barriers. The transport zones of the bordering countries, Portugal and France, where such precise delimitation was not necessary, correspond to the *concelhos* and *departments* respectively.

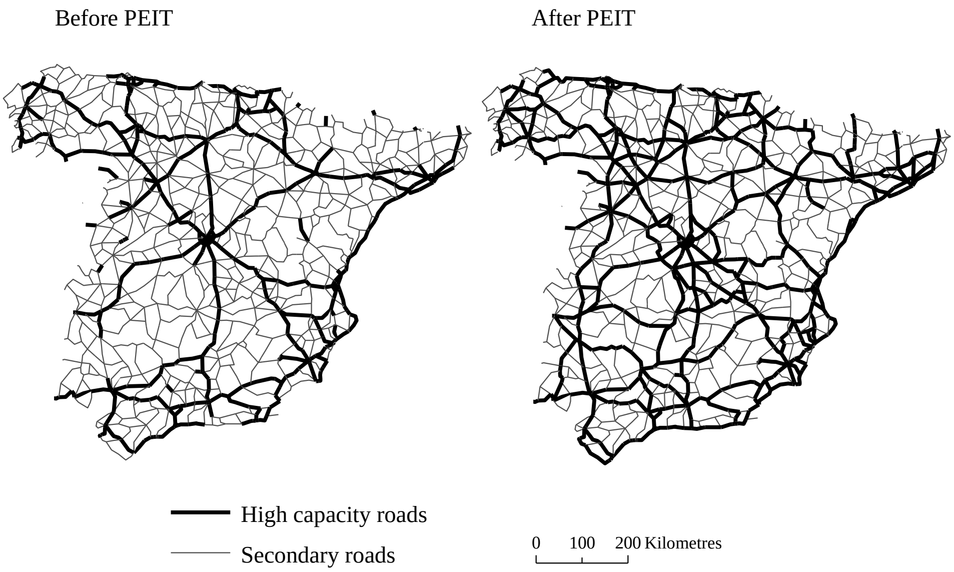

Figure 1: Motorway network before and after the Plan

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). One drawback of working with small transport zones instead of provinces is that fewer socio-economic variables are available; a considerable amount of information is available at provincial level but relatively little at municipal level (socio-economic data on transport zones comes from an aggregation of municipal data). The reason a variable as simple as population has been used as a proxy for final markets in the calculation of economic potential 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 (because there are more centroids) and mitigates the problem of calculating self-potential (Bruinsma and Rietveld, 1993; Frost and Spence, 1995). Self-potential, defined as the contribution of the internal accessibility of each zone to its total accessibility, is reduced when the size of the zones decreases.

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 provided by surveys on urban mobility). 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:

$$tij = ti + tnij + tj \tag{2}$$

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 (hub-and-spoke movements).

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:

$$SE_{xi} = A_{iP_i} - A_{iP_{x0}} \tag{3}$$

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:

$$S_{ij} = \frac{\sum_k s_{kij} p_{kj}}{\sum_k p_{kj}} \tag{4}$$

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 3) 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:

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

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. Results of sensitivity analyses

Sensitivity analyses are used to evaluate whether small changes in the input variable significantly alter the results obtained in a model (Malczewski, 1999). This study tests the robustness of estimations of spillover effects with relation to the distance exponent value (parameter α in equation 1). Prior to this, the results of the potential accessibility indicator are also analysed for robustness as these can help to interpret any changes in the spillovers; this entails repeating the calculation process several times, on each occasion using a different exponent value, while other parameters are kept fixed.

5.1 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 1 shows the descriptive statistics of the distribution of the economic potential indicator according to regions[7], 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 not uniform but it increases the differences in market potential between regions: the greater the exponent, the greater the coefficient of variation.

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

Table 1: Descriptive statistics of the distribution of market potential according to regions

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

[7] Average accessibility is calculated as a weighted average of the economic potential of the different regions, taking population as the weighting factor.

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 2). 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.

	Distance exponent value					
Regions	**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

Table 2: Contribution of self-potential to the total potential of each region (as a percentage)

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).

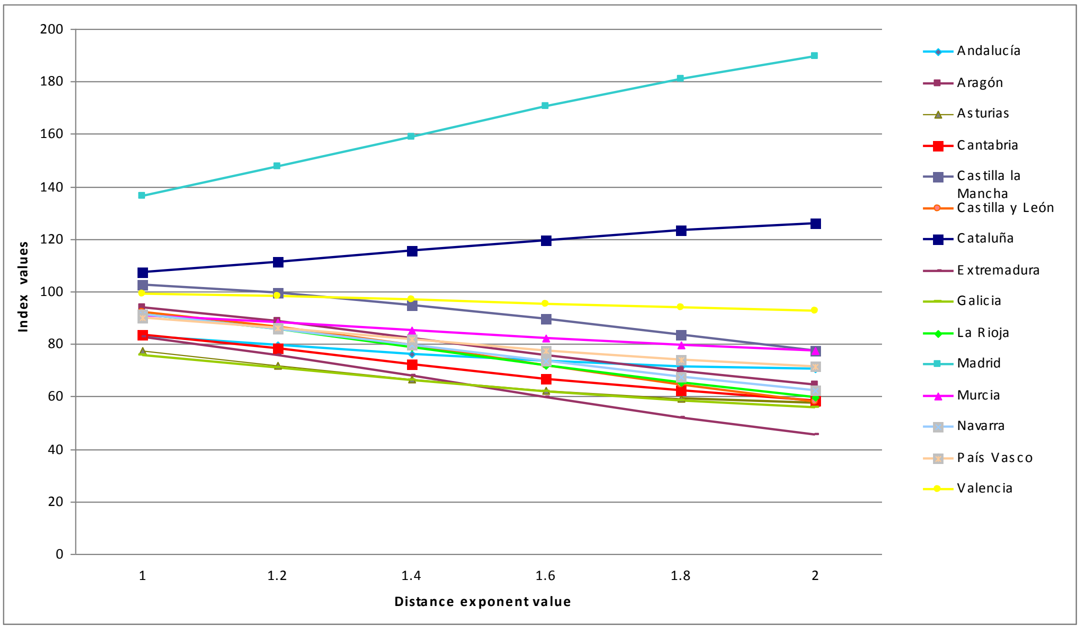

Figure 2: Regional accessibility in the plan scenario in index numbers (average accessibility of peninsular Spain with distance exponent 1 = 100).

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 3). Only between exponents 1 and 1.8 or 1 and 2 does the coefficient of determination fall below 0.9.

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.

Table 3. Coefficient of determination matrix (r2) of market potential averages according to region *

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 (the contribution of self-potential to the total potential of the region).

- 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.

5.2 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 (shown in black on the maps). 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.

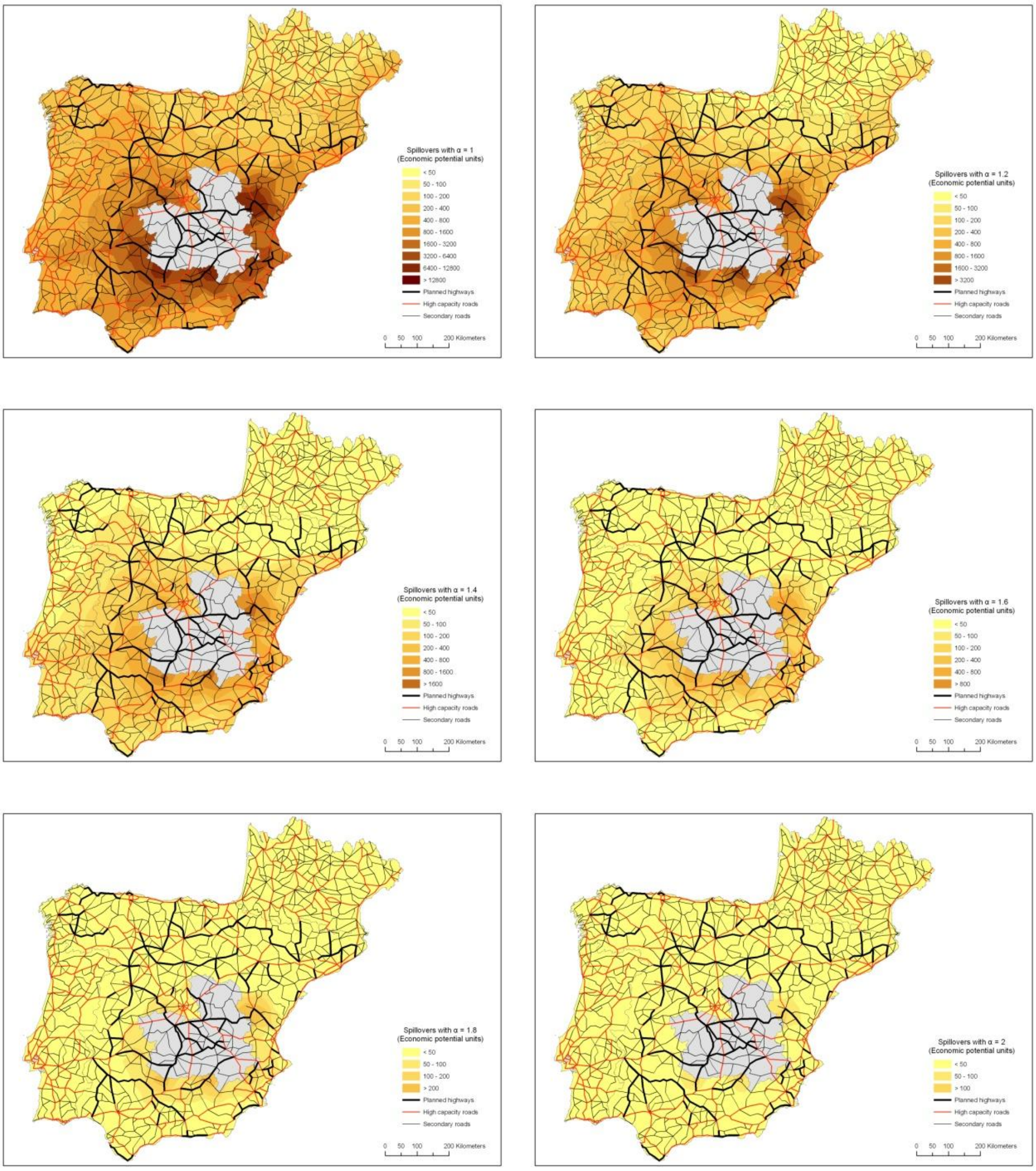

Figure 3: Spillovers, in units of economic potential, generated by new high capacity roads in Castile-La Mancha, considered with different distance exponent values (high capacity roads envisaged in the PEIT are shown by thick lines).

Using the process explained in Section 4, spillover matrices based on these results were constructed in potential units and monetary units. Tables 3 and 4 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 3 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 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 Tables 3 and 4 (exponents 1 and 2). The use of a higher exponent increases internal benefits at the same time as spillovers tend to decrease. This diminution 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 (when distances are short). 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 (over short distances) 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:

	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	**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*
Region of 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***

Table 3: 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*	*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***

Table 4 - Spillover matrix (in millions of euros) α=2

- *Analysis of exported spillovers according to region.*- Table 5 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 6), but these changes are very small compared to those observed for market potential (Table 1) or even for spillovers in units of potential (Figure 3). This greater stability is largely due to the monetisation procedure used: the sum of the benefit retained and the exports of 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. Moreover, it can be proved from calculating the coefficients of determination between the columns in Table 5 that in relative terms the distribution of spillovers according to region remains quite stable, since the coefficients, which are always very high and significant (Table 7), are always greater than those attained in the analysis of market potential.

Regions	**Exponents**						
	1	**1,2**	**1,4**	**1,6**	**1,8**	**2**	**Direct**
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	18248	17538	16778	16012	15119	32106
% of direct investment	58,9	56,8	54,6	52,3	49,9	47,1	100,0

Table 5: Spillovers exported according to region (in euros).

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

Table 6: Sensitivity analysis: descriptive statistics of the changes in exports from the regions (in euros) according to the increase in the distance exponent value.

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.

Table 7: Coefficients of determination (r2) between exports from the regions according to the distance exponent (Table 5 columns).

- *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 8). 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 9).

-

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

Table 8: Sensitivity analysis based on the spillover matrix in euros (number of cases = 210)

Distance 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

Table 9: Coefficients of determination (r2) between the spillover matrices according to different distance exponents (cell by cell).

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 (short distance relations), 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 9). The greatest amount of exports are those that go to neighbouring regions, regardless of what the distance exponent is.

Selecting the distance exponent is therefore a matter of some importance that 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 (Muhammad, S. et al., 2007; Reggiani and Bucci, 2008). Following this principle, the value of the distance exponent has been calibrated using information on trade between Spanish provinces in the year 2005 (see Llano et al., forthcoming), available in both tons and euros. For this calibration the unconstrained gravity model[8] 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 10).

Distance exponent value	
In tons	1.97
In euros	1.33

Table 10: Calibration of the distance exponent from interprovincial trade data.

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. If exponent 1.33, calibrated from trade in euros, were used, spillover values would be around 55% of total investment (Table 5).

6. Final remarks

The economic potential indicator has been widely used to measure accessibility and evaluate the impacts of plans and projects for transport infrastructure. However, the

8 Flowmap® software was used for this purpose.

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.

In this study a sensitivity analysis was carried out in order to find out to what extent variation in the distance exponent produces changes in spillovers. It was done using a methodology for calculating spillovers based on accessibility analysis and GIS (Gutiérrez et al., 2010). The new motorway programme envisaged in the Spanish Transport Master Plan was used as a study case.

The first step was to calculate the influence of the distance exponent value on the results of the economic potential indicator. The results show that when the values of this parameter 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. This is to some extent consistent with the historical evolution of transport and the differences currently found between different regions of the world: improving a transport system reduces the effect of distance decay, allowing markets to expand and the economic system to function more efficiently (Forslund and Johansson, 1995).

The next step was to assess the sensitivity of monetised spillovers to the distance exponent. The spillover matrices obtained for different exponents show that an increase in the exponent value means more of the investment received by each region is retained and less is exported to other regions. 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 market potential and spillovers. As this analysis 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.

It can therefore 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 are not available in euros and calibration is carried out in tons, the spillover value is underestimated as being about 47% of total investment). The results seem robust, especially when compared to those obtained for market potential: spillovers show moderate variation with changes in the distance exponent value. 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**.**

Acknowledgements

This study has been funded by the Hestepit (TRA2007-63564/MODAL-Ministerio de Ciencia y Tecnología, Spain) and DESTINO (P. 42/08- Ministerio de Fomento) Projects.

References

Aschauer, D. A. 1989a. Is public expenditure productive? Journal of Monetary Economics 23:177-200.

Aschauer, D. A. 1989b. Does public capital crowd out private capital? Journal of Monetary Economics 24:171-188.

Avilés, A., R. Gómez and J. Sánchez (2003): “Capital público, actividad económica privada y efectos desbordamiento: Un análisis por Comunidades Autónomas de los sectores Industria y Construcción en España”, Hacienda Pública Española, 165: 25-51.

Black, W.R. (1972): Interregional commodity flows: some experiments with the gravity mode. Journal of Regional Science, 12, 107-118.

Bruinsma, F., and P. Rietveld. 1993. Urban agglomerations in European infrastructure networks. Urban Studies 30:919-934.

Bruinsma, F., and P. Rietveld. 1998. The accessibility of European cities: theoretical framework and comparison of approaches. Environment and Planning A 30:499-521.

Cantos, P., M. Gumbau-Albert, and J. Maudos. 2005. Transport Infrastructures, Spillover Effects and Regional Growth: Evidence of the Spanish Case. Transport Reviews 25:25-50.

Dietzenbacher, E., van der Linden, J.A. and Steenge, A.E. (1993). The Regional Extraction Method: EC Input-Output Comparisons. Economic Systems Research 5 (2), 185-206.

Dundon-Smith, D.M. and Gibb, R.A. (1993) The regional impact of the Channel Tunnel. A return to potential analysis. Geoforum, 24(2), pp.183-192.

Eldridge, J. D., and J. P. Jones. 1991. Warped space: a geography of distance decay. Professional Geographer 43:500-511.

Forslund, U.M. and Johansson, B. (1995) Assessing road investments: accessibility changes, cost benefit and production effects. The Annals of Regional Science 29, 155-174.

Fotheringham, A. S. 1983. A new set of spatial interaction models: The theory of competing destinations. Environment and Planning A 15:15-36.

Frost, M. E., and N. A. Spence. 1995. The rediscovery of accessibility and economic potential: the critical issue of self-potential. Environment and Planning A 27:1833-1848.

Geurs, K. T., and Ritsema van Eck, J.R. 2001. Accessibility measures: review and applications. Report Number, RIVM report 408 505 006.

Gutiérrez, J. y Urbano, P. (1996): Accessibility in the European Union: the impact of the trans-European road network. Journal of Transport Geography, 4 (1), 15-26.

Gutiérrez, J. and Gómez, G. (1999): The impact of orbital motorways on intra-metropolitan accessibility: the case of the Madrid's M40. Journal of Transport Geography, 7 (1), 1-16.

Gutiérrez, J., A. Condeço-Melhorado, and J. C. Martín (2010): Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. Journal of Transport Geography 18:141-152.

Halden, D. (2003) Accessibility analysis: Concepts and their application to transport policy, program and project evaluation, in: A. Pearman, P. Mackie & J. Nellthorp (Eds) Transport Projects, Programs and Policies: Evaluation Needs and Capabilities (Aldershot: Ashgate).

Hansen, W. G. (1959): How accessibility shapes land-use. Journal of American Institute of Planners 25:73-76.

Harris, C. D. 1954. The market as a factor in the localization of industry in the United States. Annals of the Association of American Geographers 44:315-348.

Haynes, K.E. y Fotheringham, A.S. 1984. Gravity and spatial interaction models. Beverly Hills, SAGE.

Laird, J. J. N., J., and P. J. Mackie. 2005. Network effects and total economic impact in transport appraisal. Transport Policy 12:537-544.

Linneker, B.J. and Spence, N.A. (1992a). An accessibility analysis of the impact of the M25 London orbital motorway in Britain. Regional Studies, 26 (1), 31-47.

Linneker, B.J. and Spence, N.A. (1992b). Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain. Environment and Planning A, 24, 1137-1154.

López, E., Gutiérrez, J. y Gómez, G. (2008): Measuring regional cohesion effects of large-scale transport infrastructure investments: an accessibility approach. European Planning Studies, 16 (2), 277-301.

Llano C.; Esteban, A., Pérez, J., Pulido, A. (forthcoming): "Breaking The Interregional Trade "Black Box": The C-Intereg Database For The Spanish Economy (1995-2005)". International Regional Science Review.

Malczewski, J. 1999. GIS and multicriteria decision analysis. John Wiley & Sons.

Mas, M., J. Maudos, F. Pérez, and E. Uriel. 1994. Capital público y productividad en las regiones españolas. Moneda y Crédito 198:163-193.

Muhammad, S., T. de Jong, and H. F. L. Ottens. 2008. Job accessibility under the influence of information and communication technologies, in the Netherlands. Journal of Transport Geography 16:203-216.

Munell, A.H. (1990): Why has productivity growth declined? Productivity and public investment. New England Review, 3-22.

Munell, A.H. (1992): Infrastructure investment and productivity growth. Journal of Economic Perspectives, 6(45), 189-198.

Pereira, M. A., and O. R. Sagalés. 2003. Spillover effects of public capital formation: evidence from the Spanish regions. Journal of Urban Economics 53:238-256.

Reggiani, A., and Bucci. 2008. Accessibility and network structures: the case of commuting in Germany. Paper presented at the NECTAR Workshop, Las Palmas.

2.4 SPATIAL IMPACTS OF ROAD PRICING: ACCESSIBILITY, REGIONAL SPILLOVERS AND TERRITORIAL COHESION

Condeço-Melhorado, A.; Gutiérrez, J.; García-Palomares, J. (2001)*: Spatial impacts of road pricing: Accessibility, regional spillovers and territorial cohesion.* ***Transportation Research A: Policy and Practice****.Vol.45, 3, pp. 185-203*. (JCR. Impact factor: 1,715)

This article was developed as part of the META and GESTA projects, both financed by the CEDEX (Ministry of Public Works), coordinated by CENIT (UPC), and with the participation of Transyt (UPM) and the Department of Human Geography at the UCM. In the META project (Spanish road pricing model), the aim was to measure the costs of road transport and its externalities for the subsequent establishment of a pricing model for the use of infrastructure based on external costs. Various road-pricing systems for intercity traffic are analysed, and their possible impact on accessibility, territorial cohesion and the environment is estimated. In the case of GESTA (road management through pricing aimed at maximising the social benefits for sustainable mobility), the focus is centred on designing a pricing system for the urban road network which enables its efficient use under criteria of sustainable mobility.

The preliminary results of this study on the analysis of spillovers were presented at the 2008 Nectar workshop “The future of accessibility: new methodological developments” in Las Palmas de Gran Canaria in 2008 (Condeço-Melhorado et al., 2008b), at the 3rd International Conference on Funding Transport Infrastructure in Paris in 2008 (Condeço-Melhorado et al, 2008c), and at the 4th Kuhmo-Nectar Conference “Transport and urban economics”, held in Copenhagen in 2009 (Condeço-Melhorado et al., 2009a).

So far the studies presented apply the spillover methodology to assessing the impact of new transport infrastructure. However, the traditional “predict and provide” model which justifies the construction of new infrastructure is increasingly coming into question, and there is a change in favour of adopting policies which impose restrictions on demand and generate more sustainable patterns of mobility. This is the case of pricing systems which internalise the external costs generated by road users.

In this instance the methodology for measuring spillovers is used to evaluate the various pricing systems proposed in the META project, which vary depending on the sphere of application and the cost of the tolls. Their effects are measured for both light and heavy vehicles. In the case of positive spillovers generated by the construction of transport infrastructure, road pricing will in many cases have the opposite effect. The implementation of tolls in a region can be expected to produce an increase in transport costs and to generate negative spillovers. However, it may also lead to decreased congestion at some points and, thus to time savings, which offset and/or exceed the payment of the toll.

The work also includes several methodological improvements. One of these is the calibration of the distance exponent in the potential accessibility model using data on interprovincial commerce in euros. Another concerns the calculation of self-potential; that is the contribution of the internal accessibility of each area to its total accessibility. In this work the self-potential is calculated considering the area of each transport zone and its population density.

One of the pricing systems analysed is the introduction of tolls on the whole of Spain's high capacity network (S1A). These tolls reflect external social and environmental costs. A second scenario (S1B) proposes a toll which also includes the costs of maintaining the infrastructure; this would be applied only to heavy vehicles. The third scenario (S2A) is identical to S1A, but the scope of the toll is extended to national roads. Finally, a fourth scenario is assessed (S2B), similar to S1B but whose scope of application also extends to national roads.

All the scenarios are assessed from the perspective of their impact on accessibility, spillover effects and territorial cohesion. The accessibility impacts of each scenario are measured by comparing the base scenario –without pricing– with each of the scenarios with pricing. The market potential indicator was selected, which measures the impact of pricing on access to the markets.

In scenario S1A, accessibility is reduced particularly in the spaces located near high capacity roads and especially in regions with a great density of this type of roads, as is the case of the Madrid region. Scenario S1B shows an increase in negative impacts in the accessibility of heavy vehicles with the implementation of a higher toll which also includes the infrastructure maintenance costs. The impacts maintain a very similar spatial distribution to the previous scenario, and are more intense near high-capacity roads.

In scenario S2A the impacts extend to almost the whole country, as not only dual carriageways and motorways but also national roads are subject to pricing. Impacts can also be seen in neighbouring countries. Scenario S2B has a very similar pattern but with greater reductions in accessibility as a higher toll is considered.

In order to measure the effects on territorial cohesion, the accessibility distribution is analysed in each scenario. The results indicate that scenarios S1A and S1B, which implement pricing on high capacity roads, improve territorial cohesion due to the fact that they incur a greater penalty on spaces which were previously more accessible. In contrast, scenarios S2A and S2B increase the disparities in accessibility as they produce more generalised impacts which are localised in more peripheral regions.

The article measures the spillover effect in scenario S1B. This shows the accessibility losses generated in one region by the implementation of road-pricing in a different region. The results show that the spillovers largely depend on the density of the toll roads. For this reason Madrid is one of the regions which generates most negative spillovers, whereas the opposite occurs in Extremadura. As in the previous articles, the spillovers can be seen to depend on the region's geographic situation and the proximity of the toll roads.

The spillovers are shown in the form of maps and matrices (in potential units and as a percentage). The analysis of the matrices reveals which part of the loss of accessibility in an autonomous region is due to the pricing of their own roads, and which part is due to spillovers. As an example, in Madrid and Catalonia nearly 80% of the losses are due to the pricing of their own roads, whereas in regions with few toll roads such as Extremadura, accessibility losses owing to road pricing implemented in other regions is 67%.

Transportation Research Part A 45 (2011) 185–203

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Spatial impacts of road pricing: Accessibility, regional spillovers and territorial cohesion

Ana Condeço-Melhorado [a], Javier Gutiérrez [b,*], Juan Carlos García-Palomares [b]

[a] Departamento de Geografía, Universidad de Alcalá, Spain
[b] Departamento de Geografía Humana, Universidad Complutense de Madrid, Spain

ARTICLE INFO

Article history:
Received 4 April 2009
Received in revised form 16 November 2010
Accepted 10 December 2010

Keywords:
Road pricing
Accessibility
Regional spillovers
Territorial cohesion
Geographical information systems (GIS)

ABSTRACT

Road pricing policies are gaining prominence in EU countries. These policies have positive impacts leading to mobility patterns which are socially and environmentally more desirable, but they also have negative impacts. One negative impact is to be found in regional accessibility, due to the increase in generalized transport costs. This study presents a methodology based on accessibility indicators and GIS to assess the accessibility impacts of a road pricing policy. The methodology was tested for the Spain's road network considering two road pricing scenarios. It enables not only the more penalized regions to be identified but also negative road pricing spillover effects between regions. These effects are measured in terms of accessibility changes occurring in one region produced by charges implemented in another region. Finally, the study of accessibility disparities (by calculating inequality indexes for each of the scenarios considered), provides policymakers with useful information regarding the impact of road pricing policies from the point of view of territorial cohesion.

1. Introduction

In the transport policies of the European Union the principle that the user should pay costs has gained prominence in recent years and is one of the recommendations of the High Level Group on Infrastructure Charging (EU, 1998). The transport charges must include infrastructure costs but also externalities (environmental costs, accidents, congestion, and so on).

A pricing policy should lead to mobility patterns that are socially and environmentally more desirable. From the point of view of the modal split, a road pricing system produces positive effects, resulting in changes towards more environmentally friendly transport modes. But from the standpoint of accessibility, negative impacts are expected, due to the increase in the generalized transport cost. These effects can be measured by accessibility indicators. These indicators can help to assess not only changes in accessibility due to road pricing but also whether such changes increase or decrease accessibility disparities between regions.

Accessibility analysis applied to road pricing moves away from the traditional approach of infrastructure improvements and their positive impacts on accessibility. In fact, the introduction of charges in a transport system poses an increase in generalized transport costs and therefore a reduction in accessibility. In any case, the emergence of differential effects on the territory is expected. A pricing system penalizing traffic on high capacity road networks will negatively affect regions with a higher density of motorways and expressways, which typically corresponds to the more developed regions.

This study analyses the impact on accessibility and on territorial equity of a possible pricing policy in the Spanish road network. The methodology is based on accessibility indicators computed in a commercial GIS (ArcGIS). We also use this

* Corresponding author.
E-mail address: javiergutierrez@ghis.ucm.es (J. Gutiérrez).

0965-8564/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.tra.2010.12.003

methodology to assess spatial spillover effects. Spatial spillovers are defined in this study as the accessibility changes felt by one region, caused by road pricing in a different region. The study restricts itself to analysing the effects of pricing from the point of view of accessibility by road. Other effects, such as possible changes in modal distribution brought about by internalising the charges and their environmental consequences, are outside the scope of this paper. We do not speculate either on the use the charge collected is put to, which may also have consequences both inside and outside the transport sector.

After this short introduction, this paper will continue with a discussion of the road pricing effects on accessibility and territorial equity. The methodology implemented to measure these impacts is then presented in Section 3. In Section 4 the results are subdivided into accessibility impacts, spillover effects and equity impacts of road pricing. Finally, in Section 5 we set out the principal conclusions of this study.

2. Spatial impacts of road pricing: accessibility, cohesion and spillovers

Impacts of road pricing policies have been a relevant subject of transportation research for many years. Most literature focuses on several effects, such as impacts on traffic congestion and mobility (Johansson, 1997; May and Milne, 2000; Olszewski and Xie, 2005; Rotaris et al., 2010), on vehicle emissions (Johansson, 1997; Daniel and Bekka, 2000; Beevers and Carslaw, 2005; Rotaris et al., 2010) and equity effects (Viegas, 2001; Eliasson and Mattsson, 2006; Bureau and Glachant, 2008; Karlström and Franklin, 2009). Many studies have been conducted on road accessibility in the European Union and particularly in Spain and Portugal (see, for example, Gutiérrez et al., 1998, 2010; Holl, 2004, 2007; López et al., 2008; Ribeiro et al., 2010). But papers dedicated to the spatial impacts of road pricing using accessibility indicators are very scant. Only Tillema et al. (2003, 2007, 2008) have analysed the effects of road pricing on accessibility. In this study we propose a methodology based on accessibility indicators and GIS in order to investigate not only accessibility changes due to a pricing policy, but also territorial equity impacts and regional spillover effects.

The concept of accessibility has played a major role for several decades in the literature of regional and transport research (Reggiani, 1998). Geographical accessibility is related with a potential for territorial interaction. The accessibility concept can be defined as "the ease with which activities can be reached from a certain place and with a certain system of transport" (Morris et al., 1978). This concept is associated with the idea of the opportunities available for people and firms to reach those places where they can carry out activities which are important for them (Linneker and Spence, 1992).

Accessibility is the principal "product" of the transport system (Schürman et al., 1997). The construction of a transport infrastructure will produce immediate changes in territorial accessibility, reducing travel time and creating spatial advantages in that region. The reduction in interaction costs positively affects the competitiveness of the economic system and favours the appearance of scale and specialization economies (Forslund and Johansson, 1995).

Changes in accessibility may also be due to a change in the conditions of use of the infrastructure. Instead of the classical view of infrastructure improvements and their positive consequences for accessibility, a road pricing policy will reduce accessibility. Therefore, higher travel costs, as a consequence of the implementation of charges, will have opposite effects compared with those effects mentioned above for new transport infrastructure: increases in transport sector costs, leading to higher costs in other economic sectors, and consequently an increase in the consumer price index. At the same time, people have less spending capacity and therefore a reduction in consumption is expected. Obviously, these effects will depend on the pricing scheme characteristics and on the use given to the charge collected.

On the other hand, pricing policies may have positive effects such as congestion reduction which would impact positively on regional accessibility. Gains in travel time, especially in congested areas, are a major benefit of road pricing measures. But the accessibility gains or losses due to road pricing measures are perceived differently among road users, depending on factors such as the type of actors (firms or households) or actor characteristics (high and low income).

Furthermore, the accessibility impacts of a road pricing policy will affect the mobility patterns differently if the short, medium or long term effects are considered. In the short term, changes in departure time, in route selection and in the choice of transport mode are expected. While in the medium and long term people may vary their destination locations such as recreation and shopping activities, and even their job or their house location (Tillema et al., 2007).

Another element to assess is related to territorial cohesion, since the appearance of different territorial effects is expected. This paper uses the term territorial cohesion in the same sense as in the Third Cohesion Report, that is, as a synonym for "more balanced development", for "territorial balance" or "for avoiding territorial imbalances" (EC, 2004; Camagni, 2009). A road pricing system penalizing the flows on high capacity road networks will more negatively affect those regions where motorway density is higher. Thus, from the rural–urban perspective, it is expected that road pricing will affect more urbanized territories (with a greater density of high capacity road network) to a greater extent than rural spaces. Therefore, distributive effects over the territory may be foreseen since road pricing will impact more negatively in developed areas such as urban spaces, thus increasing the attraction for investment in less populated regions; that is, spread effects can be expected. This will lead to positive effects on territorial equity, with different magnitudes depending on the characteristics of the pricing scheme implemented. The spatial distribution of accessibility can be used as a measure of the disparities existing between regions (EC, 2004) because the equality of access to services of general economic interest is considered a key condition for territorial cohesion. In this context, after examining the new accessibility framework, as a result of a road pricing policy implementation, we will analyse accessibility disparities in order to measure equity effects. This approach could be used to enrich the planning process, providing decision makers with more information on whether a pricing scheme increases or decreases regional equity.

It is also interesting to analyse the spatial spillovers caused by changes in the road system. Spillover effects can be defined as those impacts on neighbouring regions resulting from transport changes in another region (Pereira and Roca-Sagalés, 2003). These effects can be positive (construction of new infrastructure) or negative (increase in generalized transport costs, as in the case of a road pricing policy). Measuring spillover effects is important because while one region or country can benefit from the revenues of a road pricing policy within its territory, its negative effects are 'exported' to other regions.

3. Measuring spatial impacts of road pricing

In this section we present a methodology to measure the accessibility impacts and spillover effects of a road pricing policy. The selection of the accessibility indicator, accessibility impacts and the method for obtaining the spillover effects of this kind of policy will be explained.

3.1. Accessibility: measuring spatial impacts of road pricing by the market potential indicator

In this paper the market potential indicator was used in order to measure spatial impacts of road pricing. This indicator belongs to the family of gravity models, since the weight given to the relationships between economic centres decreases with the increase in distance. Initially used by Harris (1954) it became, without doubt, the most widely used measure in accessibility studies (for example, Hansen, 1959; Clark et al., 1969; Keeble et al., 1988; Lutter et al., 1992; Spence and Linneker, 1994; Geertman and Ritsema van Eck, 1995; Gutiérrez, 2001; López et al., 2008). It is commonly shown as:

$$P_i = \sum_{n}^{j=1} \frac{M_j}{C_{ij}^a} \quad (1)$$

where P_i is the potential accessibility of centre i, M_j is the mass (population, employment, GDP) of the economic destination centre j and C_{ij} is the cost through the network between centre i and j. Finally, a is a parameter representing the friction of that cost: a high parameter value gives a greater weight to relations established with cheaper costs.

Analysing accessibility in conditions of road pricing requires the consideration of generalized transport costs as a measure of impedance between the places of origin and destination of trips (C_{ij} parameter). Implementing the cost function means including both internal costs (consumption, maintenance, vehicle depreciation) and external costs associated with trips (environmental costs, accidents, maintenance cost of infrastructure) (see cost value in Section 4.2).

Of those costs, some are measured depending on the distances covered and others depending on travel times. That is why the generalized transport cost and the corresponding charge has been obtained from the length and travel time of each section of the network in the different scenarios considered according to:

$$CGT_i = TTC + OC + F \quad (2)$$

where TTC is the travel time cost, OC is the operating cost and F is the fee value (to internalise the external costs).

These data enable least cost paths to be calculated between centroids of transport zones using a GIS. The generalized travel cost between an origin and a destination centre is calculated as the sum of the travel cost through the network between each centre plus two penalties (in origin and destination, respectively), according to:

$$GTC_{ij} = CGT_i + CGT_{rij} + CGT_j \quad (3)$$

where GTC_{ij} is the generalized travel cost between an origin i and a destination centre j, CGT_i is the half of the internal travel cost of the centre where i is located, CGT_{rij} is the minimum cost through the network between origin i and destination centre j, and CGT_j is the half of the internal travel cost of j.

These penalties simulate the cost spent using the local roads and streets in order to connect to the represented digital road network and at the same time to resolve the self-potential problem. One issue that deserves careful attention in the market potential indicator is the problem known as self-potential. The self-potential problem in accessibility studies has been discussed before (Bruinsma and Rietveld, 1993; Frost and Spence, 1995), and it is related with the contribution of the internal accessibility of each region to its total accessibility. Self-potential is particularly important in highly populated or large regions. Some studies estimate self-potential as a function of the area of each centre (Copus, 1999; Rich, 1975) or regarding the mean trip length/travel time of the agglomerations or regions (Schürmann and Talaat, 2000; Gutiérrez, 2001). In our case, the internal travel cost is the sum of the internal operating cost associated with the distance travelled and the monetary value associated with internal travel time (see Section 4.2).

The internal distance (D_{ii}) was estimated using the formula proposed by Rich (1975):

$$D_{ii} = \frac{1}{2}\sqrt{\frac{\text{area (km}^2)}{\pi}} \quad (4)$$

Internal travel times (t_{ii}) were initially hypothesized at 10 min due to the small size of the transport zones. However, a congestion effect has also been considered in urban zones with more than 75,000 inhabitants using the following correcting formula:

$$t_{ii} = 3.4336Ln(p_i) - 0.8476 \quad (5)$$

where t_{ii} is the internal time and p_i is the population of the zone i. This formula is the result of an estimation obtained with a sample of Spanish cities. Finally, the internal time ranges from 10 min for rural zones and 28 min for the zone which represents the municipality of Madrid.

Once the generalized travel cost origin–destination matrix was obtained, the economic potential value of each transport zone was calculated. Being a gravity model, this indicator seeks to represent the decrease in the spatial interaction with the increase in travel cost. In order to set a realistic value to parameter a, its value has been calibrated by using an origin–destination matrix for goods (in tonnes) transported on roads between Spanish provinces in 2005 (see Llano et al., 2010). For calibrating purposes, the unconstrained gravity model available in the *Flowmap* software was used. The result is a value for a of 1.97. Since it is not possible to obtain origin–destination travel matrices for light vehicles in Spain, the value obtained for the goods transported was also used for light vehicles.

In order to obtain the accessibility impacts of a transport policy the procedure followed is to measure the accessibility in a reference scenario (S0), representing the roads before the policy implementation and compare this with the accessibility measured once the policy has been undertaken. Applied to the case of a road pricing policy, this enables us to determine the impact of the pricing model on regional accessibility, according to:

$$A_i = A_{iSn} - A_{iS0} \tag{6}$$

being A_i the accessibility impact on zone i; A_{iS0} the accessibility value calculated for the zone i in the reference scenario and A_{iSn} the accessibility value calculated for the zone i in the road pricing scenario considered.

3.2. Measuring spillover effects

To calculate the regional spillovers of road pricing policies an accessibility analysis is conducted using the regional extraction method (Gutiérrez et al., 2010). The logic of this procedure is similar to that of the studies that use the extraction method on the basis of a many-region input–output table in order to consider the effects of hypothetically extracting a region from a many-region model (Dietzenbacher et al., 1993). Thus, evaluation of the spillover effect is based on the comparison of two spillover scenarios: the scenario with charges in all the Spanish regions and the scenario without charges in the case of the study region but with road pricing in the rest of the regions. The differences between these two scenarios (road pricing scenario in all the regions and no charges only in the region i) represent the spatial spillover effects of region i on the rest of the regions.[1] This procedure is repeated for each of the continental regions of Spain (Fig. 1) and each of the road pricing scenarios. Because we will test different road pricing scenarios in Spain, we will obtain a set of matrixes of inter-regional spillover effects (one for each of the road pricing scenarios). Fig. 2 shows the spillover scenario for the Andalusia region.

3.3. Measuring territorial cohesion

Cohesion effects between the different scenarios have been measured in terms of changes in spatial distribution of accessibility values. The selection of cohesion indices was carried out on the basis of their proven efficiency in previous studies (Martín et al., 2004; Bröcker et al., 2004; Schürman et al., 1997; López et al., 2008). These authors agree that there is no "ideal" cohesion index and therefore suggest computing a set of them in order to analyse their results in a complementary way.

Three cohesion (equality) indices have been selected. The first index—the coefficient of variation—is a statistical measure of general applicability. The two later indices are commonly used in the economic literature to assess the degree of equality of income distribution. They are the GINI coefficient and the Theil indices (a detailed formulation and a comprehensive review of inequality measurement can be found in Cowell, 1995).

In this paper, to calculate the cohesion indices the accessibility values of the different transport zones are added by region (through a regional average, weighted according to the population of each zone). Then the inequality indexes are calculated from the accessibility values of the different regions. This operation is repeated for each scenario, so that the cohesion effects of the different pricing policies may be compared.

4. Study of the spatial impacts of road pricing in Spain

4.1. Data

Accessibility analysis in a GIS requires introducing a digital road network to simulate transport flows along the network. For this study a digital road network was built to include all the Spanish national roads and the main regional ones. All the motorways and the main road network in Portugal and the South of France have also been included in the network in order

[1] The regional aggregate value of spillover effects in region j from the charges in region i (in economic potential units) is obtained by a weighted average of the municipalities of the region j according to the population as follows: $S_{ij} = \frac{\sum_k s_{kij} p_{kj}}{\sum_k p_{kj}}$ where: S_{ij} is the average spillover effect (in economic potential) in the region j from the fees in region i s_{kij} is the spillover in each kth municipality within the region j from the fees in region i, and p_{kj} is the population of each kth municipality within the region j.

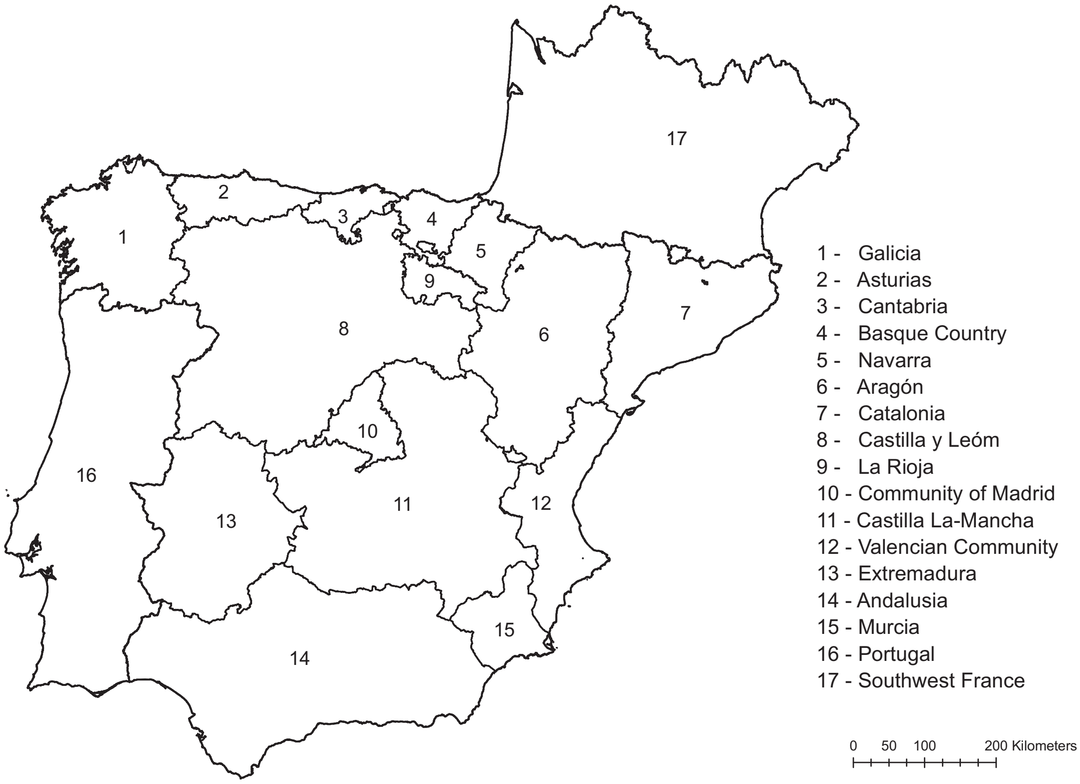

Fig. 1. Regions of mainland Spain.

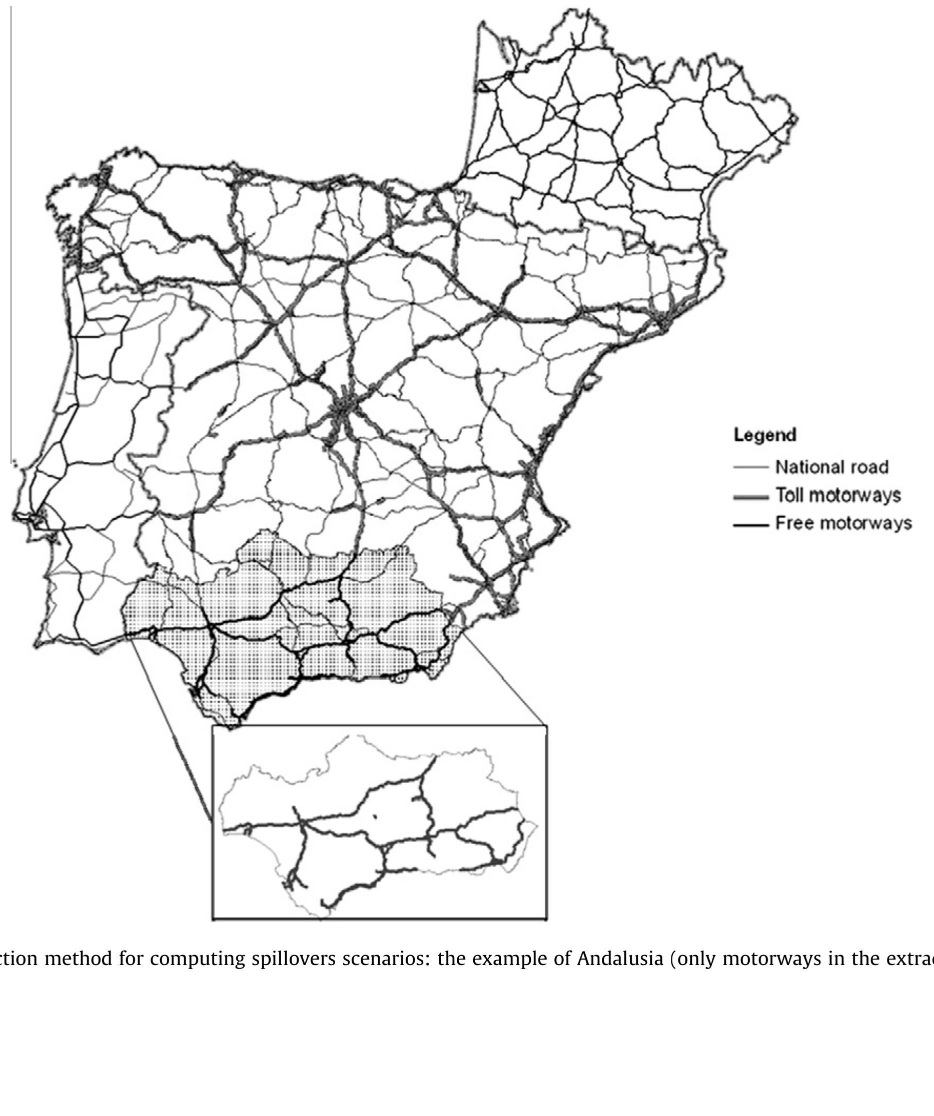

Fig. 2. Regional extraction method for computing spillovers scenarios: the example of Andalusia (only motorways in the extracted region are free).

to avoid the border effect (see Bruinsma and Rietveld, 1998 or Gutiérrez, 2001). The baseline year is 2005. It is a very dense network (about 16,000 arcs), with large territorial coverage (Fig. 3), so that it is possible to capture the spatial variability of the pricing policy effects and to interpolate the results precisely.

Each arc of the network contains information about the type of road, length, number of lanes and slope. For the main road network, speed information from official floating vehicle data (Ministerio de Fomento, 2005) was available. Where this data was not available, national speed limits for cars and for trucks were assigned. For trucks, speed was also penalized considering the road slope. With the length and speed information, and also the demand in each arc (mean veh/h) travel times for car and trucks were calculated using a stochastic user equilibrium assignment algorithm in the transportation software Transcad (Caliper Corporation). This algorithm was used in order to consider a possible congestion reduction from charge implementation.

In order to represent the places where trips have their origin and destination, 815 transport zones have been defined, with their respective centroids. In Spain, the transport zones were built from the automatic allocation of municipalities to the closest node of the network using a GIS. Each cluster of municipalities constitutes a transport zone. Subsequently this automatic allocation was adjusted with respect to various homogeneity and coherence criteria such as: size and form (avoiding vast or sinuous zones, to assure homogeneous accessibility to the network), spatial continuity and natural barriers (in order to delimitate transport zones). The transport zones present an average of 60,000 inhabitants and an area of approximately 440 km^2. In the neighbouring countries, Portugal and France, where the required precision was not so high, transport zones coincide with *concelhos* and *departments*, respectively.

For each zone the population data in year 2005 was stored. The population serves as a weighing factor in the accessibility indicator, attributing greater importance to the relations established with the most populated zones. In this way, the population will be the variable that serves as a proxy of the economic activity volume of the different transport zones. The population data were obtained from the respective national statistics institutes (INE, in Spain; INE in Portugal and INEES in France). There are no employment data at this level of spatial disaggregation.

4.2. Scenarios and generalized transport cost

To measure the spatial impacts of a pricing policy on Spanish road accessibility, a reference scenario (S0) and two road pricing scenarios (S1 and S2) have been considered, distinguishing between light (A) and heavy vehicles (B) (since they have different generalized transport costs) (Table 1):

S0: The reference scenario represents the road situation in the year 2005, without road pricing except in charged motorways (see Fig. 3).

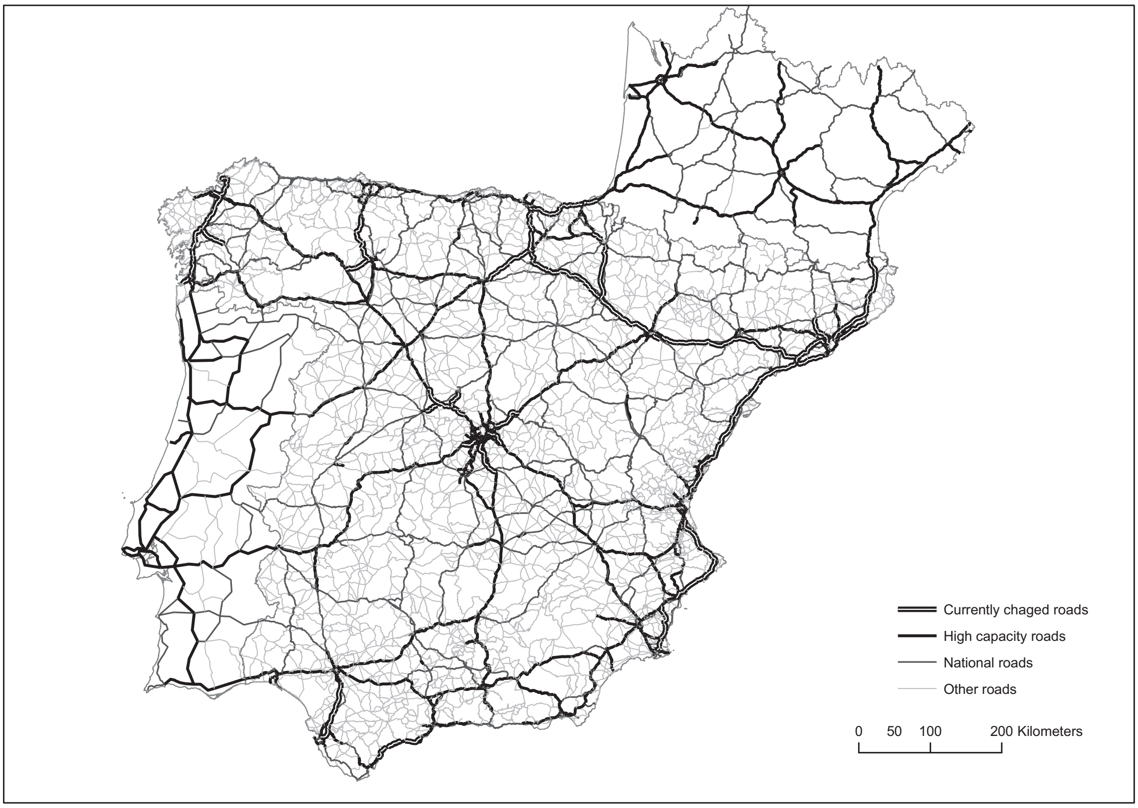

Fig. 3. Road network.

Table 1
Road pricing scenarios.

Roads with charge	Type of vehicle	
	Light	Heavy
No charge	S0A	S0B
Charge only on motorways	S1A	S1B
Charge on motorways and national roads	S2A	S2B

Table 2
Operating and external costs (Euros/veh km).

Road type	Type of vehicle			
	Operating costs		External costs	
	Light	Heavy	Light	Heavy
Roads	0.08	0.47	0.09	0.13
Motorways	0.10	0.60	0.09	0.13

S1: A pricing policy is introduced only in the Spanish high capacity roads. A charge for the distance travelled is added.
S2: The charge is applied not only to motorways but also to the national road network for the purpose of preventing the diversion of traffic from the former to the latter.

Accessibility (market potential) (see Section 3.1) is measured by using the generalized transport cost (GTC) as an impedance variable. The GTC was calculated by using as an input the transport costs obtained in a Ministry for Public Works study (META project), which includes travel time costs, operating costs and external costs.[2] The two first are internal costs and represent the costs currently borne by users (reference scenario). They are the same for all scenarios. External costs (environmental, accidents and infrastructure maintenance) represent the costs which should be included by means of a charge (road pricing scenarios). The fee value takes the value 0 in the reference scenario, except in charged motorways (Fig. 3), where the fee takes the current charge value. These current charges depend on the motorway concession but they assume a mean value of 0.09 and 0.16 Euro/km for light and heavy vehicles respectively.

The different costs are:

- *Travel time cost:* It is the value of the time of the driver, estimated on the base of available official data:
  - *Light vehicles:* The value of the travel time (0.20 Euro/min) was derived from the average salary in Spain (data from the National Statistics Institute).
  - *Heavy vehicles:* Data from the National Observatory of Goods Transport, that include the salary of the driver plus accommodation and subsistence costs, were used (0.30 Euro/min).[3]
- *Operating cost:* Operating cost includes vehicle fuel consumption cost, depreciation costs, and vehicle maintenance costs. It varies according to the type of roadway and vehicle (Table 2).
- *External costs:* They include environmental (CO_2, noise and pollution) and accidents. In the case of heavy vehicles infrastructure maintenance costs are also included (Table 2). The external costs for heavy vehicles (0.13 Euro/km) seem to be realistic when compared with the fee of 0.12 Euro/km (Eurovignette) that has already been implemented in Germany and France.

How to manage these transport costs in the GIS varies depending on whether these costs are measured in Euro/min or in Euro/km. Travel time costs are calculated based on the travel time (min) of the section, external and operation costs are calculated based on the length (km) of the section. The generalized transport cost (GTC) of the section (Euros) is obtained by summing these three types of costs.

4.2.1. Road pricing impacts on accessibility

This section presents the accessibility results for each of the scenarios considered in the study. Figs. 4–7 show the decrease in accessibility due to the increase in generalized transport costs as a result of road pricing. Darker colours are related

[2] The methodology used to calculate the transport costs in study for the Ministry of Public Works study can be found in Appendix A.
[3] On long haul trips, the total travel time for heavy vehicles suffers a penalty due to the restrictions stipulated by Spanish law: the maximum continuous driving period is 4 h and 30 min (after which the driver must rest for 45 min) and the maximum daily driving time is 9 h (including the corresponding stops, after which the driver must rest for 11 h). Since the total time calculated for heavy vehicles includes both driving time and the stipulated stops, on journeys of over 4 h and 30 min heavy vehicle travel time is disproportionately high in relation to that of light vehicles.

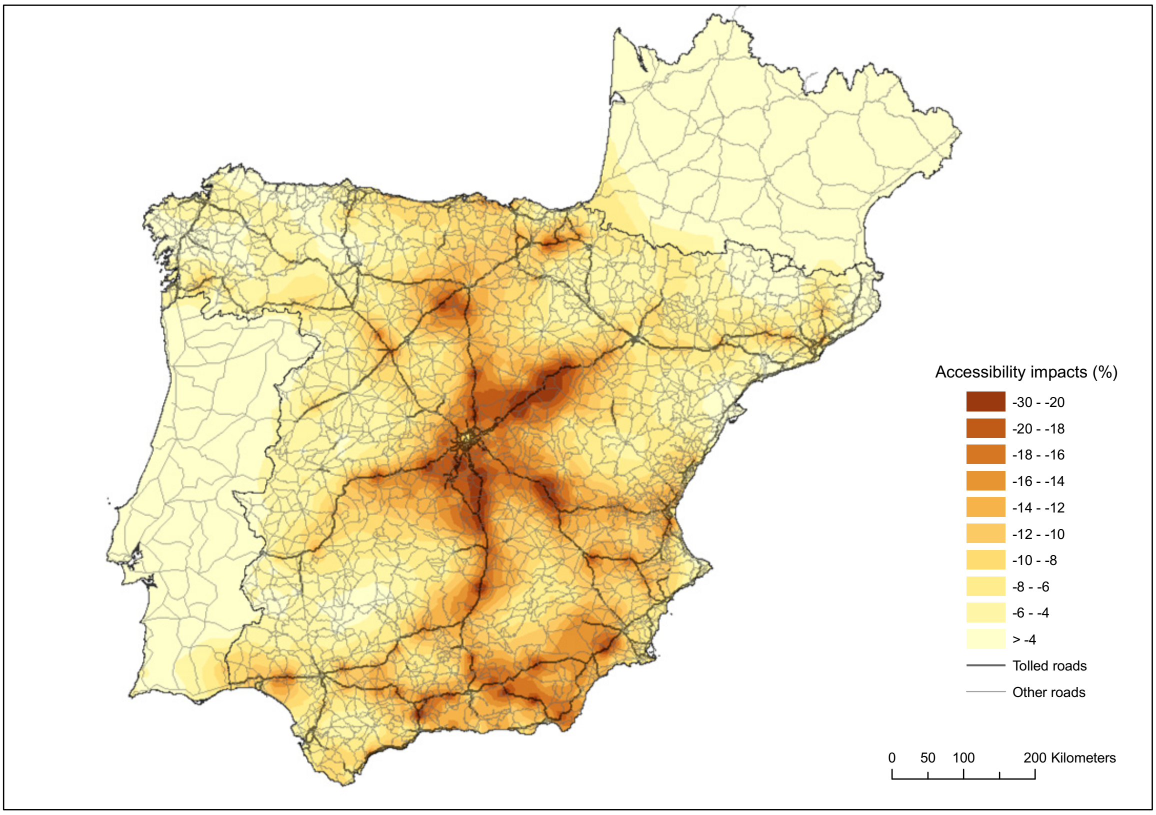

Fig. 4. Impact of road pricing on accessibility: S1A scenario.

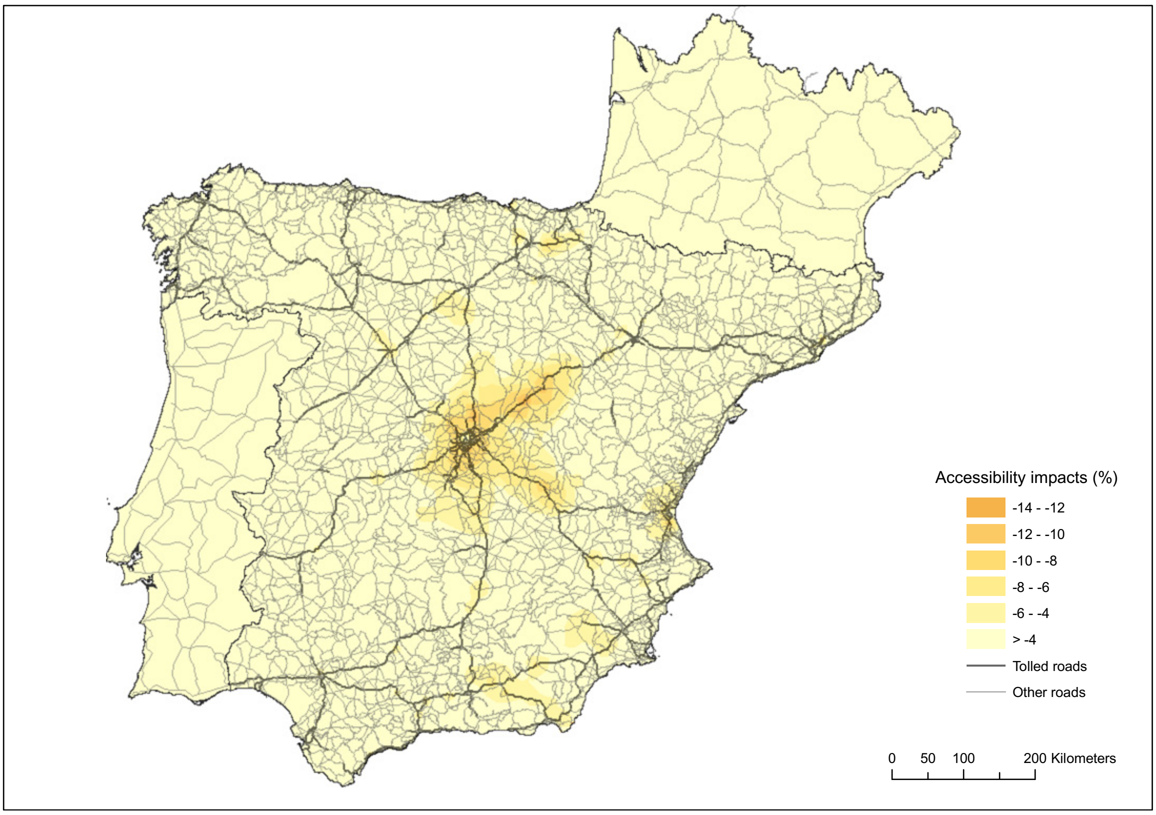

Fig. 5. Impact of road pricing on accessibility: S1B scenario.

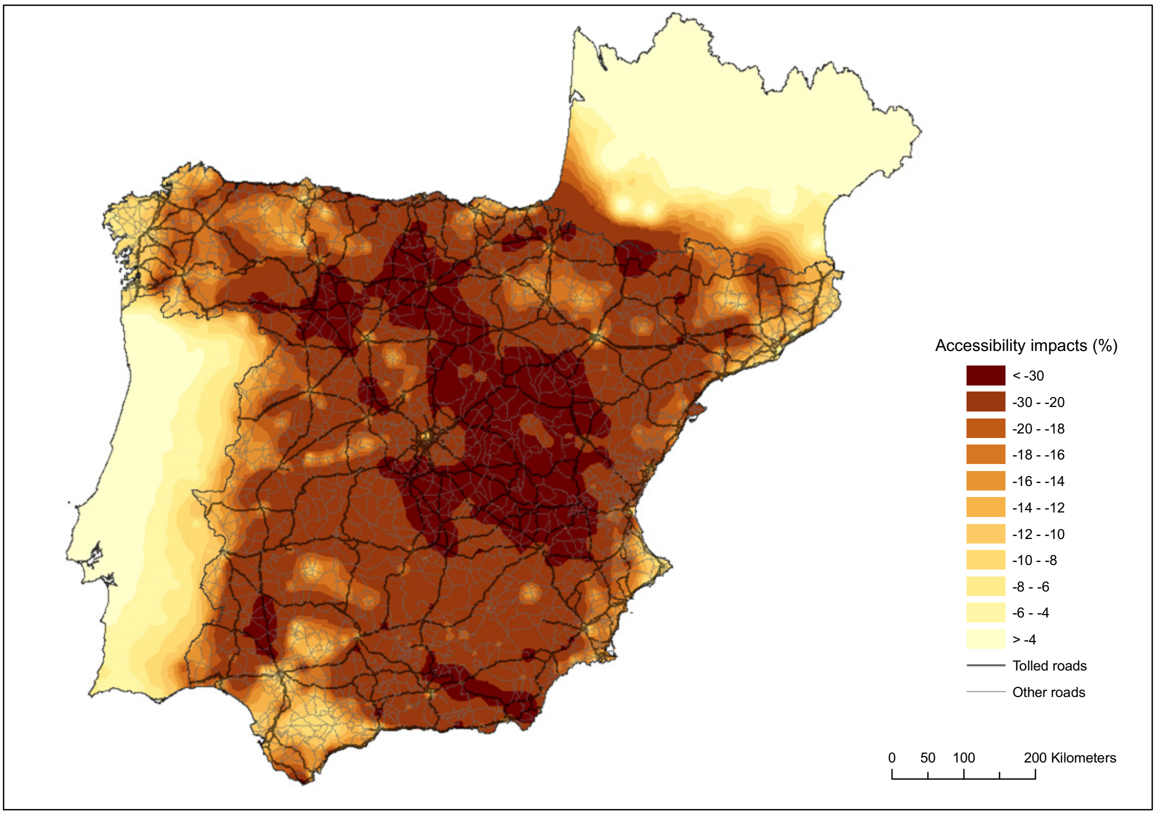

Fig. 6. Impact of road pricing on accessibility: S2A scenario.

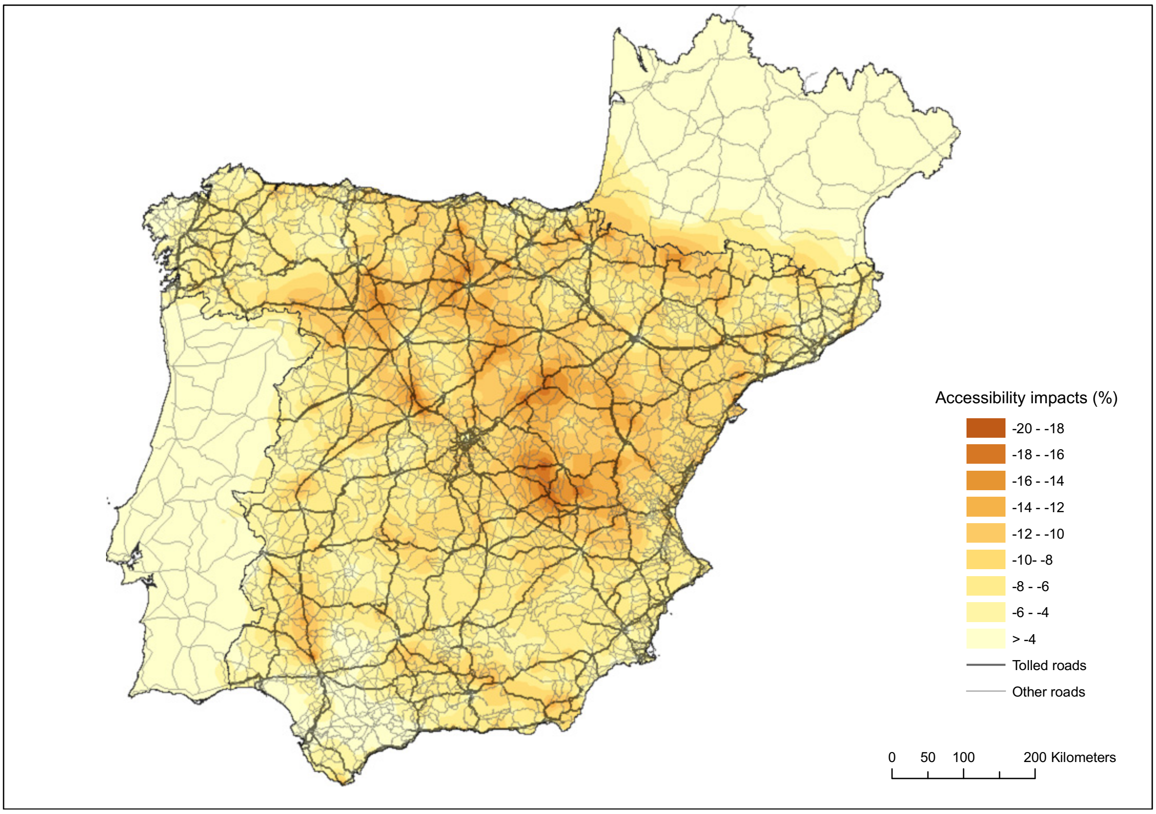

Fig. 7. Impact of road pricing on accessibility: S2B scenario.

Table 3
Mean regional accessibility values in the different road pricing scenarios (in economic potential units).

Regions	Scenarios					
	Light vehicles			Heavy vehicles		
	S0A	S1A	S2A	S0B	S1B	S2B
Andalusia	25,825	23,577	22,537	5741	5592	5492
Aragón	23,445	22,264	20,883	5447	5396	5248
Asturias	21,150	20,053	18,804	4626	4570	4415
Cantabria	20,091	18,333	16,897	4351	4266	4093
Castilla – La Mancha	23,547	19,942	18,344	4193	3991	3847
Castile and León	19,133	17,835	16,117	3777	3720	3559
Catalonia	48,752	45,542	44,238	11,598	11,312	11,132
Extremadura	15,051	14,223	12,722	2810	2786	2660
Galicia	20,484	19,634	18,593	4565	4537	4375
La Rioja	18,654	17,527	15,944	3694	3637	3469
Madrid	89,538	80,747	79,872	21,836	20,891	20,816
Murcia	26,989	24,517	23,451	6062	5963	5811
Navarre	19,891	18,753	17,126	4191	4136	3971
Basque Country	28,505	26,219	24,941	6339	6167	6028
Valencia	33,193	30,070	28,716	7339	7099	6870
Spain	38,458	35,205	33,982	8864	8589	8444

to greater accessibility reductions. Tables 3 and 4 show results according to regions. A general decrease in accessibility in Spain may be observed.

4.2.2. S1 scenario

The road pricing implementation in scenario S1 (charge only on high capacity roadways) entails a reduction in accessibility of 8.5% in light vehicles (S1A) and of 3.1% in heavy ones (S1B). The lesser impact on heavy vehicles is explained by the fact that the charge represents a much smaller proportion of the total of internal costs than in light vehicles (despite the fact that the charge on heavy vehicles is greater than that on light ones).

The most penalized areas are located near motorways, especially where there is a greater density of this type of road, such as in Madrid, Castile-La Mancha, Andalusia, Murcia and Valencia (Figs. 4 and 5, Tables 3 and 4). In regions with high motorway density, but which in 2005 already had a large number of toll motorways (such as Catalonia), the changes are much smaller. Accessibility decreases will spill over the Spanish border and will also affect to some extent the neighbouring countries of Portugal and France.

The greater generalized transport cost of heavy vehicles in peripheral spaces (the greater distances involve more stops for drivers to rest, which leads to greater internal costs) means that in relative terms impacts on accessibility are smaller in peripheral spaces than in central ones (Fig. 5 and Table 4). Thus, Madrid has accessibility losses of 4.3% in scenario S1B (against the 3.1% country average), while losses in peripheral regions are clearly below the national average.

Table 4
Percentage of change in accessibility over the reference scenario.

Regions	Scenarios			
	Light vehicles		Heavy vehicles	
	S1A–S0A	S2A–S0A	S1B–S0B	S2B–S0B
Andalusia	−8.70	−12.73	−2.59	−4.33
Aragón	−5.04	−10.93	−0.93	−3.65
Asturias	−5.19	−11.09	−1.22	−4.57
Cantabria	−8.75	−15.90	−1.95	−5.91
Castilla – La Mancha	−15.31	−22.10	−4.81	−8.25
Castile and León	−6.79	−15.76	−1.50	−5.77
Catalonia	−6.59	−9.26	−2.47	−4.02
Extremadura	−5.50	−15.48	−0.88	−5.34
Galicia	−4.15	−9.23	−0.62	−4.16
La Rioja	−6.04	−14.53	−1.56	−6.08
Madrid	−9.82	−10.80	−4.33	−4.67
Murcia	−9.16	−13.11	−1.63	−4.15
Navarre	−5.72	−13.90	−1.30	−5.24
Basque Country	−8.02	−12.50	−2.71	−4.92
Valencia	−9.41	−13.49	−3.28	−6.40
Spain	−8.46	−11.64	−3.10	−4.73

4.2.3. S2 scenario

One of the consequences observed in other countries of the introduction of charges on high capacity roadways is the diversion of traffic to conventional roads. In these cases, an increase in negative externalities may occur, especially the number of accidents. To avoid this perverse effect, scenario S2 includes charges to internalise external costs both on motorways and on main roads (national roadways).

The density of national roadways is high in all parts of the country. That is why accessibility losses are very high: an average reduction of 11.6% in light vehicles (S2A) and 4.7% in heavy (S2B). Regions with low high capacity network density but a greater density of national roadways are highly affected. This is the case with Extremadura and La Rioja, which suffered losses lower than the average in scenarios S1A and S1B and, in contrast, record losses greater than the average in scenarios S2A and S2B (Figs. 6 and 7 and Tables 3 and 4). This type of charge, therefore, has the advantage of avoiding the diversion of traffic towards national roadways, but the drawback of penalizing more the regions with lower motorway density, which are usually the least developed.

4.3. Road pricing spillover effects

The regional spillover effects of road pricing have been analysed in the example of scenario S1B. The spillovers generated by two very different regions have been mapped: Madrid and Extremadura. Madrid suffers important accessibility decreases in the S1B scenario, while Extremadura is one of the regions least affected by road pricing implementation.

Fig. 8 shows the spillover effects produced by Madrid. This region appears in grey because what we want to measure and map are the spatial spillovers (in the neighbouring regions). It can be seen that the implementation of a road pricing policy in Madrid produces major spillovers. The most penalized areas are the closest territories, especially those located very near the charge motorways. These areas depend to a great extent on the Madrid transport infrastructure, both in relationship to Madrid and to other regions. The high concentration of population in Madrid, its central position in the Iberian Peninsula and the radial structure of the motorway network determine that the implementation of a road pricing system in this region will produce major spillover effects on many others.

Extremadura (Fig. 9) produces far fewer spillover effects than Madrid. This is explained by several factors, such as the low motorway density in Extremadura, the lower weight of its transport areas as destinations and the smaller quantity of interzonal relationships crossing the region (due to its peripheral location). Market potential decreases are more accentuated in the proximity of the existing motorways. Spillovers extend beyond the Portuguese border.

The analysis of the road pricing spillover effects brought about for each region enables a spillover matrix to be obtained (Table 5). The rows show the spillovers issued (exported) by each region and the columns the spillovers received (imported)

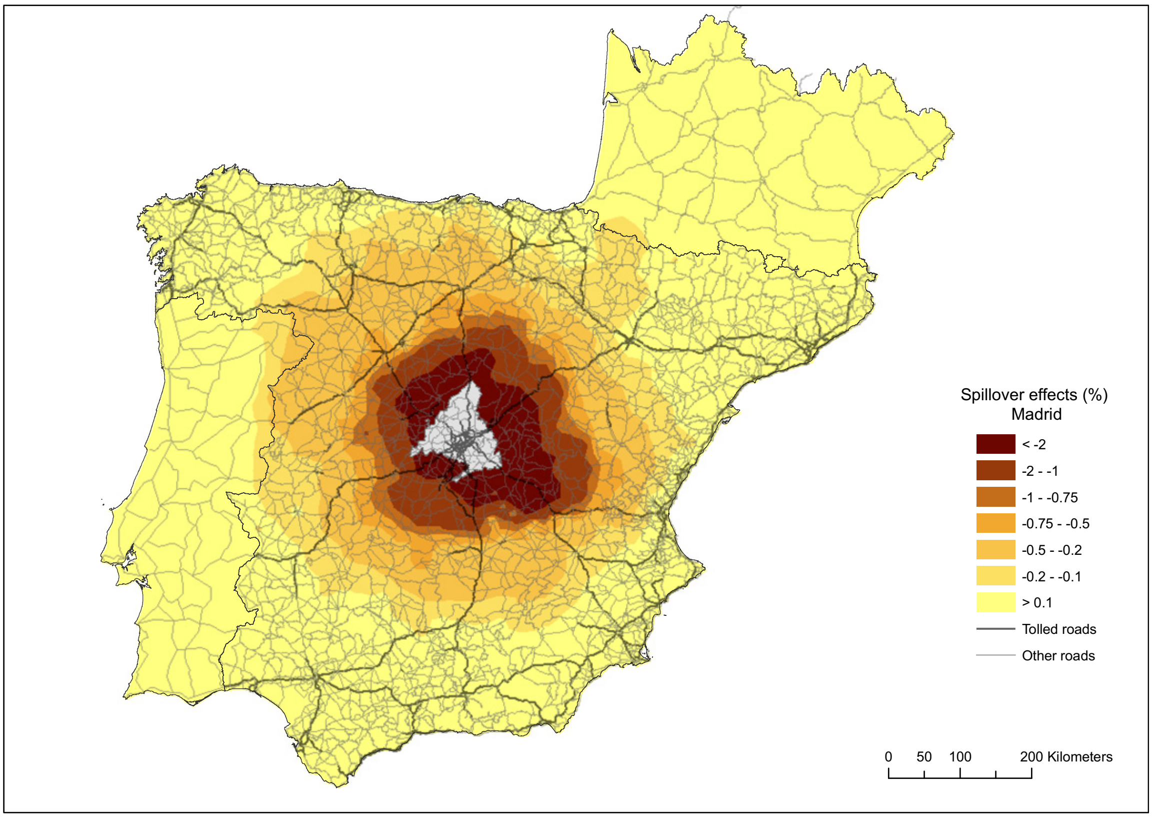

Fig. 8. Road pricing spillovers in Madrid.

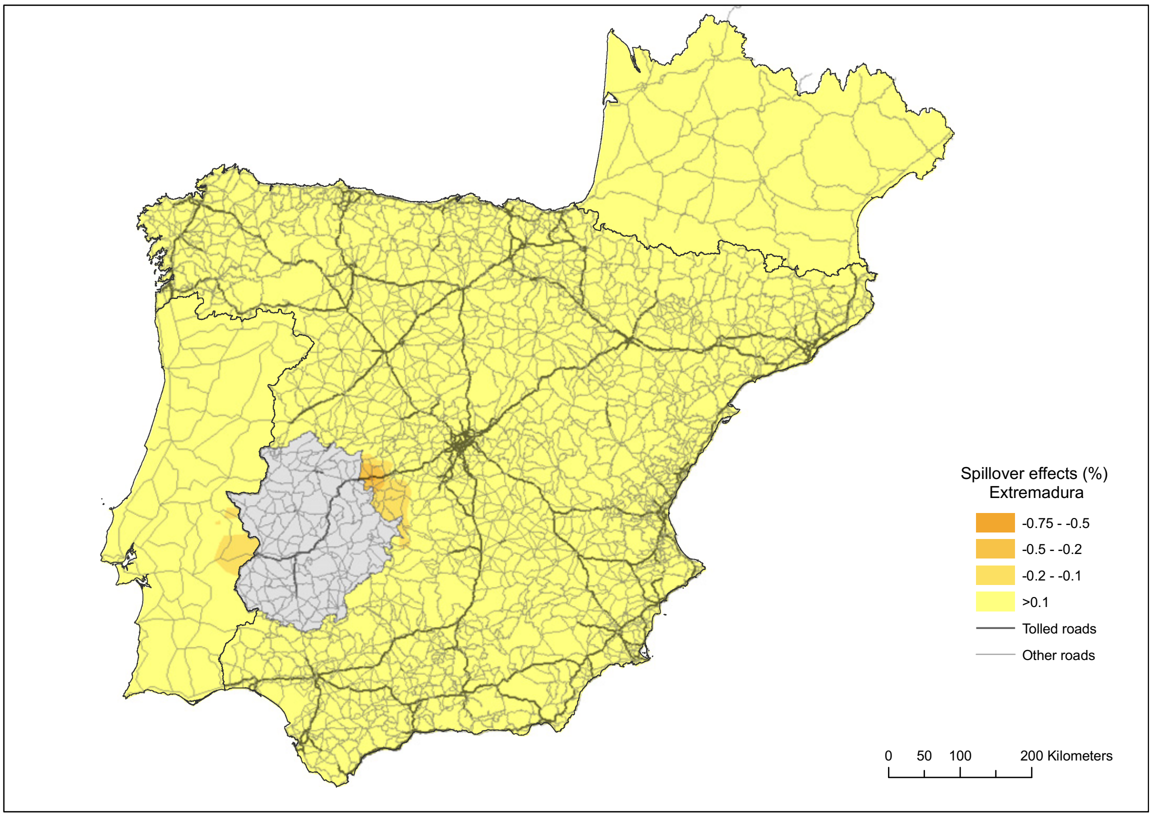

Fig. 9. Road pricing spillovers in Extremadura.

(both in market potential units). The main diagonal shows the internal impacts in each region. Thus, for example, it can be verified that a large part of the negative effects caused by road pricing in Castile-La Mancha remain in the region itself (which suffers an average loss of −66 potential units), but the neighbouring regions, such as Madrid (−24.6), Valencia (−4.5) or Extremadura (−4.4), receive intense negative spillovers. If we look at the columns, we see that Castile-La Mancha imports intense spillovers from Madrid (−110) and to a lesser extent from other neighbouring regions, such as Valencia (−6.6) and Andalusia (−4.7). We can observe how the effects of pricing are clearly asymmetrical. Thus, for example, pricing roads of Castile-La Mancha leads to a loss of 4.4 potential units in Extremadura; however, pricing on Extremadura roads only entails a loss of 0.8 potential units in Castile-La Mancha. If we observe the values in the rows we can deduce that Madrid, Catalonia and Valencia are the regions that cause most spillovers. They are highly populated regions and have a dense road network. In addition Madrid shows a central location in the Iberian Peninsula, so that its motorways are used in many inter-regional relationships. In contrast, peripheral and less populated regions tend to cause fewer spillovers, especially when their motorway network is small (for example, Galicia, Asturias, Cantabria or Extremadura).

Table 6 shows the data of Table 5 as a percentage of the total of each column in order to focus attention on the origin of the accessibility losses of each region. It can be seen spillovers represent a major proportion of their accessibility losses. However, they are very variable. The greater part of accessibility losses in highly populated regions with many kilometres of high capacity network (such as Madrid, Catalonia or Andalusia) are due to pricing on their own roadways (internal relations); in regions with few charged network kilometres, in contrast, and a low population (such as Castile-La Mancha, Cantabria, Navarre or Extremadura) the majority of their accessibility losses are due to the spillovers caused by other regions.

From all of the foregoing it may be concluded that the spillover effects produced by road pricing in the Spanish regions vary with the following factors:

- The population of the region: Since the motorways of the most populated regions (such as Madrid, Catalonia or Valencia) are necessarily used in order to access their (big) markets, tolling these motorways reduces strongly the potential of these regions (due to their greater self-potential) and produces intense spillovers in other regions.
- The geographical position of the region: The transport infrastructure of a central region has a greater impact on inter-regional relationships. The implementation of charges in this infrastructure will penalize relationships more than it would do if the charges were to be introduced in a peripheral region. Therefore, the central regions tend to produce more spillovers than the peripheral ones.
- The length of the charged motorway network within the region: Regions with many kilometres of motorway network (such as Castile and León, Castile-La Mancha, Madrid, Andalusia) tend to produce more spillovers over other regions.

Table 5
Spillover matrix (in market potential units): S1B scenario.

	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castile and León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarre	Basque Country	Valencia	Total
Andalusia	−143.7	−0.3	−0.1	−0.1	−4.7	−0.4	−0.2	−1.9	−0.1	−0.2	−1.4	−8.8	−0.2	−0.1	−2.1	−164.3
Aragón	0.0	−31.0	−0.2	−0.5	−0.4	−0.7	−0.5	−0.1	−0.1	−3.9	−0.4	−0.1	−4.4	−0.8	−0.2	−43.3
Asturias	0.0	0.0	−50.9	−0.9	0.0	−0.8	0.0	−0.1	−0.2	0.0	−0.1	0.0	0.0	−0.2	0.0	−53.2
Cantabria	0.0	0.0	−1.3	−54.7	0.0	−0.2	0.0	0.0	−0.1	−0.2	0.0	0.0	−0.6	−7.5	0.0	−64.7
Castilla La Mancha	−1.5	−2.9	−0.1	−0.1	−66.2	−1.2	−0.4	−4.4	−0.1	−2.6	−24.6	−1.9	−2.3	−0.6	−4.5	−113.5
Castile and León	−0.2	−0.5	−0.9	−9.3	−1.5	−27.8	−0.1	−1.0	−0.5	−6.0	−4.1	−0.2	−1.7	−7.5	−0.1	−61.3
Catalonia	0.0	−3.6	−0.1	−0.2	−0.2	−0.3	−281.5	−0.1	−0.1	−1.0	−0.2	−0.2	−0.8	−0.4	−0.7	−289.4
Extremadura	−0.2	0.0	0.0	0.0	−0.8	−0.2	0.0	−12.4	0.0	0.0	−0.6	−0.1	0.0	0.0	−0.1	−14.5
Galicia	0.0	0.0	−0.4	−0.2	−0.1	−0.6	0.0	−0.1	−26.4	−0.2	−0.1	0.0	−0.1	−0.1	0.0	−28.3
La Rioja	0.0	−0.5	−0.3	−0.6	0.0	−0.7	−0.1	0.0	−0.1	−25.3	0.0	0.0	−2.0	−0.2	0.0	−29.8
Madrid	−1.0	−2.3	−1.5	−2.3	−110.2	−20.9	−0.4	−3.1	−0.7	−4.9	−905.2	−1.3	−2.5	−2.2	−3.0	−1061.5
Murcia	−1.1	0.0	0.0	0.0	−2.2	−0.1	0.0	−0.1	0.0	0.0	−0.4	−72.8	0.0	0.0	−2.7	−79.8
Navarre	0.0	−0.7	0.0	−0.3	0.0	0.0	−0.2	0.0	0.0	−1.0	−0.1	0.0	−17.5	−4.5	0.0	−24.4
Basque Country	0.0	−1.4	−0.5	−14.0	−0.2	−1.3	−0.1	0.0	−0.1	−11.3	−0.2	0.0	−19.1	−146.1	−0.1	−194.4
Valencia	−0.7	−1.8	0.0	−0.1	−6.6	−0.3	−2.2	−0.4	0.0	−0.5	−0.9	−12.1	−0.5	−0.2	−226.1	−252.5
Total	−148.5	−45.1	−56.4	−83.4	−193.2	−55.5	−285.7	−23.6	−28.4	−57.0	−938.4	−97.6	−51.7	−170.5	−239.9	−2474.8

Table 6
Spillover matrix (as a percentage of the total of each column): S1B scenario.

	Andalusia	Aragón	Asturias	Cantabria	Castilla-La Mancha	Castile and León	Catalonia	Extremadura	Galicia	La Rioja	Madrid	Murcia	Navarre	Basque Country	Valencia	Total
Andalusia	96.7	0.7	0.2	0.1	2.4	0.7	0.1	8.1	0.2	0.3	0.2	9.0	0.3	0.1	0.9	6.6
Aragón	0.0	68.7	0.3	0.6	0.2	1.3	0.2	0.4	0.3	6.9	0.0	0.1	8.6	0.5	0.1	1.8
Asturias	0.0	0.0	90.3	1.0	0.0	1.4	0.0	0.2	0.7	0.1	0.0	0.0	0.1	0.1	0.0	2.2
Cantabria	0.0	0.1	2.3	65.6	0.0	0.4	0.0	0.0	0.3	0.3	0.0	0.0	1.2	4.4	0.0	2.6
Castilla La Mancha	1.0	6.5	0.1	0.1	34.3	2.1	0.1	18.7	0.2	4.6	2.6	2.0	4.4	0.4	1.9	4.6
Castile and León	0.1	1.1	1.6	11.1	0.8	50.0	0.0	4.1	1.7	10.5	0.4	0.2	3.3	4.4	0.0	2.5
Catalonia	0.0	7.9	0.2	0.3	0.1	0.5	98.5	0.2	0.2	1.7	0.0	0.2	1.6	0.2	0.3	11.7
Extremadura	0.1	0.0	0.1	0.0	0.4	0.4	0.0	52.4	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.6
Galicia	0.0	0.1	0.8	0.2	0.0	1.1	0.0	0.3	93.0	0.3	0.0	0.0	0.1	0.1	0.0	1.1
La Rioja	0.0	1.1	0.5	0.8	0.0	1.3	0.0	0.0	0.2	44.4	0.0	0.0	3.8	0.1	0.0	1.2
Madrid	0.7	5.2	2.6	2.8	57.1	37.7	0.1	13.2	2.6	8.5	96.5	1.4	4.8	1.3	1.2	42.9
Murcia	0.8	0.1	0.1	0.0	1.1	0.2	0.0	0.6	0.1	0.0	0.0	74.6	0.0	0.0	1.1	3.2
Navarre	0.0	1.6	0.0	0.4	0.0	0.1	0.1	0.0	0.0	1.8	0.0	0.0	33.9	2.6	0.0	1.0
Basque Country	0.0	3.0	1.0	16.8	0.1	2.3	0.0	0.1	0.2	19.8	0.0	0.0	36.8	85.7	0.1	7.9
Valencia	0.5	4.0	0.1	0.1	3.4	0.5	0.8	1.7	0.1	0.8	0.1	12.4	0.9	0.1	94.3	10.2
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 7
Inequality measures for the different scenarios of light vehicles.

Scenarios	S0A	S1A	S2A	Change (%) over S0A	
				S1A	S2A
Variation Coefficient	64.2	62.8	66.7	−2.23	3.85
Theil index	0.0503	0.0484	0.0542	−3.84	7.59
GINI index	0.242	0.236	0.252	−2.43	4.18

Table 8
Inequality measures for the different scenarios of heavy vehicles.

Scenarios	S0B	S1B	S2B	Change (%) over S0B	
				S1B	S2B
Variation coefficient	73.7	72.1	74.2	−2.12	0.63
Theil index	0.0654	0.0633	0.0664	−3.20	1.53
GINI index	0.280	0.276	0.283	−1.56	1.09

– The proximity between regions: Spillovers are higher near the study region due to the gravity component of the market potential indicator that gives more weight to relationships over short distances.

4.4. Road pricing and territorial cohesion

Several commonly used inequality indexes (variation coefficient, Theil index and Gini index) have been used in order to measure road pricing effects on territorial cohesion. The results obtained are shown in Tables 7 and 8.

The implementation of a fee only in motorways (S1 scenario) will reduce the values of the three cohesion measures, so that accessibility differences among regions will decrease. In contrast, if the charge is also extended to the national road network (S2 scenario), the three measures increase in value, which means that the accessibility differences between regions increase. This tendency is visible for both light vehicles and heavy vehicles. But by comparing the values of the cohesion indices for both we may draw the following conclusions:

The distributions are always more polarised in the case of heavy vehicles. These greater differences are due to the disproportionately high travel time cost that heavy vehicles must bear in outlying regions, because of Spanish regulations regarding driving time (see Section 3.3).

The changes in cohesion introduced by pricing in both scenarios are greater for light vehicles than for heavy vehicles, since accessibility changes are higher for light vehicles.

5. Conclusions

In recent years the need for road pricing policies is more and more recognized among the EU member states. These policies are viewed as a way to finance the transport infrastructure, to reduce the negative externalities produced by road transport modes (accidents, pollution, congestion, etc.) and to achieve mobility patterns that are socially and environmentally more desirable. However, any pricing scheme has consequences on the accessibility of those who use the infrastructure. Assessing the accessibility impacts of a road pricing policy is important because, while new infrastructure increase accessibility levels, a road pricing policy produces an opposite effect.

Accessibility is one of the main objectives of national transport policies, because it is associated with greater economic development whereas the lack of accessibility is related to peripheral regions characterised by major problems of access to economic markets. Changes in the transport system have immediate repercussions on accessibility and in the long term may affect the spatial location of economic activities.

In this study we have used a methodology based on accessibility indicators and geographical information system (GIS) to assess road pricing impacts on accessibility. The impacts are measured for the entire Iberian Peninsula and also the southwest regions of France. Comparing the accessibility before and after the implementation of charges it was possible to analyse the impact of such a policy.

We have simulated three road pricing scenarios, differentiating between light and heavy vehicles: scenario S0 (no charge) considers only internal costs; S1 also includes external costs (internalised via pricing) as motorways are used; and S2 is similar to S1, but the pricing is also extended to national roads. It has been possible to show that the implementation of a road pricing policy produces a significant loss of road accessibility in all regions. But in relative terms, these losses are always greater in the case of light vehicles, in which external costs represent a larger proportion of the generalized transport cost.

We also have applied a methodology that measures the spillover effects of road pricing. The results have shown that a road pricing measure implemented in the motorways of a region reduces the accessibility not only in that region, but also in other regions. The magnitude of the negative spillovers produced by pricing in a region is variable. It depends on several factors as the population of the region, its location and the number of kilometres of tolled roads within the region.

When pricing is applied to motorways only, this penalization positively affects Spanish territorial cohesion, reducing accessibility inequalities. But a road pricing policy that tries to avoid traffic diversion from motorways to national roadways, not only produces a much greater impact on accessibility by road, but is also especially detrimental to the regions that already had a poorer level of accessibility, and increases the accessibility differences of the different regions while reducing territorial equity.

The results show that the application of a policy that places a charge on both the network of motorways and national roads in Spain (scenario S2) would have negative consequences in terms of both accessibility and territorial cohesion. Areas with prior market access problems would be more penalized. In contrast, a charge on motorways only (scenario S1) would have less negative effects on accessibility and would improve territorial cohesion.

Analysing spillover effects is important in political terms as it shows that the pricing implemented in a region penalizes the accessibility of neighbouring regions. Road pricing in one region may lead the inhabitants of other regions to access the charged region less frequently and may have a negative effect on its economic development. The study of spillovers provides useful information on the regions most penalized by road pricing policies applied elsewhere.

In conclusion, this paper has endeavoured to assess the impacts of different pricing measures on accessibility, an issue which to date has not been the subject of much research. Furthermore, for the first time, the role played by regional spillovers in the spatial impacts of pricing policies has been analysed and the effects of these policies on territorial cohesion have been assessed. The article has demonstrated that the analysis of road pricing impacts on accessibility is a useful tool for predicting and assessing the spatial effects of alternative policy options and may provide important information for decision-making.

Acknowledgement

This research has been funding by the Spanish Ministerio de Fomento (META and GESTA Projects).

Appendix A. Methodology for the calculation of transport costs in the META project

Source: Di Ciommo et al. (2010) and META project (Final Report)

Following the EU policy oriented to implement a tolling system based on social costs, Spain is studying the implementation of an interurban road pricing scheme. For this purpose a model has been developed in order to estimate the external costs produced by the road users and to assign them with a cost equivalent charge, following the experience of other European countries. The estimated internal and external costs and the scenarios proposed to the Ministry of Public Works study (Di Ciommo et al., 2010) are used as an input in this article.

The applied methodology for the calculation of transport costs defines the total cost function (C_T), which is expressed depending on the hourly traffic flow. Initially, four different vehicle categories were considered:

1. A standard light vehicle with a 2 L engine.
2. An 18 tons bus for passenger transportation.
3. An 18–20 tons rigid truck.
4. An articulated heavy vehicle for freight transportation.

The final expression for the total costs in euros per vehicle km is given by:

$$C_T = C_T(V_1, V_2, V_3, V_4) \quad \text{(A.1)}$$

being V_1, V_2, V_3 and V_4 the hourly volume of the different types of vehicles.

The marginal external cost, for each kind of vehicle, is obtained deriving the total external costs function:

$$C'_i = \frac{\partial C_T(V_1, V_2, V_3, V_4)}{\partial V_i} \quad i \in \{1, 2, 3, 4\} \quad \text{(A.2)}$$

The external costs derived from road traffic can be classified according to their nature as congestion costs, environmental costs (noise, climate change, pollution), costs of accidents and, in some cases, infrastructure (CE Delf, 2008).

The final road traffic social cost function is an additive function of these costs:

$$C_T = C_{T0} + C_{TC} + C_{TI} + C_{TENV} + C_{TA} \quad \text{(A.3)}$$

where C_{T0} is the operation costs (travel time, fuel consumption, lubricant, depreciation costs, and vehicle maintenance costs), C_{TC} the congestion cost (additional travel time cost and consumption costs during congestion), C_{TI} the maintenance and operation costs for infrastructure, C_{TENV} the environmental costs (CO_2, atmospheric pollution and noise costs), and C_{TA} is the costs of accidents.

A.1. Operation and congestion costs

Operation costs include travel time value, fuel consumption, and a constant including maintenance, lubricant and depreciation of the vehicle. The congestion cost is formulated like a time operation cost where the marginal time cost is strongly increasing and higher that the average time cost.

The travel time value for light vehicles was derived from the hourly average salary in Spain (data from the National Statistics Institute): 0.20 Euro/min. For heavy vehicles it was calculated according with data of the Spanish Observatory of Goods Transport (Ministry of Public Works, 2006), that includes accommodation and subsistence costs too: 0.30 Euro/min.

Fuel consumption and time cost are related with speed, using the relationship between speed and hourly flow (Transportation Research Board, 2000), according to:

$$\frac{\text{Fuel Cons.}}{\text{km}} = a_0 + \frac{a_1}{s} + a_2 S^2 \tag{A.4}$$

where s is the average travel speed (km/h) which is a function of the average hourly volume per lane (veh/h/lane).The parameters, a_0, a_1, a_2 are estimated for each type of vehicle following their technical characteristics.

From the traffic fundamental equation between traffic volume and density (A.5) as well as the parabolic relationship between traffic volume and speed, it is possible to obtain (A.6)

$$V_h = D \cdot s \tag{A.5}$$

where V_h is the hourly traffic volume per lane (veh/h/lane), D the traffic density (veh/km/lane), and s is the average travel speed (km/h).

Therefore, s could be expressed as a function of V_h:

$$S = 0.5 * s_{\max} \pm 0.5 * [s_{\max}^2 - (4 * V_h * s_{\max}/D_{\max})]^{0.5} \tag{A.6}$$

being $s_{\max}$ is the maximum travel speed (km/h) and $D_{\max}$ is the traffic maximum density (veh/km/lane).

In this way, we can estimate the fuel consumption for each vehicle by Eq. (A.4), once estimated the hourly volume by the following equation:

$$V_h = AADT \times (k \times d)/\eta \tag{A.7}$$

where *AADT* is the annual average daily traffic, k the *AADT*'s proportion in rush hour, d the *AADT*'s proportion in rush hour and sense top, and η is the number of total lanes.

Basically, each cost term depends on vehicle hourly traffic volume V_{hi} that can be calculated by the daily flow that is a known variable offered by the data map elaborated by the Spanish Ministry of Public Works.

A.2. Maintenance and operation costs for infrastructure

Only the maintenance costs related with wear and tear of road pavement are considered, which involve the biggest expenditure for the infrastructure operators, following the formulation proposed by Small et al. (1989):

$$C_{TI} = K_0 e^{-rTs} \tag{A.8}$$

where K_0 is a constant determining the maximum cost of conservation, r the discount rate and T represents the interval of time between maintenance operations.

T is specifically determined by means of the following equation:

$$T = \frac{\theta(Q)}{(1+\alpha)AADT_4 + \alpha AADT_{2/3}} \tag{A.9}$$

Thus, T depends on the road capacity and the Average Annual Daily Traffic of the different categories of heavy vehicles (page 1). Variable θ stands for values between 0 and 1, 0 being the most unfavourable situation. Finally, α is a weighting parameter related with the heavy vehicle axle weight. It is assumed that the presence of cars brings no extra maintenance cost. They can be ignored in comparison to the cost produced by heavy vehicles.

A.3. Environmental costs

Environmental costs were classified into three categories: costs related with CO_2 emissions; with noise caused by vehicles; and with atmospheric pollution.

Costs of CO_2 were estimated considering a ton cost of 20 Euros. CO_2 emissions costs are related to fuel consumption according to (Friedrich and Bickel, 2001):

$$C_{Env,CO_2} = C_{CO_2} \cdot K \cdot \sum_{i=1}^{i=4} V_i \cdot F_{C_i}(S_i) \tag{A.10}$$

where V_i is the hourly volume of vehicle type i, F_{Ci} (s_i) the fuel consumption depending on the speed of vehicle i, C_{CO_2} the CO_2 emission costs and K is a constant representing the relation between emissions and consumption.

The cost of noise caused by vehicles is related to the vehicle flow by a logarithmic function (Weinberger et al., 1991):

$$L_{eq} = a + 10 * \log(Q * (1 + b * p)) \tag{A.11}$$

where L_{eq} is the equivalent noise level, a and b the specific constants according to transportation modes (in this case, road), Q the overall vehicle flow in the stretch studied and p is the distribution of heavy vehicles regarding the total flow.

Finally, atmospheric pollution costs (in Euros per vehicle km) from particle emissions are considered. They depend on the population (P_t); the average value ϕ of the PM10 emissions (particles below 10 μm); the amount of new cases per million inhabitants from the new health effects i ($i = 1, \ldots, 8$), which are considered to be the consequences of a PM10 level of 10 μg/m^3 a year (n_i); and the cost on human health one each of these effects, according to the following expression:

$$CT_{Env,p} = \frac{P_t * \phi * \sum_{i=1}^{8} n_i c_i}{10} \tag{A.12}$$

A.4. Accident costs

External costs caused by road accidents have been classified as regards the slightly injured, serious injured and killed in an accident ratio (R_{sl}, R_{se}, R_k) and as regards the value associated with each type of casualty. The formula is a linear expression as regards vehicle flow:

$$CT_{acc} = V_i(R_{sl} * VR_{sl} * R_{se} * VR_{se} * R_k * VR_k + \varphi) \tag{A.13}$$

where V_i represents the traffic flow in vehicle i, R is the risk associated to the different types of accident victims, V the monetary value associated to those types of victims, and φ represents human capital losses and medical costs.

Marginal costs can be the optimal pricing principle in the case of congestion conditions. Since in Spain congested sections are very few, average and marginal costs are virtually identical. Thus road pricing based on marginal costs is equivalent to pricing by average costs. Therefore META proposed a pricing scheme based on average costs calculated for each type of vehicle following the interurban road characteristics (AADT, capacity and traffic composition for each section). The average external cost, for each kind of vehicle, was obtained by dividing the total external costs function on the traffic flow.

References

Beevers, S.D., Carslaw, D.C., 2005. The impact of congestion charging on vehicle emissions in London. Atmospheric Environment 39, 1–5.

Bröcker, J., Capello, R., Lundqvist, L., Meyer, J., Rouwendal, J., Schneekloth, N., Spairani, A., Spangenberg, M., Spiekermann, K., Van Vuuren, D., Vickerman, R., Wegener, M., 2004. Final Report of Action 2.1.1. of the European Spatial Planning Observatory Network (ESPON) 2000–2006 (Kiel: Christian-Albreschts-Universität Kiel).

Bruinsma, F.R., Rietveld, P., 1993. Urban agglomerations in European infrastructure networks. Urban Studies 30, 919–934.

Bruinsma, F.R., Rietveld, P., 1998. The accessibility of European cities: theoretical framework and comparison approaches. Environment and Planning A 30, 449–521.

Bureau, B., Glachant, M., 2008. Distributional effects of road pricing: assessment of nine scenarios for Paris. Transportation Research Part A 42, 994–1007.

Camagni, R., 2009. Territorial impact assessment for European regions: a methodological proposal and an application to EU transport policy. Evaluation and Program Planning 32, 342–350.

Clark, C., Wilson, F., Bradley, J., 1969. Industrial location and economic potential in Western Europe. Regional Studies 3, 197–212.

Copus, A.K., 1999. A New Peripherality Index for the NUTS III Regions of the European Union. Aberdeen, Rural Policy Group, Management Division, Scottish Agricultural College, Report Number, Report for General Directorate XVI.A.4 (Regional Policy and Cohesion).

Cowell, F., 1995. Measuring Inequality, second ed.. LSE Handbooks in Economics Prentice Hall, London.

Daniel, J., Bekka, K., 2000. The environmental impact of highway congestion pricing. Journal of Urban Economics 47, 180–215.

Dietzenbacher, E., van der Linden, J.A., Steenge, A.E., 1993. The regional extraction method: EC input–output comparisons. Economic Systems Research 5 (2), 185–206.

Di Ciommo, F., Monzón, A., Comendador, J., 2010. Road transport social costs in Spain: a new rationale for pricing policy ID 02235. In: Selected Proceeding of the 12th World Conference on Transport Research Society, pp. E3 02235-8–13, ISBN 978-989-96986-1-1.

EU, 1998. Fair Payment for Infrastructure Use: A Phased Approach to a Common Transport Infrastructure Charging Framework in the EU. White Paper. COM (98) 466 Final.

EC, 2004. A New Partnership for Cohesion: Convergence, Competitiveness, Cooperation: Third Report on Economic and Social Cohesion. Luxembourg, Office for Official Publications of the European Communities.

Eliasson, J., Mattsson, Lars-Göran, 2006. Equity effects of congestion pricing: quantitative methodology and a case study for Stockholm. Transportation Research Part A 40 (7), 602–620.

Forslund, U.M., Johansson, B., 1995. Assessing road investments: accessibility changes, cost benefit and production effects. The Annals of Regional Science 29, 155–174.

Frost, M.E., Spence, N.A., 1995. The rediscovery of accessibility and economic potential: the critical issue of self-potential. Environment and Planning A 27, 1833–1848.

Geertman, S.C.M., Ritsema Van Eck, Jan R., 1995. GIS and models of accessibility potential: an application in planning. International Journal of Geographical Information Systems 9, 67–80.

Gutiérrez, J., Monzón, A., Piñero, J.M., 1998. Accessibility, network efficiency, and transport infrastructure planning. Environment and Planning A 30, 1337–1350.

Gutiérrez, J., 2001. Location, economic potential and daily accessibility: an analysis of the accessibility impact of the high-speed line Madrid–Barcelona–French border. Journal of Transport Geography 9 (4), 229–242.

Gutiérrez, J., Condeço, A., Martín, J.C., 2010. Using accessibility indicators and GIS to assess and monetarize spatial spillovers of transport infrastructure. Journal of Transport Geography 18 (1), 141–152.
Hansen, W.G., 1959. How accessibility shapes land-use. Journal of American Institute of Planners 25 (2), 73–76.
Harris, C.D., 1954. The market as a factor in the localization of industry in the United States. Annals of the Association of American Geographers 44, 315–348.
Holl, A., 2004. Start-ups and relocations: manufacturing plant location in Portugal. Papers in Regional Science 83, 649–668.
Holl, A., 2007. Twenty years of accessibility improvements. The case of the Spanish motorway building programme. Journal of Transport Geography 15, 286–297.
Johansson, O., 1997. Optimal road-pricing: simultaneous treatment of time losses, increased fuel consumption, and emissions. Transportation Research Part D: Transport and Environment 2, 77–87.
Keeble, D., Offord, J., Walker, S., 1988. Peripheral Regions in a Community of Twelve. Brussels/Luxembourg: Office for Official Publications of the European Communities.
Karlström, A., Franklin, J.P., 2009. Behavioral adjustments and equity effects of congestion pricing: analysis of morning commutes during the Stockholm Trial. Transportation Research Part A 43, 283–296.
Linneker, B., Spence, N.A., 1992. Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain. Environment and Planning A 24, 1137–1154.
López, S., Gutiérrez, J., Gómez, G., 2008. Measuring regional cohesion effects of large-scale transport infrastructure investments: an accessibility approach. European Planning Studies 16, 277–301.
Lutter, H., Pütz, T., Spangenberg, T., 1992. Accessibility and Peripherality of Community Regions: The Role of Road, Long-Distance Railways and Airport Networks. Report Number, Report to the European Commission DG XVII. Bundesforschungsanstalt für Landeskunde und Raumordnung, Bonn.
Llano, C., Esteban, A., Pérez, J., Pulido, A., 2010. Breaking The Interregional Trade "Black Box": The C-Intereg Database for the Spanish Economy (1995–2005). International Regional Science Review 33, 302–337.
Martín, J.C., Gutiérrez, J., Román, C., 2004. Data envelopment analysis (DEA) index to measure the accessibility impacts of new infrastructure investments: The case of the high-speed train corridor Madrid–Barcelona–French border. Regional Studies 38 (6), 697–712.
May, A.D., Milne, D.S., 2000. Effects of alternative road pricing systems on network performance. Transportation Research Part A 34 (6), 407–436.
Ministerio de Fomento, 2005. Mapa de velocidades de tráfico 2005. Ministerio de Fomento, Madrid.
Morris, J.M., Dumble, P.L., Wigan, M.R., 1978. Accessibility indicators for transport planning. Transportation Research Part A 13, 91–109.
Olszewski, P., Xie, L., 2005. Modelling the effects of road pricing on traffic in Singapore. Transportation Research Part A 39, 755–772.
Pereira, M.A., Roca-Sagalés, O.R., 2003. Spillover effects of public capital formation: evidence from the Spanish regions. Journal of Urban Economics 53, 238–256.
Reggiani, A., 1998. Accessibility, Trade and Locational Behaviour. Ashgate.
Ribeiro, A., Pais, A., Páez, A., 2010. Road accessibility and cohesion in lagging regions: empirical evidence from Portugal based on spatial econometric models. Journal of Transport Geography 18 (1), 125–132.
Rich, D., 1975. Accessibility and Economic Activity: A Study of Locational Disadvantage in Scotland. Unpubl. PhD Thesis, Univ. of Cambridge.
Rotaris, L., Danielis, R., Marcucci, E., Massiani, J., 2010. The urban road pricing scheme to curb pollution in Milan, Italy: description, impacts and preliminary cost–benefit analysis assessment. Transportation Research Part A 44, 359–375.
Schürman, C., Spiekermann, K., Wegener, M., 1997. Accessibility Indicators. Berichte aus dem Institut für Raumplanung, 39, IRPUD, Dortmund.
Schürmann, C., Talaat, A., 2000. Towards a European Peripherality Index. Dortmund: Report Number, Final Report.
Spence, N., Linneker, B., 1994. Evolution of the motorway network and changing levels of accessibility in Great Britain. Journal of Transport Geography 2, 247–264.
Tillema, T., van Wee, B., de Jong, T., 2003. Road pricing from a Geographical Perspective: A Literature Review and Implications for Research into Accessibility. Paper Presented at the 43rd ERSA Congreso, Jyväskylä (Finland).
Tillema, T., Jong, T., Wee, B., 2007. Modelización de la accesibilidad geográfica en condiciones de tarificación viaria. In: Martín, J.C., Reggiani, A., Rietveld, P. (Eds.), Las redes de transporte desde un enfoque multidisciplinar. Thomson Civitas, pp. 397–426.
Tillema, T., Jong, T., Wee, B., van Amelsfort, D., 2008. Sensitivity of geographical accessibility measures under road-pricing conditions. In: Steg, L., Verhoef, E., Bliemer, M., van Bee, B. (Eds.), Pricing in Road Transport. Edward Elgar Publishing.
Viegas, J.M., 2001. Making urban road pricing acceptable and effective: searching for quality and equity in urban mobility. Transport Policy 8, 289–294.
Friedrich, R., Bickel, P., 2001. Environmental External Costs of Transport. Springer, Berlin.
Ministry of Public Works, 2006. Encuesta Permanente del Transporte de Mercancías por Carretera 2005. Madrid, Centro de Publicaciones, Secretaría General Técnica, Ministerio de Fomento.
Small, K.A., Winston, C., Evans, C.A., 1989. Road Work: A New Highway Pricing and Investment Policy. The Bookings Institution, Washington.
Transportation Research Board, 2000. Highway Capacity Manual. TRB, Washington.
Weinberger, M., Thomassen, G., Willeke, R., 1991. Kosten des Lärms in der Bundesrepublik Deutschland. Berichte 9/91 des Umweltbundesamtes, Berlin.

2.5 EVALUATING THE EUROPEAN ADDED VALUE OF TEN-T PROJECTS: A METHODOLOGICAL PROPOSAL BASED ON SPATIAL SPILLOVERS, ACCESSIBILITY AND GIS

Gutiérrez, J., Condeço-Melhorado, A., López, E., Monzón, A. (In Press): Evaluating the European added value of TEN-T projects: A methodological proposal based on spatial spillovers, accessibility and GIS. ***Journal of Transport Geography.*** doi:10.1016/j.jtrangeo.2010.10.011. (JCR. Impact factor: 1,421)

This work was done as part of the Transportrade network and the HESTEPIT project (within the MICINN's national R+D plan). The preliminary results were presented at the NECTAR Cluster 6 Meeting on Accessibility, Policy Making and Spatial Planning in Cagliari (Condeço-Melhorado et al., 2009b), and more recently at the 4th National Congress of Geographic Information Technologies in Seville (Condeço-Melhorado et al., 2010).

The study aims to measure the European added value (EAV) of the projects included in the trans-European transport networks (TEN-T) by calculating transnational spillovers. Until the present, the methodology was applied to the assessment of transport plans carried out on a national level. However this study measures the spillovers generated by the different segments of a project.

Many of the TEN-T infrastructure form transport corridors to be built between several countries. Although these infrastructures are of interest to Europe as a whole, they are assessed from the national standpoint, which frequently means that parts of these projects are considered to be loss-making and are never brought to conclusion.

There are currently a series of TEN-T projects remaining to be completed and with little prospect of this occurring in the near future, owing to financing problems. In practice, the most efficient connections –those which connect the main economic centres and support a greater volume of traffic– are the first to be built, whereas the segments located in peripheral areas are postponed indefinitely. However, if supranational and EU interests are studied in their conjunction, it is precisely these peripheral segments which have the greatest EAV, due to the fact that they contribute to the completion of the major European transport axes. Thus the segments considered as loss-makers from the national standpoint, but which have a high EAV, should receive more aid from community funds.

The case study used in this work is Project 25, one of the 30 projects defined as priority areas within the framework of the TEN-T. This involves the construction of a high-capacity road to connect the port city of Gdansk (in northern Poland) with Vienna, passing through Lodz (Poland) and Brno (Czech Republic), and with Bratislava (Czech Republic). The project was divided into 16 segments and the spillover methodology was applied in order to assess the EAV of each segment. The effects are measured for the whole of the EU: the greater the spillover effect, the greater the EAV of the segments considered.

In this case the scenarios are approached differently to the previous studies, given that a single project is assessed. The reference scenario is the completion of the whole of Project no. 25, and the partial scenarios are built by extracting segments instead of regions.

The distance exponent in the potential accessibility model is calibrated using data on commerce in tons between the NUTS-2 regions. The self-potential is calculated considering the area of each zone and its population density. One of the methodological achievements in the article is the calculation of the border effect, which is measured by reducing the importance of international destinations in the accessibility model based on data for cross-border flows.

The results show that the border segments of the project usually generate more spillovers and fewer internal benefits. For this reason these segments generally have a greater EAV. However this depends on the strategic function of the segment for the country that builds it. Thus for example in spite of the fact that the segment between Trečin and Bratislava is a border segment, it has a very significant internal function for the Slovaks themselves, given that it improves connections with their capital.

In addition to determining the EAV for each segment of the project, the methodology used contributes information on its efficiency and its impact on territorial cohesion.

Journal of Transport Geography xxx (2010) xxx–xxx

Contents lists available at ScienceDirect

Journal of Transport Geography

journal homepage: www.elsevier.com/locate/jtrangeo

Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS

Javier Gutiérrez [a,*], Ana Condeço-Melhorado [b], Elena López [c], Andrés Monzón [c]

[a] Departamento de Geografía Humana, Facultad de Geografía e Historia, Universidad Complutense de Madrid, Calle Profesor Aranguren, s/n, 28040 Madrid, Spain
[b] Departamento de Geografía, Universidad de Alcalá, Calle Colegios, 2, 28801 Alcalá de Henares, Spain
[c] TRANSyT-UPM, Centro de Investigación del Transporte, Universidad Politécnica de Madrid, Calle Profesor Aranguren, s/n, 28040 Madrid, Spain

ARTICLE INFO

Keywords:
European value added (EVA)
Trans-European Transport Networks (TEN-T)
Trans-national projects
Project appraisal
Spatial spillovers
Accessibility

ABSTRACT

This paper develops a methodology for calculating the European value added value (EVA) generated by transport infrastructure projects. This approach is particularly useful for evaluating projects in the framework of Trans-European Transport Networks (TEN-T), although it may also be used in trans-national projects in other geographical areas. The methodology is based on the appraisal of spatial spillovers generated by trans-national projects by using accessibility indicators (access to markets) and Geographical Information Systems (GIS). Projects are split into sections and spillover effects of each section are then computed. The sections that produce a high proportion of spillovers in relation to internal benefits generate a high EVA. Additionally, indicators are obtained of the effects of each section in terms of spatial concentration on the different countries affected, efficiency (general improvement in accessibility) and territorial cohesion (reduction in accessibility disparities between regions). The validity of this approach is verified by applying it to TEN-T priority project 25. This methodology does not seek to replace existing project appraisal methodologies (particularly the cost-benefit analysis); rather it provides complementary data for decision-making. Sections which are scarcely profitable from the cost-benefit analysis perspective but which have high European value added should receive more European funding than more profitable sections of markedly national interest.

1. Introduction

Historically, most European countries have given priority to the development of their national transport networks; this favoured the integration of their territories and the consolidation of truly national markets. In contrast, less attention was paid to links with other countries. The result at the supranational level, therefore, was the existence of a set of independently developed national transport networks, weakly interconnected. In a context of progressive European integration, improving connections between member States constitutes a political priority.

Articles 154–165 of the EC Treaty define Trans-European Transport Networks (TEN-T) policy in an attempt to transcend national attitudes and adopt a European dimension. Consequently, the EU may support projects of "common interest" among Member States proposals (Commission of the European Communities, 2009). Viewed from this perspective, major European transport corridors are the focus of interest, rather than connections within one country. In this context, a set of missing links has been identified; that is, non-existent, or insufficient, international links which are strategic from the European point of view and have high "European value added" (EVA) (van Exel et al., 2002) or an important "community component" (Roy, 2003). In this context the concept of "European value added" can be defined as the extent to which a policy action increases transport efficiency or stimulates new development which is over and above what is seen as a national or local priority (van Exel et al., 2002). Projects with a high European value added should contribute to the welfare and efficiency of the single market. From this point of view, cross-border effects (trans-national spillovers) are of special relevance and should be considered as important elements for the evaluation of TEN projects (van Exel et al., 2002).

The TEN-T program consists of many projects whose purpose is to ensure the cohesion, interconnection and interoperability of the trans-European transport network (Commission of the European Communities, 1994). As a whole, TEN-T projects aim to:

- Establish and develop the key links and interconnections needed to eliminate existing bottlenecks to mobility.
- Fill in missing sections and complete the main routes – especially their cross-border sections.

* Corresponding author.
E-mail addresses: javiergutierrez@ghis.ucm.es (J. Gutiérrez), ana.condeco@alu.uah.es (A. Condeço-Melhorado), elopez@caminos.upm.es (E. López), andres.monzon@upm.es (A. Monzón).

0966-6923/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jtrangeo.2010.10.011

- Cross natural barriers.
- Improve interoperability on major routes.

The selection of TEN-T "priority projects" to be part-financed by European funds is largely associated with the definition of transport networks of European interest (Commission of the European Communities, 2009).

There is increasing insistence on the need to develop integrated methodologies to cover a wider range of impacts in the appraisal of strategic plans and projects such as the TEN-T (Beuthe, 2002). However, a consensus has yet to be reached on the procedure for appraising these effects, and to subsequently include them in the appraisal methodologies. The recent TEN-T Green Paper (Commission of the European Communities, 2009) raises the question of the methodological soundness of the selection of priority projects, both geographically and modally. One of these impacts is the project's contribution in terms of European value added. Due to their very dimension and their trans-national nature, international projects have much greater effects and they require more criteria to be taken into consideration than domestic projects (van Exel et al., 2002; Roy, 2003). Criteria such as the project's contribution to regional integration (Lopez et al., 2009) or community integration (Roy, 2003) and its effects on territorial cohesion are typical issues with regard to this type of project. Both these issues are important from the point of view of funding transport infrastructure projects in the European Union: the goal of supranational integration should be taken into account in order to grant better funding terms to projects with greater European value added, and the project's contribution to reducing regional disparities should also be considered.

In this context, this paper proposes a methodology for appraising the European value added of transport infrastructure projects, based on calculating spillover effects by means of accessibility indicators and Geographical Information Systems (GIS)[1]. The paper proposes that not only should the project as a whole be appraised but also each one of its sections, since each of them may contribute in a different way to TEN-T project goals and also require different funding. The methodology proposed also provides information on the contribution of each section of the project to the goal of territorial cohesion. TEN-T priority Project 25 has been chosen as a case study due to its markedly trans-national character; it crosses four European countries (Poland, Czech Republic, Slovakia and Austria). The structure of the article is as follows. After this brief introduction, Section 2 introduces the concept of European value added and reviews the latest developments in researching the analysis and application of the latter to appraising transport infrastructure projects. Section 3 outlines the methodology proposed, which is subsequently validated by applying it to the abovementioned case study in Section 4. Finally, Section 5 includes a discussion and some final considerations.

2. European value added and spatial spillovers of transport infrastructure projects

2.1. Spatial spillovers and European value added

Trans-national projects produce a number of impacts that go beyond so-called "direct impacts" to include others called "wider policy impacts" (Grant-Muller et al., 2001). One of these impacts is the abovementioned European value added, which is also called the "Community component" of transport infrastructure projects (Roy, 2003), that is to say, the degree to which the project contributes to the goal of European integration by helping to develop truly Trans-European Transport Networks.

The European value added of a trans-national project is closely related to its spillover effects, i.e., the benefits a country receives from the infrastructures built in another country (Pereira and Roca-Sagalés, 2003)[2]. Logically, the projects with greatest spillover effects (a large part of the benefits generated by a section built in one country spreads to neighbouring countries and vice versa, so that a true exchange of spillovers occurs) are the ones that contribute most to the goal of European integration. In this context, three types of projects may be differentiated from the perspective of the spillovers they cause (Van Exel et al., 2002):

- *National projects* – These are projects that are carried out within one country but which produce benefits in neighbouring countries, especially when they are located close to the border.
- *Cross-border projects* – They affect two countries and attempt to improve integration by improving or constructing a new link across the common border.
- *International transport corridors* – These are larger and involve the creation or improvement of an international transport hub crossing two or more countries.

Logically, cross-border projects produce greater spillover effects and have a greater regional integration value than national projects; and international transport corridors, due to their size, have greater effects than cross-border projects. However, if spillover effects are calculated in relative rather than absolute terms (for example, spillover effect per kilometres of project) cross-border projects generate greater integration effects than international corridors, as the latter include sections which are really border sections (with major effects) as well as others which are far from the border (with minor effects) It must be noted that spillovers are inversely proportional to distance and also depend on the position of the section with regard to the border: thus, for example, a national project parallel to the border produces fewer spillover effects than one approaching the border perpendicularly.

Spillovers are closely related to the network effect (Laird et al., 2005; Banister and Berechman, 2001). From a spatial point of view, the network effect means that an improvement in one element of a network (an arc or a node) produces positive effects in many other elements of the network. Part of the network effect is confined to the country in which the infrastructure is built, but another part may spill over its borders and generate benefits (spatial spillovers) in other countries. These spillover effects are of special importance in the case of major cross-border transport infrastructure corridors, precisely because they generate potential spillovers on very large areas due to the network effect.

2.2. Implications for the appraisal process of cross-border transport infrastructure projects

In the context of developing TEN-Ts, a prime use of calculating European value added is precisely to assess the impact of the different projects from the perspective of European integration; this would enable projects that contribute to that goal to be looked on more favourably. In these projects, the sections built in each

[1] This methodology may be also be applied to appraise international transport infrastructure projects in other geographical contexts where regional integration initiatives are proposed, such as in the case of IIRSA (*Iniciativa de Integración Regional Sur Americana* – South American regional integration scheme), in which all the countries of South America are participating.

[2] On a European scale, the paradigm of this type of trans-national project is to be found in TEN-Ts. Appraisal of the spillover effects of TEN-T projects may be approached by spatial analysis in a complementary way to the cost-benefit approach or multicriteria analysis. It is not, therefore, a question of seeking alternative methodologies to traditional assessment procedures but of integrating methodologies that provide complementary information in the appraisal.

Please cite this article in press as: Gutiérrez, J., et al. Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS. J. Transp. Geogr. (2010), doi:10.1016/j.jtrangeo.2010.10.011

country produce a positive spillover effect in other countries. The possibility of calculating the extension and the intensity of spillover effects of transport infrastructure projects, therefore, acquires special interest in appraising cross-border projects from the perspective of the allocation of costs and benefits between the countries involved. In these projects the costs for each country are well known (they correspond to the section built in its territory) but the benefits produced as spillovers are less well known. Knowing the benefits deriving from spillover effects may provide a rational basis for the decision-making process when seeking acceptable solutions for different countries. From the perspective of TEN-Ts, projects or project sections that generate intense spillovers would have high European added-value, so they would be contributing to the goal of improving network interconnection, particularly in the case of border sections.

Another element to appraise relates to the TEN-T program's objective of promoting territorial cohesion. This paper uses the term territorial cohesion in the same sense as the Third Cohesion Report, that is, as a synonym for "more balanced development", "territorial balance" or "avoiding territorial imbalances" (Commission of the European Communities, 2004; see also Camagni, 2009 and López et al., 2008). In this sense, it is interesting to assess the different intensity of impacts on the territory in order to ascertain the distributive effects of the project that is, whether greater positive effects occur in less favoured regions, in terms of prior accessibility or other socioeconomic indicators such as income per capita or unemployment (Hay, 1995). On a national scale it is a question of assessing whether the balance between "exported" and "imported" benefits due to spillover effects favours the country with a higher or a lower accessibility or income level. At a regional level, it must be considered that by definition cross-border projects affect border regions more intensively, generally speaking in a situation of marginalisation or at least one of disadvantage compared to other parts of the country, precisely because of the negative border effects; an analysis of the distributive effects of this type of projects, therefore, must also be taken into account in decision-making. A cross-border project may have the virtue of transforming a peripheral area (from a national perspective) into a central one (from the perspective of the new international relations created). Therefore, an analysis of the distributive effects of this type of projects must also be taken into account in decision-making.

3. Proposed methodology

3.1. The market potential indicator: border effect and calibration

Accessibility analysis has been widely used in regional and transport research (Reggiani, 1998), boosted in recent years by the development of network analysis routines in the GIS environment. However, it is acknowledged that the potential of accessibility analyses in transport planning has yet to be fully exploited (Halden, 2003). One of the fields with promising perspectives is spillover analysis, which has direct application in assessing the profitability of transport infrastructure project investments. However, to date accessibility indicators have not been included in transport infrastructure assessment methodologies (Grant-Muller et al., 2001). The great advantage of accessibility analyses via GIS is that they enable the network effect, and therefore the geographical dimension of the project, to be identified spatially (the territory in which the project causes significant impacts), and they also enable the intensity with which spillovers occur to be determined (López et al., 2009; Gutiérrez et al., 2010). Therefore, it is possible to determine the spillovers produced by each project as an indicator of its European value added by means of an accessibility analysis. Projects with high European added value should receive better funding terms from the European Union than those with a national dimension.

There are many approaches and very varied formulations with which to address accessibility analysis (see, for example, Pirie, 1979; Koenig, 1980; Song, 1996; Kwan, 1998; Geurs and van Wee, 2004). Accessibility can be defined as the ease with which activities may be reached from a given location by using a certain transport system (Morris et al., 1978), or in other words, the opportunities available to individuals and companies when reaching those places in which they carry out their activities (Linneker and Spence, 1992).

Accessibility indicators may be used to help decide what transport infrastructure projects contribute most to improving access to other countries' markets and, therefore, to the goal of European integration. The accessibility indicator used in this paper is market potential (Hansen, 1959), which has been used in many studies. Economic or market potential can be interpreted as the accessibility of opportunities from a zone i to all other zones j in which smaller and/or more distant opportunities provide diminishing influences (Geurs and van Wee, 2004). This feature has prompted an extensive use of the potential model for accessibility studies approached from an economic perspective (Bruinsma and Rietveld, 1998). The underlying assumption in the use of this model is that regions with better access to markets have a higher probability of being economically successful (Wegener and Bökemann, 1998). According to this model, the level of opportunities between a place i and a destination node j is positively related to the mass of the destination and inversely proportional to the distance or travel time between both nodes. Its classical mathematical expression is as follows:

$$P_i = \sum_{j=1}^{n} \frac{m_j}{d_{ij}^x}, \quad (1)$$

where P_i is the market (economic) potential of node i, m_j is the mass (in our case, GDP) of the destination j, d_{ij} is the distance (in our case, travel time) by the minimum-time route in the network between origin i and destination j, and x is a parameter that reflects the effect of the distance decay function.

This x parameter is particularly critical in market potential analyses, as a low value may overestimate long-distance relations and a high value may underestimate them; this means it must be calibrated with passenger or freight travel demand data (see, for example, Reggiani and Bucci, 2008). On the other hand, with regard to the distance decay function, the border effect must be taken into consideration; according to this, trade and passenger flows undergo a sharp fall at national borders (Knowles and Matthiessen, 2009; McCallum, 1995). This sharp fall does not only depend on tariffs and quotas, but also on factors such as geographical proximity, and border 'barrier' effects such as language, different currencies, passport and border controls, trade policy, different taxation systems, common history and quality of governance (de Groot et al., 2004; Knowles and Matthiessen, 2009). In the case of Europe it has been verified that averaged over all EU countries, intranational trade is about ten times as high as international trade with an EU partner country of similar size and distance (Nitsch, 2000). Therefore, although it is true that freight traffic tends to fall progressively with distance, one must also consider that borders represent abrupt changes in those trade flows.

On the basis of these considerations, in order to take the border effect into account when calculating market potential, international relations have been given ten times less weighting than would be attributed to them if those relations were between regions in the same country. For this purpose, the GDP of the destination has simply been divided by ten in international relations, so that the value of each of these relations when calculating the market potential of each origin diminishes by the same proportion. The travel time exponent has been calibrated from trade data in tonnes between NUTS-2 regions (there are no data available at the NUTS-3 level) considering only the internal relations of the countries in the project. Calibration was conducted with an unconstrained gravity model, available in Flowmap® software (see de Jong et al., 2000), and a value of 1.77 was obtained.

Hence, the economic potential model provides a realistic approach to the question of the ease of access to markets from each region, as it considers the GDP of the destination region as a *proxy* of its market, a progressive fall in trade relations with distance for national relations (calibration with internal relations from trade flow data between its regions) and a sharp fall in these relations at national borders (reduction in the importance of destinations in international relations due to the border effect).

3.2. Appraisal scenarios

The common practice when planning transport infrastructure is to assess the project as a whole in order to determine its profitability and where appropriate funding needs according to the principle of subsidiarity[3] of the member countries of the European Union.

However, cross-border projects and corridors are usually very long, with the result that the different sections may have different funding needs. Internal sections in a country connecting two large cities may be profitable, but border links are not usually profitable from the point of view of each country, as the forecasted travel demand is low due to the abovementioned border effect (McCallum, 1995; Chen, 2004). The European Union, therefore, in accordance with the principle of subsidiarity and the aims of TEN-T should help to fund these links. Viewed in this way, the appraisal of each of its sections should be added as a second step to the traditional assessment of the project as a whole, in order to differentiate those which are of fundamentally national interest from those having a truly European interest. The European Union would thus have a mechanism for assigning financial resources in a better way: when spillovers are high with regard to internal benefits it is reasonable to think that these sections should receive special funding attention from the European Union, as they have high European value added.

Scenarios must be set out in a different way from the usual one to calculate spillovers generated by each section. To evaluate spillovers generated by the project as a whole the usual scenarios with and without a project are constructed (see, for example, Linneker and Spence, 1992; Dundon-Smith and Gibb, 1994; Gutiérrez, 2001). But in this case what is compared for each section is the scenario "with a project" (reference scenario) and the scenario with a project except for the section being appraised, which remains in the without a project situation (therefore, what changes between the two scenarios is only the section being evaluated). By comparing these two scenarios, we assess the distribution of spillover effects between the countries involved – in terms of enhanced access to markets – generated by that particular section of the project. That second scenario should be repeated for each section in order to calculate spillovers produced by each one of them. It is obvious that the assessment scenarios of each section are not realistic insofar as the project acquires full meaning when considered as a whole, but they are useful as assessment scenarios in terms of appraising the European value added of each section.

This methodology is based on the hypothetical extraction method for calculating regional spillovers of transport infrastructure plans (Gutiérrez et al., 2010). But instead of extracting the future infrastructures of each region, what is extracted is each section of the project in order to construct the different scenarios. By comparing each of these scenarios with the reference scenario (construction of the complete project) it is possible to ascertain the amount of benefits received from spillover effects in each region in terms of market access.

3.3. Implementing the proposed methodology: the case study of the TEN-T priority project 25

To test the proposed methodology project 25 of the TEN-T priority projects is appraised[4]. This project consists of the construction of a motorway from Gdańsk (in the north of Poland) which diverges in the south of the country: one section leads to Vienna (in the west) and the other to Bratislava (in the east). The project has been divided into 16 sections, in order to ascertain the spillover effects of each one of them (Fig. 1).

The economic potential indicator was obtained using a commercial GIS (ArcGIS) that includes specific network simulation routines for the calculation of minimum paths through the network. As origins and destination we considered NUTS-3 regions, which are the smallest spatial unit covering all EU countries, with socioeconomic information available for all the study area. We use the GDP of each NUTS-3 region, referring to the year 2005, to represent the attraction of the destinations.

A dense digital road network covering all EU countries was used for the calculation of travel times among zones. It has 377,797 arcs including the main roads and ferry connections. Each arc has information about its type (road or ferry); road class; speed in free flow according to the class of road of each arc; length; travel time; and a waiting time when a connection with ferry exists. The network as well as NUTS-3 data were provided by the TRANS-TOOLS model[5].

The impedance between each origin and destination (parameter D_{ij} in Eq. (1)) was calculated considering the shortest travel time route between the two points, plus a penalty for entering and leaving the transport zones (they can be interpreted as access and dispersion times, since most of the trips do not start in the centroid of the origin zone and end in the centroid of the destination zone). This can be seen in the following formula:

$$D_{ij} = p_i + tr_{ij} + p_j \quad (2)$$

where tr_{ij} is the impedance between origin i and destination j, p_i is a penalty for leaving the origin zone i, p_j is a penalty for entering the destination zone j.

The penalties for leaving and entering the origin and destination zones are equivalent to half the internal travel time of the respective NUTS 3 regions. This is a critical issue in the calculation of the potential market indicator, since the self-potential (internal accessibility) can represent an important part of the total potential market of the zone (Bruinsma and Rietveld, 1998). For the estimation of the internal travel time of each zone an

[3] The principle of subsidiarity is defined in Article 5 of the 1992 Treaty of Maastricht establishing the European Community. It is the principle whereby the Union does not take action unless it is more effective than action taken at national, regional or local level.

[4] This project can be consulted in http://ec.europa.eu/transport/infrastructure/maps/maps_en.htm.

[5] TRANS-TOOLS ("TOOLS for TRANSport Forecasting and Scenario testing") is an European transport network model that has been developed in collaborative projects funded by the European Commission Joint Research Centre's Institute for Prospective Technological Studies (IPTS) and DG TREN. More information about the data used in this study can be consulted in the web page http://energy.jrc.ec.europa.eu/transtools/index.html.

Fig. 1. Sections of the TEN-T priority project 25.

average internal travel distance was estimated according to (Rich, 1978):

$$D_{ii} = \frac{1}{2}\sqrt{\frac{\text{area}}{\pi}} \qquad (3)$$

D_{ii}, being a proxy for the internal distance (km) within each zone.

The internal travel time depends not only on internal distances but also on the average travel speeds within the zones. Since some NUTS are urban in nature (such as, for example, Warsaw) and other ones are rural, a congestion effect should be considered within zones. Thus internal average travel speeds in this paper were estimated taking into account the population density of the zones (as a proxy of the congestion), from a maximum speed of 80 km/h within the lowest populated zone to a minimum of 20 km/h within the most populated one. Finally, the internal travel time within each zone was calculated using the estimated internal distances and speeds.

Once the times matrix has been obtained, the market potential of each area in each scenario is calculated, using the GDP of each NUTS region as a *proxy* of the volume of its market. Therefore, by comparing the with-project scenario (reference scenario) and the with-project scenario except for one section we obtain the benefits which, in the project framework, that section produces in terms of market access (expressed in market potential units). Differentiating between internal benefits (those that stay in the country in which the section is located) and external benefits (those that are exported to other countries in the form of spillovers) we obtain an indicator expressing the EVA of each section. As the sections have different lengths, the benefits (increase in economic potential) are expressed in relative terms (in relation to the number of kilometres of each section); this allows us to compare the results.

4. Results

The results may be presented in a disaggregated way as maps or in an aggregated way as tables. Fig. 2 shows spillovers generated by the internal Łódź – Piotrków Trybunalski (Poland) section in terms of enhanced market access (measured in potential accessibility units per kilometre constructed). Poland is shaded in grey in order to highlight the changes occurring beyond its borders (spillovers). Figs. 3 and 4 map the spillovers generated by the border sections Bielsko-Biala – Poland/ Czech Republic border (Poland) and Trečin – Bratislava (Slovakia).

The analysis was repeated for all the 16 sections of project 25, so that for each NUTS-3 region there is a value for the spillovers produced by each section of the project. The national aggregate value of spillover effects in country j from the investment made in section i (in potential units) is obtained by a weighted average of these of the NUTS regions of country j, using population as the weighting factor, as follows:

$$S_{ij} = \frac{\sum_k s_{kij} w_{kj}}{\sum_k w_{kj}} \quad (4)$$

where S_{ij} are average spillover effects (gains in potential) in country j from the investment on section i, s_{kij} are spillover effects in each kth NUTS region within country j from the investment made in section i, and w_{kj} is the population of each kth NUTS region within the country j.

The results are presented in Table 1. Countries are ordered according to the magnitude of received spillovers (last row). Hence, for example, row number 4 shows spillovers produced by the Łódź – Piotrków Trybunalski section (in market potential units per kilometre constructed) (see also Fig. 2). The majority of benefits are internal (they stay in Poland), as this section is located in the interior of the country. However, this section generates major spillovers in the Baltic countries (their accessibility to Katowice, Bratislava, Vienna and other Central European cities is improved). Noteworthy spillovers may also be observed in Slovakia, the Czech Republic, Austria and Hungary, whose accessibility to the north of Poland and the Baltic states is increased. The spillovers are asymmetrical: in general, the Baltic States improve more than Central European countries as the GDP of the latter is far greater than that of the former.

Border sections tend to produce fewer internal benefits and more spillovers. This can be seen, for example, in the case of the section Bielsko-Biala – Poland/Slovakia border (Fig. 3), which generates more spillovers in the country situated on the other side of

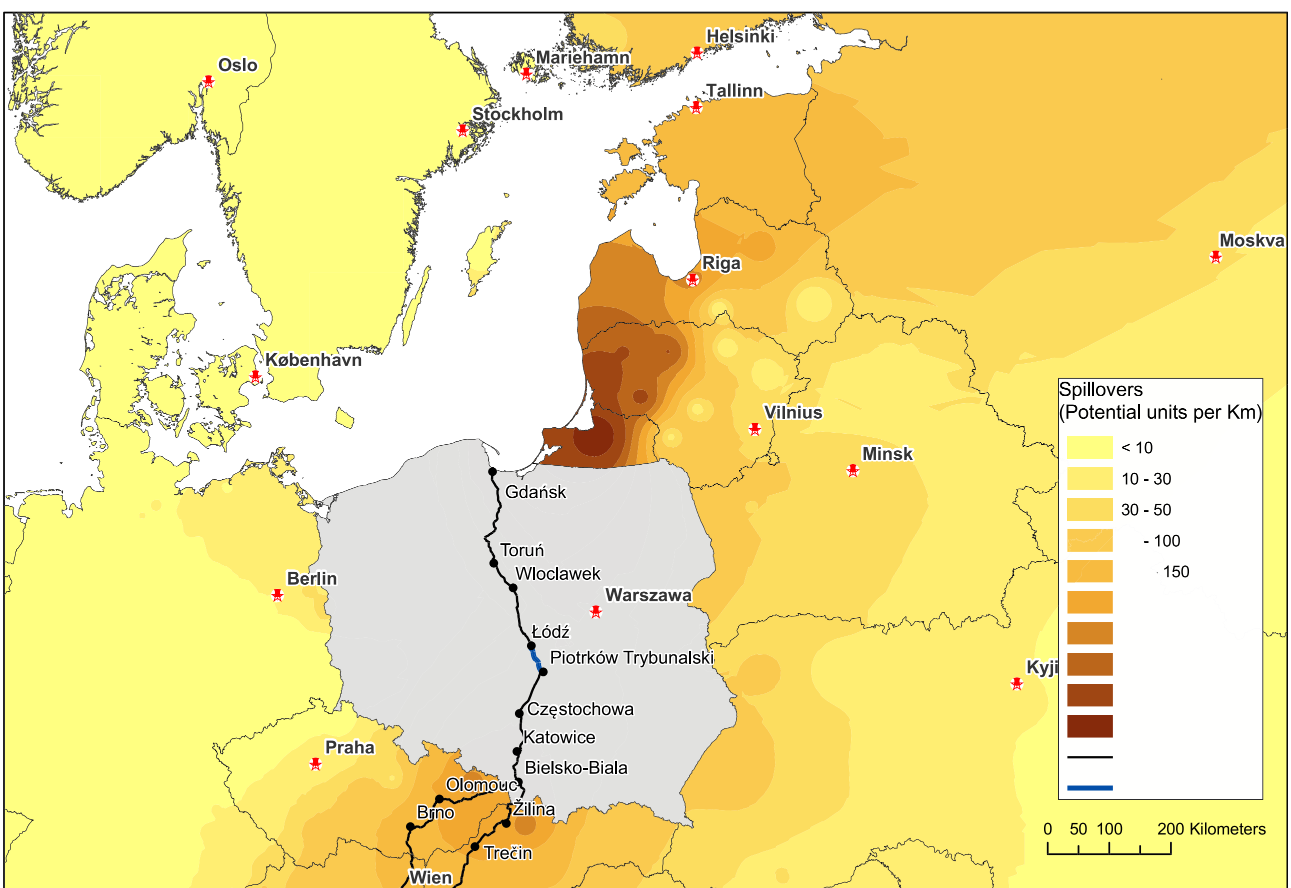

Fig. 2. Spillovers generated by the internal Łódź – Piotrków Trybunalski section.

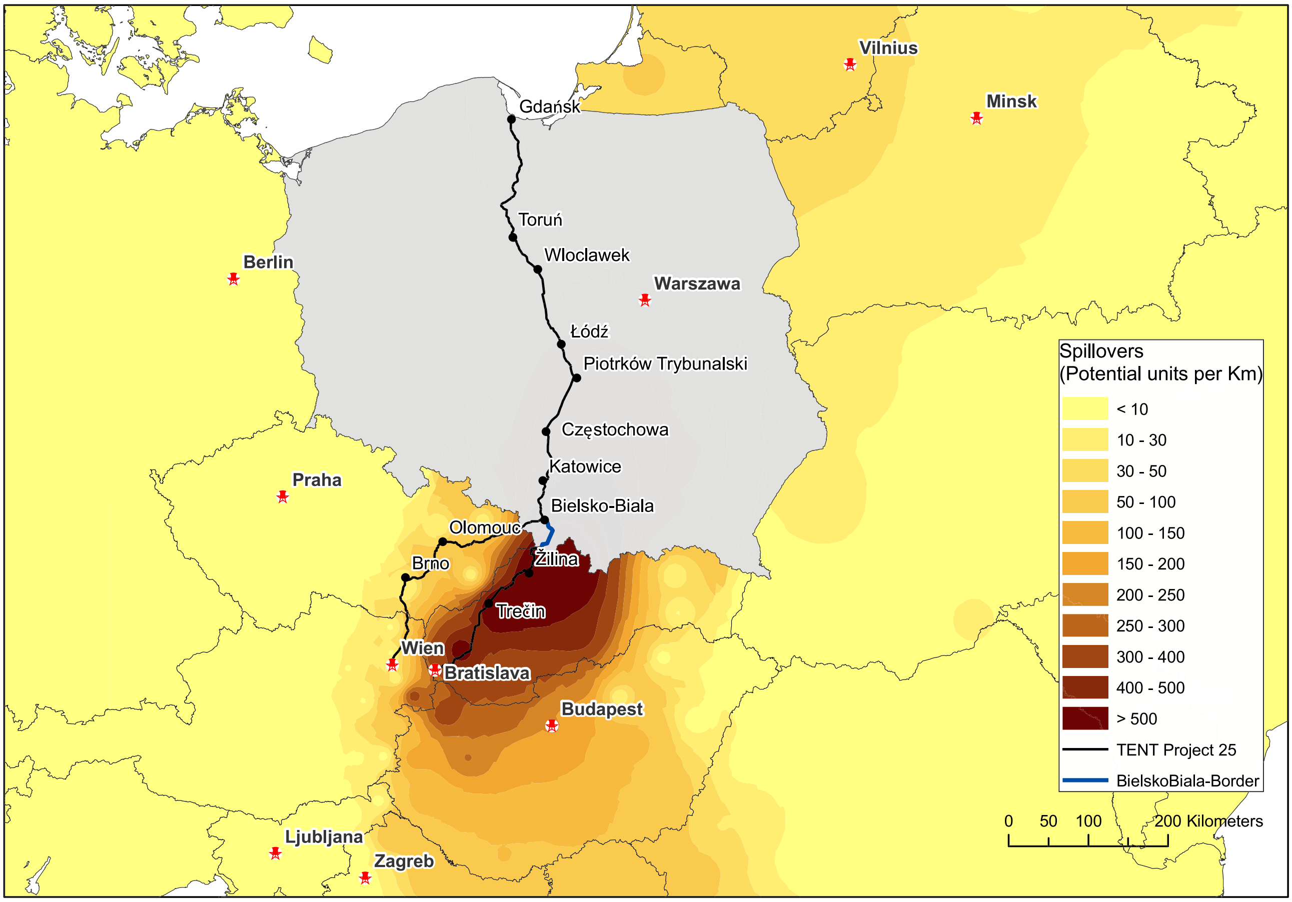

Fig. 3. Spillovers generated by the section Bielsko-Biala – Poland/ Slovakia border.

the border (Czech Republic) than internal benefits (in Poland). The generation of spillovers in border sections depends to a large extent on the distribution of economic activity along the section and its natural prolongation; if the main activity centre is located next to the border (and not towards the interior) few spillovers are generated. This happens in the Trečin – Bratislava section (Fig. 4), which produces many internal benefits (it provides Slovakians with better access to Bratislava and also to Vienna) but it hardly generates any benefits on the other side of the border (in Austria), which improves its access to a smaller market (Trečin and other nearby regions). The area located to the north of Budapest, close to the Slovak border, benefits from a better access to Bratislava and Vienna via part of the new section.

In addition to the benefits produced by each section, Table 1 shows the average benefit obtained by each country taking the different sections into consideration. Thus, in the second last row we can see that the four countries which the project crosses are the ones that obtain the greatest increases in accessibility. This figure includes both accessibility increases owing to sections located in the country itself and spillovers received from sections constructed in other countries. But there is also a group of countries which only receive spillovers as the project does not cross their territory. Among these we may mention the Baltic States and Belarus (which benefit especially from the Polish sections), Hungary and Croatia (from the eastern hub of the project, as far as Bratislava) and Slovenia (from the western hub, as far as Vienna). Bosnia and Finland receive less intense spillovers.

A set of useful indicators from the point of view of decision-making in transport planning have been extracted from the information contained in Table 1 and are shown in Table 2. Both the averages and the standard deviations (necessary for calculating the variation coefficients) have been calculated taking the population of NUTS regions as a weighting factor):

4.1. Efficiency

Column 1 of Table 2 shows the average increase in market potential produced per kilometres of each section in the group of countries which have benefited most from the project (those which have an average improvement greater than 25 potential units). These improvements may be interpreted in terms of efficiency. In general, internal sections are more efficient than border sections (with less traffic due to the border effect). Furthermore, we can see how the eastern branch of the project (as far as Bratislava) behaves less efficiently than the western branch (as far as Vienna), due to the greater volume of the markets that are accessed by the latter. The Gdańsk – Torum section is also very inefficient; it is the final section of the project, and it is only continued by sea via ferry (with a very high impedance).

4.2. European value added

This is the central point of this article. Columns 2 and 3 of Table 2 show the internal benefits and average spillovers produced by each of the sections, respectively. In the case of spillovers, the average is calculated using the countries that receive spillovers greater than 25 potential units (see Table 1). In principle, sections that show a greater accessibility increase tend to produce greater spillovers. In order to neutralise this effect the percentage represented by spillovers (column 3) with regard to internal benefits (column

Please cite this article in press as: Gutiérrez, J., et al. Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS. J. Transp. Geogr. (2010), doi:10.1016/j.jtrangeo.2010.10.011

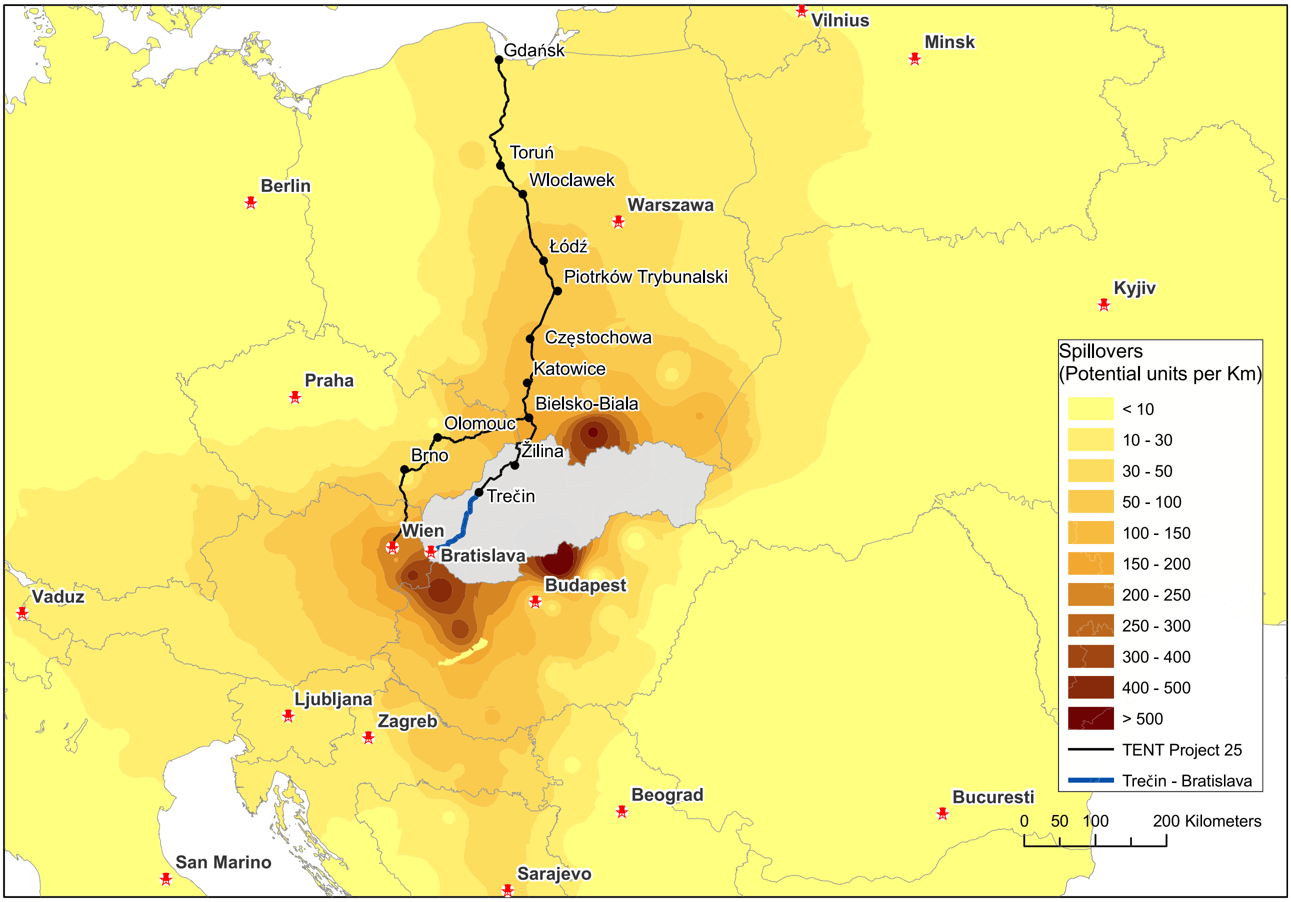

Fig. 4. Spillovers generated by the Trečin – Bratislava section.

2) has been calculated in column 4. The conclusion that may be drawn is that it is in border sections where spillovers represent a higher proportion of benefits, in relation to internal benefits. Those border sections, therefore, are of low national interest in relation to their high European interest (precisely because they serve to develop cross-border corridors).

However, not all border sections present the same proportion of spillovers. The Polish and Czech border sections achieve a very high proportion of spillovers in relation to internal benefits, but this does not occur in the Trečin – Bratislava section, which really behaves as an internal section due to the fact that Bratislava is located on the border: the section is of great national interest (it provides Slovakians with better access to their capital) but it contributes little to the other side of the border (it generates few spillovers). In contrast, the opposite occurs in the Vienna-border section; Vienna is not located close to the border but on the other edge of the section. This section contributes little for internal Austrian relations but it contributes a lot for international relations, especially on the Czech side, as Vienna has much more weight than Brno. It is not therefore sufficient to consider the border location of a section as the only variable to determine the need for European funding. Hence, the proportion of spillovers to internal benefits is an indicator of EVA and should be a criterion when assigning different European funding to the different sections, whether or not they are border sections.

4.3. Spatial dispersion of spillovers

The variation coefficient of spillovers (column 5) provides information on their distribution among the different countries. The lower its value, the less concentrated the distribution of spillovers. In general, a trade-off is observed between EVA and spillover dispersion, so that sections with low EVA produce very scattered spillovers. This is the case, for example, with the central Polish sections. In contrast, border sections concentrate their effects on the neighbouring country. Thus, for example, the high variation coefficient of spillovers from the section Bielsko-Biala – Poland/Slovakia border reflects the fact that these effects are very much concentrated in a single country (Slovakia).

4.4. Territorial cohesion

Finally, the changes in the accessibility variation coefficient of each scenario with respect to the reference scenario (bearing in mind the 13 countries most affected by the project) report on the effects of each section on territorial cohesion (column 6). All the scenarios produce an increase in the variation coefficient compared to the reference scenario (the construction of the complete project). This means that failing to build any of the sections would entail an increase in regional disparities in terms of market access[6]. But this effect is unequal. In general, it may be observed that the sections that produce a greater increase in market potential (efficiency) are also those that most contribute to reducing disparities, as in the case of the central Polish sections, which benefit peripheral areas to a large extent (such as the north of Poland, the Baltic states and

[6] In fact, with the construction of the whole project the variation coefficient decreases by 0.58 units compared to the without-project scenario. Therefore, both the construction of the complete project and the construction of each section produce an increase in territorial cohesion.

Table 1
Average accessibility increase (in potential market units per kilometre constructed) from the effect of the different motorway sections in the most benefited countries by the project (internal benefits are shown in italics, the rest are spillovers).

Sections		Project countries				Countries external to the project								
		Poland	Czech Republic	Austria	Slovak Republic	Lithuania	Slovenia	Belarus	Latvia	Hungary	Croatia	Estonia	Bosnia	Finland
Poland	Gdańsk – Toruń	*725.5*	12.6	10.9	16.3	47.9	8.6	1.2	60.4	9.9	6.7	42.6	4.8	19.7
	Toruń – Wlodawek	*1345.2*	28.7	31.9	51.3	90.9	24.7	11.0	132.7	29.6	19.2	103.9	13.7	49.1
	Wlodawek – Łódź	*1243.2*	25.6	27.9	47.8	80.2	21.2	0.0	89.4	26.7	16.3	63.0	11.3	29.7
	Łódź – Piotrków T.	*3514.2*	81.6	67.2	121.6	115.6	46.2	34.3	155.9	60.1	34.5	123.7	23.1	59.0
	Piotrków T. – Częstochowa	*3065.4*	166.7	121.2	195.7	294.3	78.1	246.7	157.0	91.7	56.1	88.8	35.2	45.9
	Częstochowa – Katowice	*3113.6*	162.8	130.9	218.6	245.1	81.1	231.6	137.3	95.1	57.3	78.8	35.2	40.8
	Katowice – Bielsko-Biala	*1052.8*	229.1	146.4	309.7	165.0	82.1	156.9	92.9	101.9	57.2	54.1	33.9	28.3
	Bielsko-Biala – Slovak border	*186.1*	8.0	12.6	433.6	36.1	2.7	11.4	24.1	134.6	23.0	14.7	24.7	7.9
	Bielsko-Biala – Czech border	*811.2*	466.5	263.2	1.7	201.4	146.2	220.9	108.6	0.3	61.9	62.5	10.6	32.5
Czech Rep.	Olomouc – border	479.8	*1193.3*	185.5	16.8	116.2	90.7	125.6	63.0	2.3	39.4	36.2	6.1	18.8
	Olomouc – Brno	656.4	*4157.6*	385.0	134.7	152.8	186.6	167.0	82.3	53.7	88.6	47.6	21.8	24.8
	Brno – border	610.8	*2103.2*	1187.7	0.8	163.8	414.5	181.7	88.4	47.3	210.8	51.4	58.3	27.0
Austria	Vienna – border	462.9	1654.7	*1586.2*	5.5	128.5	338.2	141.5	69.8	45.0	171.9	40.8	45.7	21.4
Slovakia	Žilina – border	251.3	0.0	18.8	*819.5*	61.7	3.7	17.6	41.3	234.4	34.1	25.3	42.3	13.5
	Žilina – Trečin	85.7	22.0	44.6	*2054.8*	13.2	12.8	9.5	8.3	66.6	25.2	4.8	28.8	2.4
	Trečin – Bratislava	59.5	27.1	108.2	*3459.1*	9.5	28.4	6.8	6.1	90.6	26.7	3.5	26.5	1.8
Country average		1104.0	646.2	270.5	493.0	120.1	97.9	97.7	82.3	68.1	58.1	52.6	26.4	26.4
Spillovers received		372.3	222.0	182.8	119.5	120.1	97.9	97.7	82.3	68.1	58.1	52.6	26.4	26.4

Table 2
Indicators for decision-making: efficiency, EVA, spillover dispersion and territorial cohesion.

Countries	Criteria	Efficiency	European added value			Spillover dispersion	Territorial cohesion
	Indicators	1	2	3	4	5	6
	Motorway sections	Average market potential increase	Average internal benefits	Average spillovers	Spillovers with regard to internal benefits (%)	Variation coefficient of spillovers	Changes in market potential variation coefficient
Poland	Gdańsk – Toruń	274.0	725.5	14.3	2.0	335.3	0.06
	Toruń – Wlodawek	514.6	1345.2	36.8	2.7	260.6	0.04
	Wlodawek – Łódź	472.2	1243.2	28.6	2.3	263.1	0.06
	Łódź – Piotrków T.	1326.9	3514.2	68.6	2.0	167.4	0.08
	Piotrków T.– Częstochowa	1209.1	3065.4	141.2	4.6	184.4	0.11
	Częstochowa – Katowice	1224.9	3113.6	138.3	4.4	172.7	0.10
	Katowice – Bielsko-Biala	473.8	1052.8	140.7	13.4	195.3	0.03
	Bielsko-Biala – Slovak border	110.4	186.1	66.8	35.9	608.1	0.01
	Bielsko-Biala – Czech border	400.7	811.2	164.6	20.3	338.4	0.01
Czech Rep.	Olomouc – border	329.8	1193.3	236.0	19.8	304.4	0.05
	Olomouc – Brno	721.9	4157.6	348.8	8.4	266.8	0.07
	Brno – border	572.7	2103.2	406.5	19.3	295.0	0.02
Austria	Vienna – border	496.8	1586.2	403.6	25.4	402.5	0.02
Slovakia	Žilina – border	166.8	819.5	131.3	16.0	301.2	0.01
	Žilina – Trečin	153.4	2054.8	50.0	2.4	226.6	0.02
	Trečin – Bratislava	223.8	3459.1	48.0	1.4	231.5	0.03

Belarus). However, the Vienna – border section, due to its more central position, produces a major increase in potential, but hardly contributes at all to reducing disparities, and the Gdańsk – Toruń section produces a small increase in potential but reduces disparities to a greater extent than the Austrian section, as it especially benefits a peripheral region such as the north of Poland.

The results show the validity of the proposed indicators to rank priorities among sections of projects at European level. They prove to be a good basis for an assessment methodology to measure the European value added of different sections of a number of projects and to identify who are the winners and the losers.

5. Conclusions

Cross-border transport projects, such as the TEN-Ts, often face funding problems due to the fact that, if their assessment is carried out from a national perspective, benefits are usually lower than project costs. However, given the international nature of these types of infrastructure projects, we must assess additional types of impacts that are generated at the trans-national level. One of these impacts is the contribution to regional integration (in the case of the EU, the above mentioned European value added-EVA).

This paper develops a methodology for assessing the regional integration value (EVA) of cross-border projects. In this article a motorway axis was evaluated, but this methodology could be applied to other modes of transport and even for monitoring multimodal integration of different modal projects.

Not only does this methodology enable an EVA indicator to be obtained (proportion of spillovers to the internal benefits of a section), it also measures the spatial concentration of spillovers (via the variation coefficient), appraises the impact of each section in efficiency terms (improvement in market potential) and, finally, evaluates their effect in terms of territorial cohesion, that is, whether the greater increases in market potential correspond to regions that formerly had greater or lesser market potential.

The results obtained show that the construction of border sections is not very efficient due to the border effect (they produce a lower increase in market potential), though they generate many spillovers. Internal sections, by contrast, are more efficient, producing more internal benefits but comparatively fewer spillovers. However, neither all border sections nor all internal ones behave in the same way as regards efficiency and EVA.

The methodology proposed provides important information for decision-making and has major political implications. If the different sections of the same cross-border project have different EVA, it does not seem logical that they should receive the same European funding. Sections of national interest should not be financed (at least in the same proportion as other sections) by the European Union; the latter should concentrate the investment efforts on those sections with greater EVA, which are less profitable and therefore, in many cases, would not be built if only national funds were available. This idea is fully in line with the goal of TEN-T projects to construct missing links and complete the major European corridors – especially their cross-border sections. In addition, the reduction in accessibility disparities between regions provides useful information as to what extent each section contributes to the goal of ensuring territorial cohesion.

This methodology does not seek to replace existing project appraisal methodologies (particularly cost-benefit analysis); rather it provides complementary data for decision-making. Sections which are scarcely profitable from the cost-benefit analysis perspective but which have high EVA should receive more European funding than those more profitable with lower EVA. Additionally, for the purpose of establishing European funding for each section other criteria should be considered, such as the spatial dispersion of spillovers (on the different countries affected) and their contribution to the goal of improving territorial cohesion. All these findings make that this methodology could be a suitable tool to select priority sections of projects for the further extension of the Trans-European Networks as proposed in the Green Paper (Commission of the European Communities, 2009).

Acknowledgments

This paper was produced with funding from the research projects DESTINO (Spanish Ministry of Public Works) and HESTEPIT (MICINN). The authors thank to TRANS-TOOLS model for allowing access to the data (GIS layers) used in producing this paper. The authors are grateful for the comments received during the NECTAR Meeting on Cluster 6: Accessibility – Policy Making – Spatial Planning (2009, Pula-Cagliari, Italy).

References

Banister, D., Berechman, Y., 2001. Transport investment and the promotion of economic growth. Journal of Transport Geography 9 (3), 209–218.
Beuthe, M., 2002. Transport evaluation methods: from cost-benefit analysis to multicriteria analysis and the decision framework. In: Giorgi, L., et al., (Eds.), Project Policy Evaluation in Transport, Ashgate, Burlington, United Kingdom, pp. 209–241.
Bruinsma, F.R., Rietveld, P., 1998. The accessibility of European cities: theoretical framework and comparison approaches. Environment and Planning A 30, 449–521.
Camagni, R., 2009. Territorial impact assessment for European regions: a methodological proposal and an application to EU transport policy. Evaluation and Program Planning 32, 342–350.
Chen, N., 2004. Intra-national versus international trade in the European Union: why do national borders matter? Journal of International Economics 63 (2004), 93–118.
Commission of the European Communities, 1994. Proposal for a European Parliament and Council Decision on Community Guidelines for the Development of the Trans-European Transport Network, Brussels.
Commission of the European Communities, 2004. A New Partnership for Cohesion, Third Report on Economic and Social Cohesion, Brussels.
Commission of the European Communities, 2009. Green Paper: TEN-T: A policy review. Towards a better integrated Transeuropean Network at the service of the Common Transport Policy, Brussels, COM, p. 44.
de Groot, Henri, L.F., Linders, Gert.-Jan., Rietveld, P., Subramanian, U., 2004. The institutional determinants of bilateral trade patterns. Kyklos 57 (1), 103–124.
de Jong, T., Ritsema van Eck, J., E.A., 2000. Flowmap 6.3. Manual and web site: http://flowmap.geog.uu.nl.Utrecht: Faculty of Geographical Sciences.
Dundon-Smith, D.M., Gibb, R.A., 1994. The channel tunnel and regional economic development. Journal of Transport Geography 2 (3), 178–189.
Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. Journal of Transport Geography 12, 127–140.
Grant-Muller, S., Mackie, P., Nellthorp, J., Pearman, A., 2001. Economic appraisal of European transport projects: the state-of-the-art revisited. Transport Reviews 21 (2), 237–261.
Gutiérrez, J., 2001. Location, economic potential and daily accessibility: an analysis of the accessibility impact of the high-speed line Madrid–Barcelona–French border. Journal of Transport Geography 9 (4), 229–242.
Gutiérrez, J., Condeço, A., Martín, J.C., 2010. Using accessibility indicators and GIS to assess and monetarize spatial spillovers of transport infrastructure. Journal of Transport Geography 18, 141–152.
Halden, D., 2003. Accessibility analysis: concepts and their application to transport policy, programme and project evaluation. In: Pearman, A., Mackie, P., Nellthorp, J., (Eds.), Transport Projects, Programmes and Policies: Evaluation Needs and Capabilities, Ashgate, Aldershot.
Hansen, W.G., 1959. How accessibility shapes land-use. Journal of American Institute of Planners 25 (2), 73–76.
Hay, A., 1995. Concepts of equity, fairness and justice in geographical studies. Transactions of the Institute of British Geographers, New Series 20 (4), 500–508.
Knowles, R.D., Matthiessen, C.W., 2009. Barrier effects of international borders on fixed link traffic generation: the case of Øresundsbron. Journal of Transport Geography 17 (3), 155–165.
Koenig, J.G., 1980. Indicators of urban accessibility: theory and applications. Transportation 9, 145–172.
Kwan, M.-P., 1998. Space–time and integral measures of individual accessibility: a comparative analysis using a point-based framework. Geographical Analysis 30 (3), 191–216.
Laird, J., Nellthorp, J., Mackie, P., 2005. Network effects and total economic impact in transport appraisal. Transport Policy 12, 537–544.

Linneker, B., Spence, N.A., 1992. Accessibility measures compared in an analysis of the impact of the M25 London orbital motorway on Britain. Environment and Planning A 24, 1137–1154.

López, E., Gutiérrez, J., Gómez, G., 2008. Measuring regional cohesion effects of large-scale transport infrastructure investments: an accessibility approach. European Planning Studies 16 (2), 277–301.

Lopez, E., Monzón, A., Ortega, E., Mancebo, S., 2009. Assessment of cross-border spillover effects of national transport infrastructure plans: an accessibility approach. Transport Reviews 29 (4), 515–536.

McCallum, J., 1995. National borders matter: Canada–US regional trade patterns. American Economic Review 85 (3), 615–623.

Morris, J.M., Dumble, P.L., Wigan, M.R., 1978. Accessibility indicators for transport planning. Transportation Research 13A, 91–109.

Nitsch, V., 2000. National borders and international trade: evidence from the European Union. Canadian Journal of Economics 33 (4), 1091–1105.

Pereira, M.A., Roca-Sagalés, O.R., 2003. Spillover effects of public capital formation: evidence from the Spanish regions. Journal of Urban Economics 53, 238–256.

Pirie, G.H., 1979. Measuring accessibility: a review and proposal. Environment and Planning A 11, 299–312.

Reggiani, A., 1998. Accessibility, trade and locational behaviour. Ashgate.

Reggiani, A., Bucci, 2008. Accessibility and network structures: the case of commuting in Germany. In: Paper Presented at the 2008 Nectar Workshop "The Future of accessibility: New Methodological Developments". Las Palmas, Spain.

Rich, D.C., 1978. Population potential, potential transportation cost and industrial location. Area 10, 222–226.

Roy, R., 2003. European versus national-level evaluation: the case of the PBKAL high-speed rail project. In: Pearman, A., Mackie, P., Nellthorp, J., (Eds.), En Transport Projects, Programmes and Policies: Evaluation needs and capabilities. Ashgate, Aldershot.

Song, S., 1996. Some tests of alternative accessibility measures: a population density approach. Land Economics 72 (4), 474–482.

Van Exel, J., Rienstra, S., Gommers, M., Pearman, A., Tsamboulas, D., 2002. EU involvement in TEN development: network effects and European value added. Transport Policy 9 (4), 299–311.

Wegener, M., Bökemann, D., 1998. The SASI Model: Model Structure. SASI Report D8. Berichte aus dem Institut für Raumplanung 40. Dortmund: Institut für aumplanung, Universität Dortmund.

Please cite this article in press as: Gutiérrez, J., et al. Evaluating the European added value of TEN-T projects: a methodological proposal based on spatial spillovers, accessibility and GIS. J. Transp. Geogr. (2010), doi:10.1016/j.jtrangeo.2010.10.011

CONCLUSIONS AND FUTURE RESEARCH LINES

3. CONCLUSIONS AND FUTURE RESEARCH LINES

The final chapter of this doctoral thesis consists of three sections. Section 3.1 examines the degree of correspondence with each of the specific objectives by assessing the initial proposals, the steps taken to achieve these objectives and evaluating how far these objectives have been met. Section 3.2 is dedicated to various final considerations on the main objective and the research questions. Finally Section 3.3 proposes various lines of research for future exploration.

3.1 CONCLUSIONS RELATING TO THE SPECIFIC OBJECTIVES

Objective 1

Establish a theoretical framework which allows an understanding of the importance of accessibility and of the spillover effect, and select the most suitable accessibility indicators to measure this effect.

The spillovers from transport infrastructure have previously been approached from an economic standpoint using econometric techniques such as production functions which compare transport infrastructure with traditional factors of production such as private capital and labour. Many of these studies highlight the positive effect of infrastructure on productivity in the private sector. An interesting result of some studies (García-Milá and McGuire, 1992; Cantos et al., 2005; Delgado and Álvarez, 2007) is that the values obtained for the elasticity of public capital are usually lower when using data with a level of regional disaggregation than in studies carried out on a national scale. This has been attributed to the fact that infrastructure generate positive effects over a much greater sphere than the one in which they are located, which provides evidence of the presence of spillover effects.

However this thesis is critical of the econometric techniques traditionally used to measure spillovers. These limitations are described in Section 1.3.4, and a brief summary is given below:

- The measure of public capital stock reflects the cost of building and maintaining the infrastructure. It is therefore not an accurate indicator of the quality and service provided by the infrastructure, as these aspects are more closely related to the commercial flows which make use of them.
- Spillovers depend on economic relations. These effects are measured by extending one region's public capital stock to the stock existing in neighbouring regions. Although it is true that commercial relations decrease as the distance increases, the exclusion of non-adjacent regions may mean that the spillovers in these regions are overlooked, especially when there are significant commercial flows with more distant regions. It may also overvalue the spillovers in neighbouring regions when barely any commercial relations occur with some of these regions.
- This problem can be partly overcome by weighting the capital stock of the neighbouring regions with commercial flows. However this approach is simplistic. A particular region may scarcely use certain of the infrastructure in the neighbouring regions and yet make abundant use of various others to access the markets in those neighbouring regions; this infrastructure cannot therefore all be weighted in the same way. In addition, some infrastructures in neighbouring regions are also used to access other more distant regions (through traffic).
- Spillovers depend on the characteristics of the transport infrastructure. Certain infrastructure is used in a multitude of interregional relations, and generates numerous spillovers. However, others will be more important for local commerce, generating more internal benefits and fewer spillovers.

In summary, the econometric methods used to measure spillovers are not capable of correctly capturing the network behaviour which characterise transport infrastructure; this however can be achieved by using accessibility analyses.

Accessibility is understood in this study as the facility of a territory for accessing markets. As opposed to econometric techniques, accessibility depends on the characteristics of the infrastructure and is a good indicator of the service or utility of transport networks. Accessibility also reflects the localisation of economic activities and thus makes it possible to show the economic flows that are channelled through the network.

Accessibility is related to regional development (Forslund and Johanson, 1995; Vickerman, R. et al., 1999) and territorial cohesion (López, et al., 2008). Accessibility indicators have therefore been used on numerous occasions to study the territorial effects of transport infrastructure. However they have never before been used to analyse spillovers, and this is one of the most innovative aspects of the present thesis.

A review of the bibliography enabled the identification and assessment of the advantages and drawbacks of the accessibility indicators in the study of spillover effects. Finally it was decided to work with the market potential indicator, which has the advantage of being easy to calculate and requiring very few data, rendering it easy to use on a national and international scale. In addition this indicator correctly represents access to the markets, as it attributes greater weight to relations over short distances due to the fact that it includes a gravity component in its formulation.

Objective 2

Implement the methodology for measuring the spillover effects on a GIS.

The next step after the selection of the accessibility indicator consists of preparing the databases necessary for its calculation in the GIS. In the case of the market potential indicator it was necessary to define a set of transport zones to represent the localisation of economic activities in the space, as well as a digital road network along which the traffic is channelled between the zones. This required a laborious process for the creation of digital maps and databases containing alphanumerical information on the zones and the networks used.

The transport zone database contains socio-economic information (such as population or employment) obtained from the official statistical institutes. Different attributes were assigned to the network arcs, and different assessment scenarios were built in order to carry out the simulations. These involved a series of partial scenarios prepared based on the hypothetical extraction method. This method follows a similar logic to the interregional analysis used in input-output tables, which considers the hypothetical effect of extracting one region from a series of regions (Dietzenbacher et al., 1993). In our case, when assessing national plans the partial scenarios consider all the actions included in the plan and extract the plans for the study region. If the assessment involves a single transport project, then the partial scenarios consider the finalisation of the whole project, with the exception of the segment to be analysed. These partial scenarios are then compared with the reference scenario, which represents the finalisation of the plan or project.

Most of the accessibility and spillover calculations are done in ArcGIS®, owing to its tools for network analysis, database management and final presentation of results in the form of maps and tables. In certain cases more complex models were used which contributed functionalities that were not available in this program. This was the case of the article on road pricing, which required the use of a traffic assignment model to simulate the effects of pricing on congestion. In addition, Flowmap®, which incorporates different gravity models, was used to calibrate the distance exponent of the accessibility indicator.

Objective 3

Identify the spatial patterns of the spillover effects in order to understand the main factors which determine the spatial scope and the intensity of these effects.

All the transport actions analysed generate both internal benefits in the region itself, and spillovers. However the proportion of these effects (internal and spillovers) varies according to a series of characteristics which are listed below:

- Spillovers are more intense in territories near the transport actions, due to the gravity component of the accessibility indicator.
- The segments located in the centre of a region generate fewer spillovers and more internal benefits, while those situated in border areas give rise to more spillovers.
- The localisation of the transport infrastructure in relation to the spatial distribution of the economic activity acts independently of the site of the segment in the region. It may be that an infrastructure on the border of a region generates more internal benefits than spillovers, as it may provide service to important centres in the region which are located on the border.
- Spillovers depend on the characteristics of the transport infrastructure. Thus if the new infrastructure passes through a region with a north-south orientation, the

spillovers will be more intense to the north and south of the segment due to the fact that these territories will make greater use of the infrastructure than those located to the east or west.

- The degree of prior infrastructure provision affects the importance of the spillovers. In established networks which are well-endowed with infrastructure, the actions in the transport system generate fewer spillovers than in regions where there is a deficient network. This is consistent with the law of decreasing returns of transport infrastructure (Rus de Mendonza, 2003).
- Transport infrastructure give rise to spillovers of different intensity and spatial scope, depending on the location of the region within the study area. Central regions serve as through regions for interregional traffic. These regions normally generate more spillovers than peripheral regions, due to the fact that the infrastructure in more distant regions are more heavily used by local traffic or by the traffic these regions attract.
- Spillovers also depend on the role of the infrastructure in channelling traffic flows. Certain roads are important for local flows, and therefore generate more internal effects, while others are fundamental for interregional traffic, thereby giving rise to more spillover effects.
- The magnitude of the actions in the transport system is also an important factor. The greater the changes in the network, the more intense the spillovers.
- Following the logic of the market potential indicator, spillovers are asymmetrical. A new infrastructure between a densely populated and a sparsely populated region benefits the sparsely populated region more, as it improves its accessibility to a large market. However these asymmetries change when the spillovers are monetarised (see the objective below).

Objective 4

Monetarise the spatial spillovers, deriving from the investment in new transport infrastructure.

The investment in new transport infrastructure planned for each region can be classified according to the internal benefits and the spillovers it generates. In the example of the PEIT, it has been demonstrated that a significant part of the investment earmarked for each region remains in the same region, but part of it derives to other regions in the form of spillovers. Using the methodology proposed in this thesis it is now possible to prepare a matrix which reflects the increases in accessibility in each region which are due to the region's own infrastructure (internal benefit) and the improvements due to the infrastructure in each of the other regions (spillover effect).

The matrix in market potential units can be converted into monetary units, considering both internal changes and spillovers, as well as the potential beneficiaries. The matrix in euros offers information for each region on the investment retained and the investment exported and imported (as a function of the spillovers).

The procedure for calculating spillovers addresses one of the main criticisms levelled at the potential market model from an economic standpoint. When assessing the effects of building a new infrastructure between two regions, the potential market indicator produces markedly asymmetrical results, always in favour of the weaker region, which is not consistent with economic logic. However the procedure for monetarising the spillovers developed in this work acts as a compensating factor for these asymmetries, as although the region with the lower population will obtain greater improvements in accessibility, there will be far fewer potential users. Thus considering the number of potential users in the monetarisation favours the larger regions. The resulting balance will be very different in each case, and may be favourable to either the more or less populated region.

The most interesting information provided by the monetarised matrix is the variation between the investment planned by the PEIT in each autonomous region (direct investment), and the investment actually obtained once the spillovers are considered (real investment); that is, after adding the imported investment and subtracting the investment exported to other regions. Generally speaking it can be observed that the peripheral regions, which are more dependent on other regions' infrastructure for their links with these regions, have a higher real than direct investment. In contrast, direct investment in central regions tends to be lower than real investment. Their infrastructure fulfils an important function in serving interregional traffic, therefore generating many spillovers and exporting much of the direct investment received.

Objective 5

Analyse the spillover effect from the standpoint of territorial cohesion.

Territorial cohesion, understood as more balanced development with fewer disparities and territorial imbalances (CEC, 2004), is one of the main objectives of transport policies. Various studies have used accessibility analyses to assess the results of these policies, taking into account the role of access to services and markets in improving territorial cohesion. However the role of spillovers in territorial cohesion has not so far been analysed.

The new high capacity motorways planned in the PEIT are used as a case study. Improvement in territorial cohesion is one of the objectives of the PEIT, and thus a considerable proportion of the investment is dedicated to less developed and more distant regions. However it is worth remembering that this infrastructure will also be used by other regions (spillover effect).

Different inequality indices were calculated to measure the distribution of accessibility before and after the plan, as well as in the different partial scenarios represented by the finalisation of the PEIT, with the exception of the region analysed. The results provide a general idea of the impact of the plan in furthering the reduction in regional disparities.

The inequality indicators show an improvement in cohesion in the scenario with the PEIT compared to the situation without the plan. This indicates a reduction in accessibility disparities, as proposed by the plan. Accessibility levels are more unequal in partial scenarios than in the situation prior to the plan, which demonstrates that even if actions were not to be implemented in any one of the regions, territorial cohesion would still improve. However, if this is compared to the situation with the PEIT, the failure to build infrastructure in the regions of Aragon, Castile-La Mancha, Catalonia and Valencia would have a positive effect on territorial cohesion. These regions enjoy above-average accessibility, and thus failure to invest in their roads in favour of investing in roads in other regions would give rise to more equal accessibility levels. In other cases such as Madrid, La Rioja and the Basque Country, the changes in the cohesion levels are negligible due to the fact that the plan contemplates very little investment in these territories.

From the standpoint of territorial cohesion, it is important to determine whether the spillovers are directed away from the less developed/peripheral regions to the more developed/central regions or vice versa. In order to analyse this issue, we used an original approach based on the spillover matrix, in order to assess their direction. Two categories of spillovers are defined:

- Regressive spillovers (upstream or periphery-core effects) are those which go from the less accessible to the more accessible regions;
- Progressive spillovers (downstream or core-periphery effects) are those which go from the more accessible to the less accessible regions.

This last direction is the more desirable from the point of view of territorial cohesion. The analysis of the spillover matrix (in market potential units) shows a predominance of core-periphery effects, which is consistent with the results of the inequality indices and with the evidence in the literature indicating that an improvement in the connection between two regions benefits less accessible regions more, due to the greater increase in their potential markets. However an analysis of the monetarised matrix shows a practically neutral spillover pattern: the asymmetries favourable to the regions with less accessibility are offset in the monetarisation process by the greater number of potential users in the regions with greater market potential. An analysis made in terms of more or less developed regions (not published in the corresponding article due to lack of space) highlighted the fact that there is a predominance of spillovers from less developed to more developed regions. Therefore all spillovers may have a detrimental effect on transport policies, as they transfer the benefits of the investment from peripheral regions towards the central regions, and from rich regions to poor.

Objective 6

Conduct a sensitivity analysis of the results obtained.

It is well-known that the results of the market potential indicator depend on the value of the distance exponent, which represents the effect of the friction of the geographic space on economic flows. High values in the exponent imply a greater resistance to displacement and a greater weight of relations over short distances.

In order to assess the impact of the value of the exponent on the results obtained from applying the hypothetical extraction method, we first carried out a sensitivity analysis on the market potential indicator and then on the spillovers. This sensitivity analysis consisted of repeating the calculations using a different distance exponent each time. Once again the PEIT was used as a case study, and specifically the new roads planned in this master plan for each autonomous region.

The following conclusions can be drawn from the sensitivity analysis of the economic potential model:

- The market potential decreases as the exponent increases.
- With high exponents, the weight of self-potential increases; that is, the contribution of each area's internal accessibility to its total accessibility.
- The potential of the regions with larger internal markets (more self-potential) therefore decreases less when the exponent value is increased.
- As a result, the greater the exponent, the higher the differences in relative terms between the central (with greater self-potential) and peripheral regions.
- The variation in the exponent does not significantly affect the general distribution of economic potential among the regions.

These results are consistent with the evidence in the literature regarding the weight of transport costs in economic flows. When transport costs are very high, markets become more local. As these costs decrease, the markets expand, as occurs nowadays.

An analysis was also made of the effect of varying the exponent on the PEIT accessibility changes (comparison between the situation with and without the PEIT). The results show that the changes increase with the use of higher exponent values. However, this increase occurs particularly near the new infrastructure, and thus there is an increase in the intensity of the changes in accessibility, even though their spatial scope is reduced. Thus the regions which benefit most from this plan do so to an even greater degree when high values of the exponent are used. The trend of the changes in the regions remains stable.

The following conclusions can be drawn regarding the sensitivity of the spillover methodology to variations in the distance exponent:

- In monetary terms, higher exponents increase the internal benefits and reduce spillovers.
- Spillovers decrease their spatial scope and are reduced in more distant regions, although they are more intense in the regions near the new roads.
- In spite of this, the spatial distribution of the spillovers remains stable (the regions which receive more spillovers continue to be the same).
- The process of monetarising the spillovers reduces the sensitivity of the results to the exponent value, as the sum of the benefit retained and the exports for each region is always the same, even though the distance exponent may change. Thus the procedure for monetarising the spillover matrices in potential units has the virtue of contributing more robust results.

Finally it can be concluded that the choice of exponent is an important aspect to be taken into account when using the market potential indicator and spatial spillovers according to the method described. The calibration of the distance exponent based on the data on interprovincial commerce in tons and in euros gave very different values – much higher in the first case – which is consistent with economic logic: many tons of low-value goods are transported over short distances but goods of greater value tend to travel greater distances. The distance exponent value must be fixed according to whether the objectives of the study are oriented primarily towards assessing the economic impact (euros) or mobility (tons).

Objective 7

> *Apply the spillover methodology to various transport planning contexts, not only to the construction of new infrastructure, but also to the improved management of existing roads by means of pricing policies.*

Most of the case studies carried out in this thesis have focused on measuring the spillover effects of new transport infrastructure. The construction of this type of infrastructure reduces transport costs and has a positive impact on accessibility, giving rise to positive spillovers.

However this methodology can be applied to another type of policies which are more restrictive to mobility, as in the case of road pricing. Numerous recommendations indicate that in order to promote a more sustainable mobility, users must be made to pay the costs they generate to the rest of society; that is to say, the so-called external costs. The spillover methodology was used to measure the changes in accessibility registered in one region as a result of the implementation of pricing in other regions.

In contrast to the reduction in transport costs and improved accessibility brought about by the construction of new transport infrastructure, the implementation of pricing measures generally entails an increase in generalized transport costs. However in extremely congested networks the positive effects of pricing may compensate for the additional cost of the toll.

In order to comply with its proposed objective, this thesis studies the spillovers generated by various pricing systems on high capacity intercity roads in Spain. Road pricing internalises the external costs (social, environmental and the costs deriving from the maintenance of the infrastructure) generated by vehicles.

A series of partial scenarios are built (one for each autonomous region) for each pricing system using the hypothetical extraction method. This case supposes the implementation of pricing on the whole of the Spanish territory, extracting the tolls in the region corresponding to the object of the analysis. The comparison between each partial scenario and the reference scenario (which represents the pricing in all intercity roads of Spain) represents the spillover effect.

The results show that implementing pricing systems for road use generates negative spillovers. This can be justified in view of the low congestion on intercity roads in Spain, which means there is no significant effect on travel times to offset the additional cost of the toll.

However the magnitude of the negative spillovers varies according to the region, and depends on factors such as population or the density of the tolled roads. Pricing the motorways in Madrid would imply more intense and more far-reaching spillovers, as such a move would penalise a whole range of relations due to the radial nature of the network and the higher density of the high capacity roads in this autonomous region. At the other extreme is Extremadura, where road pricing would generate very limited spillovers. This region has very few motorways, a reduced internal market, and given its peripheral character, is little used by interregional traffic.

The results can be presented in the form of maps or matrices. The matrices offer the advantage of revealing which part of the loss of accessibility in an autonomous region can be attributed to the pricing of its own roads, and which part is due to road pricing policies implemented in other regions. The matrix reveals that Madrid, Valencia and Catalonia generate abundant spillovers in other regions due to the importance of their markets and to their greater density of high capacity roads. In contrast, peripheral, less populated regions with fewer high capacity roads generate fewer spillovers. These effects decrease as the distance between the toll roads increases, given the gravity character of the accessibility indicator. The spillovers are asymmetrical, and are more intense when generated by regions used for interregional traffic, and particularly if they have important markets.

Spillovers can also be seen to represent a significant proportion of the losses in accessibility of the autonomous regions and especially in regions with a low density of tolled roads and which are more dependent on external markets. In contrast, regions with numerous motorways and more potent internal markets (such as Madrid and Barcelona) owe most of their losses in accessibility to tolls levied on their own roads.

Objective 8

Develop a methodology based on spillover effects to measure the European added value of the transport projects in the European Union (EU).

The trans-European transport networks (TEN-T) are one of the cornerstones of the EU's transport policy. However many of these infrastructure have yet to see the light, due to the fact that they do not fulfil the profitability objectives established by the countries charged with their construction. One of the main obstacles is that the procedures for economic assessment use classical methodologies such as cost-benefit analyses, which consider only national objectives. However given the importance of this infrastructure to the Union as a whole, other types of effects must be included in order to represent the contribution of these projects to European objectives.

The spillover methodology can be a useful tool for assessing the European added value (EAV) of projects within the framework of the TEN-T. EAV can be defined as the contribution of transport policies to the objectives of territorial integration and cohesion established by the European Union. Projects which generate high spillovers (benefits recorded in countries outside the project) will have a greater EAV as they contribute to improving international links and thereby to the consolidation of the single market.

The EAV can be assessed for the whole of a project, but also for each one of its segments. Some segments are very important for national interests, whereas others are somewhat unprofitable for the country, and run into financing problems. This explains why there are currently a series of "missing links" in the transport corridors of the TEN-T. It therefore makes sense to assume that segments with a higher EAV should receive greater financing from the EU.

Project no. 25, one of the 30 projects defined as priority within the framework of the TEN-T, was selected as a case study for this thesis. This project consists of the construction of a motorway crossing various European countries (Poland, Czech Republic, Slovakia and Austria). The project is divided into 16 segments, which allows a study of the EAV of each one. Its importance is also analysed from the point of view of efficiency and territorial cohesion.

The results show that the most intense impacts are usually seen in the country which builds the segment, but a significant proportion of the effects spread to other countries in the form of spillovers. The spillovers are asymmetrical: the Baltic countries, (more peripheral) perceive more benefits than those in central Europe, due to the fact that the former states can expand their access to more important markets.

In terms of efficiency (increase in market potential considering both internal impacts and spillovers) it can be seen that segments localised in the interior of countries are more efficient than border segments. This is due to the fact that the centres of economic activity are usually located in the interior of a country and that a significant drop in traffic is observed at the borders (the internal segments therefore favour greater volumes of traffic). The western segments, which link Vienna with southern Poland, are more efficient than those in the east, linking Bratislava with southern Poland, due to the fact that the former segments provide access to the more important markets localised in central Europe.

The results also show that the segments located on borders usually generate more spillovers and fewer internal benefits, and thus have a greater EAV. However the mere fact of a segment being on the border is not sufficient to give it a high EAV. The main centres of economic activity may be located near the border, which would thus give rise to substantial internal benefits. This is the case with the segment between Trečin and Bratislava, which is of significant national interest as it improves the access of the Slovaks to their capital and generates little spillover.

This thesis also analyses the effect of each segment on territorial cohesion. It concludes that a failure to construct any of the segments included in Project 25 would decrease territorial cohesion, given that the project affects regions with low market potential. The most efficient segments have a more positive effect on cohesion, and particularly the Polish segments, which benefit the more distant Baltic countries. In contrast, the Austrian segments, which favour particularly central European regions, produce less impact on territorial cohesion.

In conclusion, the methodology based on spillover measurement can be used to assess trans-national projects, by differentiating which segments are of national importance and which are of European importance in order to provide increased financing for those which benefit the European Union as a whole.

3.2 FINAL CONSIDERATIONS IN RELATION TO THE GENERAL OBJECTIVE

The general objective of this thesis is to *propose a methodology to measure the spillover effect produced by transport infrastructure.* This methodology is based on the calculation of accessibility indicators and on GIS, and overcomes the limitations indicated earlier of the econometric techniques which have traditionally been used to measure spillovers. In view of this, and in response to the first question posed by this research, –namely, whether accessibility analyses and GIS can be used to measure spillovers more correctly– we conclude that spillovers from transport infrastructure can be adequately measured with accessibility indicators and GIS.

Actions in the transport system lead to changes in the cost of travel and affect the degree of interaction between economic centres. Both effects (transport costs and economic interaction) can be addressed by accessibility indicators. Thus compared to using aggregate measures such as public capital stock in transport infrastructure, accessibility indicators offer numerous advantages.

In comparison with the econometric techniques traditionally used to measure spillovers, the methodology presented in this thesis permits the inclusion of as many regions as may be considered relevant. Accessibility analyses are capable of differentiating the unique contribution of each region based on the importance of its markets, as well as the different utility of its infrastructure for channelling traffic flows.

GIS are an indispensable tool for spillover methodology, as they provide network analyses which simulate the relations between the territories, channelled through the transport network, but also due to their cartographic, spatial analysis and database management tools, which facilitate data processing and the final presentation of the results.

Spillovers measured in this way can be used in transport policy assessment. It has been demonstrated that a large part of the investment dedicated to building new transport infrastructure flows towards other regions in the form of spillovers. Thus, in response to the second question posed by this research regarding the role played by spillovers in the distribution of the investment in new transport infrastructure, it can be concluded that spillovers do indeed significantly vary this distribution in certain regions. In the case of the investment in new motorways proposed in the PEIT, spillovers have been shown to represent a combined total of 58% of the investment, which signifies that on average over half the investment earmarked for a particular region also benefits several other regions. Some regions serve a strategic function for channelling traffic flows, due to the fact that their roads give service to many other regions; if in addition they have little population and economic activity, the internal benefit is reduced. The investment exported by these regions may be over 70%, whereas others, due to their peripheral position and their greater dependence on the infrastructure of other regions, import more investment than they export.

The spillover methodology is able to measure the impact of transport actions on territorial cohesion. One of the questions formulated at the beginning of the research was whether spillovers from transport infrastructure alter the levels of territorial cohesion. We are now in a position to conclude that they do. It is not enough to know how much has been invested in peripheral/less accessible regions, since part of that investment may benefit central territories and thereby dilute any possible cohesive effects. We therefore consider it important to determine the predominant direction of the spillovers. Spillovers can be regressive, when investments flow away from the peripheral regions towards the central regions, or progressive when they flow in the opposite direction. From the point of view of improving territorial cohesion, progressive spillovers should clearly predominate. However, regressive spillovers may become dominant and serve as a perverse mechanism for policies designed to improve territorial cohesion, as they divert a large part of the benefits of the investment from regions with lower income levels to more prosperous regions.

This thesis provides abundant evidence in response to the fourth research question, namely whether the spillover effect contributes relevant information to the transport planning process. Spillovers have been measured for various different transport actions such as the construction of new infrastructure in transport plans on either a national or transnational scale, but also from a completely different approach: the pricing of existing infrastructure. In all cases it is clear that any actions carried out on a region's transport system generate effects in other regions. Spillovers also provide information on the objective of territorial cohesion. It is therefore safe to conclude that the study of spillovers provides information of great significance for transport planning procedures and cannot be ignored in the decision-making process.

3.3 FUTURE RESEARCH LINES

Throughout the period in which this work was researched and drafted, there was a continual appearance of new lines of research which we have been unable to include in this thesis. This section describes various research lines which are currently underway, as well as others which are scheduled to begin.

All the case studies in this thesis have focused on the road mode. This decision was taken due to the fact that in Spain, 86% of goods transport and 88% of passenger transport takes place by road. Road transport is thus the dominant mode, and also has the particularity that it provides access to the whole of the territory, due to its capillary nature (Ministerio de Fomento, 2005). However the spillover methodology can also be applied to other modes of transport such as railways or to multimodal networks.

One of the lines of research currently underway is the study of spillovers calculated from the real use of roads, which provides information on the real use that a region makes of its own infrastructure and on the infrastructure of other regions for its exports. In this case the capital stock in transport infrastructure in each region will be weighted by the number of relations using it and by the value of these relations. Some roads will be used in numerous relations, whereas others will make a residual contribution to the channelling of interregional flows (and will thus generate few spillovers). The value of each road will be shared between the different regions based on the commercial flows (in euros) channelled by this segment. This process is repeated for each road, so that the total stock is distributed and a spillover matrix is obtained which shows the stock used by each region in each of the other regions, and also in that region itself.

This spillover matrix enables two production functions to be calculated: one with the value of the use of the region's own infrastructure and another with the stock value reflecting the real use of all infrastructures. The difference in elasticities will provide a measure of the spillover (which part of the regional production is attributable to the use of the infrastructure in all the other regions). This value may be distributed according to the spillover matrix in such a way that interregional spillovers are obtained in terms of economic benefit (the benefit each region receives from the infrastructure in each of the other regions).

Another of the proposed lines of research suggests that if the flow of goods in tons is known for the different segments of the road network, it can be translated into a number of lorries (taking as an example an average tonnage lorry, with an average occupation level, and considering whether the return journey is empty or not). As the origin and destination of the flows is known, we can determine how many lorries use each region in their exports and where they are heading. By applying a toll to each lorry, it is possible to establish the additional cost of transport incurred by the various regions due to the payment of this toll. It also allows the creation of a spillover matrix to show the tolls paid for the use of the region's own roads, and for the use of roads in other regions. This methodology may be useful in assessing pricing policies as in the case of the Eurovignette in the EU (O J L 187 of 20.7.1999).

In the near future, the aim is also to integrate the spillover methodology into regional input-output tables (IOT). IOT are a suitable tool for analysing the impact of infrastructure on economic activities, employment, inflation and interregional commerce. The changes in generalised transport costs due to improvements in infrastructure, for example, can be incorporated by adjusting the intermediate consumption –technical coefficients– relating to the use made of the transport sector by the whole set of economic activities. By distinguishing between the contribution of the improvements in the region itself and in other regions, it is possible to measure the spillover effect in terms of its impact on the economy.

REFERENCES

Arauzo, J. M. 2005. Determinants of industrial location. An application for Catalan municipalities. *Papers in Regional Science* 84:105-120.

Aschauer, D. A. 1989b. Does public capital crowd out private capital? *Journal of Monetary Economics* 24:171-188.

———1989a. Is public expenditure productive? *Journal of Monetary Economics* 23:177-200.

Banister, D., and Y. Berechman. 2001. Transport investment and the promotion of economic growth. *Journal of Transport Geography* 9:209-218.

Ben-Akiva, M., and S. R. Lerman. 1979. Disaggregate travel and mobility choice models and measures of accessibility. In *Behavioral Travel Modeling,* ed. D. A. Hensher and P. R. Sopher, 654-679 en Geurs y Ritsema, 2001. Andover: Croom Helm.

Berry, B. J. 1959. Recent studies concerning the role of transportation in the space economy. *Annals of the Association of American Geographers* 49:328-342.

Biehl, D. 1991. The role of infrastructure in regional development. In *Infrastructure and Regional Development,* ed. R. W. Vickerman, Pion, London.

Boarnet, M. G. 1998. Spillovers and the locational effects of public infrastructure. *Journal of Regional Science* 38:381-400.

Breheny, M. J. 1978. The measurement of spatial opportunity in strategic planning. *Regional Studies* 12:463-479.

Bruinsma, F., and P. Rietveld. 1998. The accessibility of European cities: theoretical framework and comparison of approaches. *Environment and Planning A* 30:499-521.

Calvo, J. L., A. Pueyo, and J. M. Jover. 1993. *Potenciales demográficos de España*. *Atlas Nacional de España* Sección IV:14b.I-VII-14b.18-23.

Camagni, R.2009. Territorial Impact Assessment for European regions: A methodological proposal and an application to EU transport policy. *Evaluation and Program Planning* 32:342-350.

Cantos, P., M. Gumbau-Albert, and J. Maudos. 2005. Transport Infrastructures, Spillover Effects and Regional Growth: Evidence of the Spanish Case. *Transport Reviews* 25:25-50.

Cavailles, H. 1948. Introduction a una géographie de la circulation. *Ann. de Géog.* 28: 170-182.

CEC (Commission of the European Communities). 2001. *WHITE PAPER. European transport policy for 2010: time to decide.* Report Number, COM (2001) 370 final.

CEC (Commission of the European Communities). 2004. *A new partnership for cohesion: convergence, competitiveness, cooperation: Third Report on Economic and Social Cohesion.* Brussels: Office for Official Publications of the European Communities.

CEC (Commission of the European Communities). 2008. *Green Paper on Territorial Cohesion Turning Territorial Diversity into Strength.* Brussels: .

CEC (Commission of the European Communities). 2009. *Libro Verde - RTE-T: Revisión de la política.* Report Number, 44 final.

Condeço-Melhorado, A., J. Gutiérrez. 2007. Proposta metodológica de medição dos spillovers effects com indicadores de accessibilidade. Estudo das actuações em Espanha e em Portugal. VI Congresso da Geografía Portuguesa. Lisboa, 17-20 Octubre.

———2006. Medición de efectos de desbordamiento de las infraestructuras de transporte a través de indicadores de accesibilidad. PANAM XIV - XIV Congreso Panamericano de Ingeniería de Tráfico y Transporte. Las Palmas de Gran Canaria, 20 – 23 de Septiembre.

Condeço-Melhorado, A., J. C. Martín, and J. Gutiérrez. (*In press*) Regional spillovers of transport infrastructure investment: A territorial cohesion analysis. Accepted in *European Journal of Transport and Infrastructure Research*

Condeço-Melhorado, A. M., J. Gutiérrez, and J. C. García-Palomares. 2008b. Accessibility and road pricing: application to the Spanish motorway network. NECTAR. Las Palmas de Gran Canaria, 27-28 Junio.

Condeço-Melhorado, A., J. Gutiérrez, and J. C. García-Palomares. In Press. Spatial impacts of road pricing: Accessibility, regional spillovers and territorial cohesion. *Transportation Research A.* doi:10.1016/j.tra.2010.12.003

Condeço-Melhorado, A., J. Gutiérrez, and J. C. García-Palomares. 2008c. Using accessibility indicators and GIS to assess spatial spillovers of road pricing policy. Third International Conference on Funding Transport Infrastructure – Paris, June 19 – 20.

Condeço-Melhorado, A., J. Gutiérrez, and J. C. Gracía-Palomares. 2008d. Measuring spatial spillovers of transport infrastructure investment using accessibility indicators – a sensitivity analysis. 55th Annual North American Meetings of the regional science Association International – Brooklyn, New York, November 19-22.

Condeço-Melhorado, A. M., J. Gutierrez, and J. C. Garcia-Palomares. 2009a. Road Pricing, Accessibility, Cohesion and Regional Spillovers: Application to the

Spanish Motorway Network. 4th Kuhmo-Nectar Conference "Transport and urban economics". Technical University of Denmark, June 29 – July 2.

Condeço-Melhorado, A., J. Gutiérrez, E. López, and A. Monzón. 2010 a. XIV Congreso Nacional de Tecnologías de la Información Geográfica Septiembre. Sevilla, España. El valor añadido europeo de los proyectos transnacionales (TEN-T): una propuesta metodológica basada en los efectos de desbordamiento, accesibilidad y SIG.

———2009. NECTAR Cluster 6 Meeting on Accessibility – Policy Making – Spatial Planning October 16-17. Pula-Cagliari, Italy. Spatial spillovers: a methodological framework to evaluate the European value added of TEN-T projects.

Copus, A. K. 1999. *A New Peripherality Index for the NUTS III Regions of the European Union.* .: Aberdeen, Rural Policy Group, Management Division, Scottish Agricultural College, Report Number, Report for General Directorate XVI.A.4. (Regional Policy and Cohesion).

Crescenzi, R., and A. Rodríguez-Pose. 2008. Infrastructure endowment and investment as determinants of regional growth in the European Union. *EIB Papers* 13:62-1001.

Crozet, R. 1930. L'aviation dans la cité. Les aéroports. *La vie urbaine* 11.

Dalvi, M. Q., and Martin K. M. 1976. The measurement of accessibility - some preliminary results. *Transportation* 5:17-42.

Delgado, M. J., and I. Álvarez. 2007. Network infrastructure spillover on private productive sectors: evidence from Spanish high capacity roads. *Applied Economics* 39:1583-15997.

Demangeon, A. 1952. Le rail et la route. In ed. Anonymous .

Di Ciommo, F., A. Monzón, and J. Comendador. 2010 b. *Road transport social costs in Spain: a new rationale for pricing policy.* July 11-15.

Di Ciommo, F., A. Monzón, and A. Fernandez. 2010 a. *Measuring the acceptability of interurban road pricing among different groups of stakeholders. The case of Spain.* January 10-14.

Dietzenbacher, E., J. A. van der Linden, and A. E. Steenge. 1993. The regional extraction method: EC input-output comparisons. *Economic Systems Research* 5:185-206.

Dundon-Smith, D., and R. A. Gibb. 1994. The Channel Tunnel and the regional economic development. *Journal of transport Geography* 2:178-189.

Forslund, U. M., and B. Johansson. 1995. Assessing road investments: accessibility changes, cost benefit and production effects. *Annals of regional science* 29:155-174.

Frost, M. E., and N. A. Spence. 1995. The rediscovery of accessibility and economic potential: the critical issue of self-potential. *Environment and Planning A* 27:1833-1848.

García-Milá, T., and T. J. McGuire. 1992. The contribution of public provided inputs to states 'economies'. *Regional Science and Urban Economics* 22:229-241.

Geertman, S. C. M., and Ritsema Van Eck, Jan R. 1995. GIS and models of accessibility potential: an application in planning. *International Journal of Geographical Information Systems* 9:67-80.

Geurs, K. T., and J. R. Ritsema van Eck. 2001. *Accessibility measures: review and applications.* Report Number, RIVM report 408 505 006.

Geurs, K. T., and B. van Wee. 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography* 12:127-140.

Goodchild, M. F. 1987. A spatial analytical perspective on geographical information systems. *International Journal of Geographical Information Systems* 1:327-334.

Gutiérrez, J. 2001. Location, economic potential and daily accessibility: an analysis of accessibility impact of the high-speed line Madrid-Barcelona-French border. *Journal of Transport Geography* 9:229-242.

Gutiérrez, J., and A. Condeço-Melhorado. 2006. Medición de efectos de desbordamiento (spillovers) a través de indicadores de accesibilidad en un entorno SIG. VI Seminario Internacional de Ingeniería de sistemas. Cozumel México. 15-18 Noviembre.

Gutiérrez, J., A. Condeço-Melhorado, and J. C. García-Palomares. 2009. Medición del efecto desbordamiento de las infraestructuras de transporte a través de indicadores de accesibilidad – Un análisis de sensibilidad. Conferencia Iberoamericana de Sistemas de Información Geográfica. Costa Rica – 17-19 Junio.

Gutiérrez, J., A. M. Condeço-Melhorado, and J. C. Martín. 2008. Nectar. Does Spain's Master plan 2005 – 20 promote regional cohesion? Las Palmas de Gran Canaria, 27-28 Junio 2008.

Gutiérrez, J., A. Condeço-Melhorado, and J. C. Martín. 2010. Using accessibility indicators and GIS to assess spatial spillovers of transport infrastructure investment. *Journal of Transport Geography* 18:141-152.

Gutiérrez, J., A. Condeço-Melhorado, E. López, and A. Monzón. In press. Evaluating The European Value Added Of Ten-T Projects: A Methodological Proposal Based on Spatial Spillovers, Accessibility and Gis. *Journal of Transport Geography*. doi:10.1016/j.jtrangeo.2010.10.011

Gutiérrez, J., C. Cristóbal Pinto, and G. Gómez Cerdá. 2000. Accesibilidad peatonal a la red de metro de Madrid: efectos del Plan de Ampliación 1995-99. *Anales de Geografía de la Universidad Complutense* 20:451-464.

Gutiérrez, J., R. Gonzalez, and G. Gómez. 1996. The European high-speed train network : Predicted effects on accessibility patterns. *Journal of Transport Geography* 4:227-238.

Gutiérrez J., Monzón A., Piñero J.M. 1998. Accessibility, network efficiency, and transport infrastructure planning. *Environment and Planning A* 30:1337-1350.

Gutiérrez, J., and Urbano, P. 1996 (b). Accessibility in the European Union: the impact of the trans-European road network. *Journal of Transport Geography* 4:15-25.

Hägerstrand, T. 1970. What about people in regional science? *Papers of the Regional Science Association* 24:7-21.

Hagget, L. 1975. *Análisis locacional en Geografía Humana.* Barcelona: Gustavo Gili.

Hansen, W. G. 1959. How accessibility shapes land-use. *Journal of American Institute of Planners* 25:73-76.

Haynes, R., A. Lovett, and G. Sünnenberg. 2003. Potential accessibility, travel time, and consumer choice: geographical variations in general medical practice registrations in Eastern England. *Environment and Planning A* 35:1733-1750.

Hilbers, H. D., and E. J. Verroen. 1993. Het beoordelen van de bereikbaarheid van lokaties. Definiëring, maatstaven, toepassing en beleidsimplicaties. *INRO-VVG* 1993-09:Delft-(in Geurs y Ritsema van Eck, 2001).

Holl, A. 2004, a. Manufacturing location and impacts of road transport infrastructure: empirical evidence from Spain. *Regional Science and Urban Economics* 34:341-363.

———2004 b. Transport infrastructure, agglomeration economies, and firm birth: empirical evidence from Portugal. *Journal of Regional Science* 44:693-712.

Holtz-Eakin, D., and Schawartz. 1995. Spatial productivity spillovers from public infrastructures: evidence from state highways. *International Tax and Public Finance* 2:459-468.

Ingram, D. R. 1971. The concept of accessibility: the search of an operational form. *Regional Studies* 5:101-107.

Izquierdo, R., and A. Monzón. 1992. La accesibilidad a las redes de transporte como instrumento de evaluación de la cohesión económica y social. *TTC* 56:33-56.

Jones, S. R. 1981. *Accessibility measures: a literature review.*Report Number, 967.

Keeble, D., J. Offort, and Walker S. 1988. *Peripheral regions in a community of twelve member states.* Luxembourg: Office for Official Publications of the European Communities.

Keeble, D., P. E. Owens, and C. Thompson. 1982. Economic potential and the Channel Tunnel. *Area* 14:97-103.

Krugman, P., and A. Venables . 1990. Integration and the Competitiveness of Peripheral Industry. *CEPR Discussion Papers* 363.

Kwan, M. 1998. Space-time and integral measures of individual accessibility: A comparative analysis using a point -based framework. *Geographical Analysis* 30:191-217.

Laird, J. J. N., J., and P. J. Mackie. 2005. Network effects and total economic impact in transport appraisal. *Transport Policy* 12:537-544.

Linneker, B. J., and N. A. Spence. 1992. Accessibility measures compared in an analysis of the impact of the M25 London Orbital Motorway on Britain. *Environment and Planning A* 24:1137-1154.

Linneker, B., and N. Spence. 1996. Road transport infrastructure and regional economic development : The regional development effects of the M25 London orbital motorway. *Journal of Transport Geography* 4:77-92.

Llano, C., A. Esteban, J. Pérez, and A. Pulido. 2010. Opening The Interregional Trade "Black Box": The C-Intereg Database For The Spanish Economy (1995-2005). *International Regional Science Review* 33:302-337.

———2008. La base de datos C-intereg sobre el comercio interregional de bienes en España: metodología y primeros resultados (1995-06). *Ekonomiaz. Revista Vasca de Economía* 69:244-270.

López, E. 2007. Assessment of Transport Infrastructure Plans: a strategic approach integrating environmental, efficiency and cohesion aspects. Ph.D. dissertation, Madrid: Universidad Politécnica de Madrid.

López, E., J. Gutiérrez, and G. Gómez. 2008. Measuring regional cohesion effects of large-scale transport infrastructure investments: an accessibility approach. *European Planning Studies* 16:277-301.

Lutter, H., T. Pütz, and T. Spangenberg. 1993. *Lage und Erreichbarkeit der Regionen in der EG und der Einfluss der Fernverkehrssysteme.* Bonn.: Bundesforschungsansalt für Landeskunde und Raumordnung, Report Number, Forschungen zur Raumentwicklug Band 23. (In Geurs y Ritsema van Eck, 2001)

Martín, J. C., J. Gutiérrez, and C. Román. 2004. Data envelopment analysis (DEA) Index to measure the accessibility impacts of new infrastructure investments: the case of the high-speed train corridor Madrid-Barcelona-French border. *Regional Studies* 38:697-712.

Mas, M., J. Maudos, F. Pérez, and E. Uriel. 1994. Capital público y productividad en las regiones españolas. *Moneda y Crédito* 198:163-193.

Ministerio de Fomento. 2005. *PEIT: Plan estratégico de infraestructuras y transporte 2005-2020.* Madrid: Centro de Publicaciones.

———2005. Mapa de Tráfico 2005. Madrid. D.G. de Carreteras. Centro de Publicaciones.

MOPU (Ministerio de Obras Públicas y Urbanismo). 1984. *Plan General de Carreteras 1984-1991.* Madrid: Dirección General de carreteras.

Morris, J. M., P. L. Dumble, and M. R. Wigan. 1979. Accessibility indicators for transport planning. *Transportation Research Part A: General* 13:91-109.

Munnell, A. H. 1990. How does public infrastructure affect regional economic performance? In *Is there a shortfall in public capital investment?* ed. A. H. Munnell, Boston MA.

Muraco, W. A. 1972. Intra-urban accessibility. *Economic Geography* 48:388-405.

Nijkamp, P., P. Rietveld, and H. Voogd. 1990. *Multicriteria Evaluation in Physical Planning.* Amsterdam: North Holland.

Nombela, G. 2008. El análisis económico de las infraestructuras de transporte. In *5ª Jornada de reflexión y debate. Infraestructuras de transporte, economía y territorio.* ed. Anonymous 17-43. Madrid: Ineco Tifsa.

Pardo, A. A., and J. M. Arauzo. 2009. *Accessibility and industrial location: Evidence from Spain.* Report Number, 2009-001.

Pereira, M. A., and O. R. Sagalés. 2003. Spillover effects of public capital formation: evidence from the Spanish regions. *Journal of Urban Economics* 53:238-256.

Reggiani, A. 1998. Accessibility, Trade and Location Behavior: An Introduction. In *Accessibility, Trade and Location Behaviour,* ed. A. Reggiani, 1-14. Aldershot, England: Ashgate.

Ribeiro, A., A. P. Antunes, and A. Páez. 2010. Road accessibility and cohesion in lagging regions: Empirical evidence from Portugal based on spatial econometric models. *Journal of Transport Geography* 18:125-132.

Rietveld, P. 1989. Infrastructure and regional development. A survey of multiregional economic models. *Annals of regional science* 23:255-274.

Rus Mendonza, G. d. 2003. *Economía del transporte.* Barcelona: Antoni Bosch.

Salado García, M. J. 2001. Incorporación de medidas de accesibilidad espacio-temporal a un Sistema de Información Geográfica. 1-333.

Schürmann, C., K. Spiekermann, and M. Wegener. 1997. *Accessibility indicators.* Dortmund: Berichte aus dem Institüt für Raumplanung. IRPUD, Report Number, 39.

Schürmann, C., and A. Talaat. 2000. *Towards a European peripherality index.* Dortmund:Report Number, Final Report.

Spiekermann, K., and J. Neubauer. 2002. *European accessibility and peripherality: concepts, models and indicators.* Report Number, Report 2002:9. Nordregio, Stockolm.

Taaffe, E. J. 1962. Transportation and regional specialization. *Annals of the Association of American Geographers* 80-98.

Thomopoulos, N., S. Grant-Muller, and M. R. Tight. 2009. Incorporating equity considerations in transport infrastructure evaluation: Current practice and a proposed methodology. *Evaluation and Program Planning* 32:351-.59.

Tillema,T. 2007. Road pricing: a transport geographical perspective. Ph.D. dissertation, Utrecht: Faculty of Geosciences, Utrecht University.

Törnqvist, G. 1970. Contact Systems and Regional Development. *Lund Studies in Geography* 35.

Torrego, F. 1986. Geografía de los transportes. *Anales de Geografía de la Universidad Complutense* 6.

Ullman, E. L., and H. M. Mayer. 1954. Transportation geography. *American Geogr.*

van Excel, J., S. Rienstra, M. Gommers, A. Pearman, and D. Tsamboulas. 2002. EU involvement in TEN development: network effects and European value added. *Transport Policy* 9:299-311.

Vickerman, R. W. 1998. Accessibility, Peripherality and Spatial Development: Question of Choice. In *Accessibility, Trade and Location Behavior,* ed. A. Reggiani, 79-93. Aldershot, England: Ashgate.

———1996. Location, accessibility and regional development: the appraisal of trans-European networks. *Transport Policy* 2:225-234.

———1974. Accessibility, attraction and potential: a review of some concepts and their use in determining mobility. *Environment and Planning A* 6:675-691.

Vickerman, R. W., K. Spiekermann, and M. Wegener. 1999. Accessibility and economic development in Europe. *Regional Studies* 33:1-15.

Wegener, M., and D. Bökemann. 1998. *The SASI Model: Model Structure. SASI Deliverable D8.* Berichte aus dem Institut für Raumplanung 40. Dortmund: Institut für Raumplanung, Universität Dortmund. http://www.raumplanung.uni-dortmund.de/irpud/pro/sasi/ber40.pdf., .

Wegener, M., H. Eskelinen, F. Fürst, C. Schürmann, and K. Spiekermann. 2000. *Geographical Position.*Report Number, Final Report - Part 1.

Zhu, X., and S. Liu. 2004. Analysis of the impact of the MRT system on accessibility in Singapore using an integrated GIS tool. Journal of Transport Geography 12:89-101.