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Economic Analysis of High Speed Rail in Europe

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This is not a new edition of the report on the economic analysis of high speed rail. The research papers published in the initial report are basically the same as well as their results and conclusions. The purpose of this new edition is to correct some figures on maintenance and operating costs taken from the database provided by the International Union of Railways (UIC) which seem to be incorrect.
The operating and maintenance costs of HSR services vary across rail operators depending on the specific technology, organization, labour conditions, and traffic volumes. Adding operating and maintenance costs and taking into account the volume of train-km per train and the number of seats, the operating cost per seat-km can vary widely between countries.
The figures on the operation and maintenance of trains per seat-km are subject to some controversy and therefore we have preferred to ignore and omit this information in the report.

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Ginés de Rus
Tafira, September 2008

Summary
Resumen

Many countries are taking into consideration the construction of new high speed rail lines. The European Commission explicitly deems the expansion of high speed rail as a priority within the trans-European networks, allocating an important part of the community funds for its development with the declared aim of increasing the market share of rail transport.

High speed rail generates social benefits, which stem from time savings, increase in reliability, comfort and safety, as well as from the reduction of congestion and accidents in alternative modes. Another benefit of investing in the construction of new lines is the capacity released in the conventional network, when the latter itself can be used for freight transport.

The question is not whether users and other possible beneficiaries of high speed rail would vote in favor of constructing a new line. The question is whether they would be willing to pay (regardless of what they actually pay) for its social costs. The answer to this question varies widely depending on the particular characteristics of the project. An exhaustive review of the economic literature shows that the research effort dedicated to the economic analysis of investing in high speed railways is insignificant when compared with the economic importance of such technology and its public financing within the transport plans and budgets of member states and the European Commission.

The aim of this report is to contribute to the economic analysis of new high speed rail investment projects requiring public funds. The economic evaluation of projects can help governments to obtain a clearer view of the expected net benefits of different lines of action, as it attempts to identify the projects which really deserve the sacrifice of other social needs competing for the same public funds. We analyze the circumstances under which society may benefit from investing in high speed rail, and when it is sensible to delay the investment decision. The high speed rail network may be built gradually, adding new lines once the economic evaluation of projects shows a positive social profitability.

La construcción de líneas ferroviarias de alta velocidad es una opción que está siendo considerada por muchos países en el mundo. La Comisión Europea considera que la expansión de la red de alta velocidad es una prioridad dentro de las redes transeuropeas, destinando una importante cantidad de fondos comunitarios para su desarrollo con el objetivo explícito de aumentar la cuota de mercado del ferrocarril.

La alta velocidad genera beneficios sociales procedentes de ahorros de tiempo, mejoras en la fiabilidad, confort y seguridad del servicio de transporte; y de la reducción de la congestión y los accidentes en los modos alternativos de transporte. Liberar capacidad en la red convencional, que puede utilizarse para el transporte de mercancías, es también un beneficio adicional de la inversión en la construcción de nuevas líneas.

La cuestión no es si los usuarios y otros potenciales beneficiarios votarían a favor de la construcción de nuevas líneas de alta velocidad. La cuestión relevante es si estarían dispuestos a pagar (con independencia de lo que paguen) los costes sociales de su puesta en funcionamiento. La respuesta a esta pregunta varía ampliamente dependiendo de las circunstancias concretas del proyecto. Una exhaustiva revisión de la literatura económica muestra que el análisis económico de las inversiones en alta velocidad es insignificante comparado con el papel concedido a esta tecnología dentro de los planes de transporte de muchos países miembros y de la propia Comisión Europea, y más aún si tenemos en cuenta la financiación pública destinada a los mismos.

Este informe pretende contribuir al análisis económico de los proyectos de inversión en alta velocidad ferroviaria. La evaluación económica de proyectos puede ayudar a los gobiernos a formarse una idea más precisa sobre los beneficios esperados de distintas líneas de actuación que absorben dinero público para resolver un mismo problema de transporte. En este informe tratamos de determinar las circunstancias en las que la inversión en alta velocidad es socialmente deseable y en que otras la sociedad gana posponiendo la inversión. La red de alta velocidad puede construirse gradualmente, añadiendo nuevas líneas una vez que la evaluación económica muestra una rentabilidad social positiva.

Introduction

The allocation of public resources to the expansion of the high speed rail network is a significant element of transport policy in many countries all over the world. This includes both the construction of new lines and the upgrading of part of the conventional network, so that trains can run at speeds of more than 200 km per hour. The demand for the new rail transport alternative comes from deviated traffic from conventional trains, air and road transport, and also from generated traffic, thanks to the combination of time savings, increased comfort and more price choices associated to this new transport option.

The European Union has explicitly considered the expansion of high speed rail as a priority within the trans-European networks, assigning an important part of Community funds for its development, with the declared aim of changing the modal split to the benefit of railways. This *revitalization of railways strategy,* as announced by the European Commission, reflects the relevance that this transport mode is gaining in Europe in a context of increased worries about congestion and traffic accidents in roads, the delays and discomfort associated with air traffic, as well as the negative environmental impacts of these modes.

Although the construction and operation of high speed rail lines imply significant environmental costs (land, noise, barrier effects, visual intrusion and global warming) the train still retains a good environmental image, though the actual environmental balance depends on the volume of traffic and its composition.

The interest of the European Commission in high speed rail is shared by most member state governments, and, obviously, by the industrial lobbies that supply rolling stock and other rail inputs, as well as by users, who generally enjoy its speed, comfort and price—three elements responsible for the dramatic recovery of the railway's market share over medium distances.

If users, governments, industries and the European Commission support such a technological option for passenger travel, we could be in a situation that economists call *Paretian improvement,* characterized by the existence of winners, indifferent agents and the inexistence of losers. Nevertheless, the price that users pay for high speed rail infrastructure and services in many routes is far from covering construction, maintenance and infrastructure operation costs. That means taxpayers must contribute financially to the support of these projects. So there are in fact losers, as in all public policies and investment projects.

The question is not whether users and other possible beneficiaries of high speed rail would vote in favor of the construction of high speed lines. The question is whether they would be willing to pay (independently of what they actually pay) their social costs. The answer to this question varies widely depending on the local characteristics of the project: routes, crossed urban zones, required bridges and tunnels, volume of demand, per capita income, and the level of capacity use in competing modes.

Social benefits of high speed rail mainly accrue from users' time savings and the willingness to pay of generated traffic. To these benefits we should add those that users experience thanks to the reduction of congestion and accidents in alternative modes. The benefits obtained from the release of capacity in the conventional network should also be added.

The conventional economic evaluation of projects requires the identification of the benefits and costs during the life of the project. And once these have been quantified, the next step is to calculate their net value. When benefits are higher than costs, the investment is probably socially worthy, although even with a positive net present value, there may be other alternative projects providing a higher social benefit.

What happens when the flow of expected net benefits is lower than the investment costs of the project under evaluation? Or, in more intuitive terms: what happens when the society is willing to pay a price for a high speed rail line which is inferior to its cost? The answer is clear: reject the project.

In the debate in favor of large infrastructure investment projects, there is a recurrent argument which defends the existence of economic benefits greater than those described above. It also suggests that the exclusion of these unaccounted benefits would make the high speed rail line appear less profitable than it really is. The identification and magnitude of these wider economic benefits are difficult to determine, and it may well be that, due to this fact, promoters and politicians who support high speed lines mention them frequently when debating the convenience of building new lines.

The indirect economic benefits are located in markets other than those directly affected by the project, or the primary markets. No one doubts the existence of secondary effects. A city that is connected to a high speed network may experience an economic expansion and an increase in its land value. Unemployment may be reduced as a consequence of the activity generated thanks to the construction of the rail line and the generation of economic activity.

However there are also some other effects to account for. Someone has to pay for the higher price of the land; and although there are net benefits, the analyst has to be careful not to count pure rent transfers as net benefits, or to see the increase in land value as something additional to time savings and other primary benefits. Regarding employment, we ought not to confuse inputs with outputs. If there is unemployment, the price of labor will be reduced in the evaluation to reflect its opportunity cost. Adding it again on the benefit side would lead to double counting.

Before adding the secondary benefits, it is important to distinguish the creation of a new activity from one that emerges from a simple relocation of an already existing economic activity. In general, the analysis of indirect economic effects is more complicated than it may seem at first glance. Moreover not all of them are positive while many others reflect already accounted-for benefits of the primary market.

Even assuming that all the benefits of high speed rail were adequately measured and compared to its costs, promoters will frequently argue that these large infrastructure initiatives (mega-projects) will have more important, long-term effects on society than direct economic benefits. Although very difficult to predict, these effects are usually related to the regional development benefits of investing in infrastructure. Nevertheless, thanks to the efforts of new economic geography researchers, we know that the effects of infrastructure on the location of economic activity are ambiguous at times: occasionally reinforcing the central region and making the periphery worse off.

Investment in building HSR lines and the associated rolling stock to operate them is very expensive, and their indivisibility and irreversibility increase the cost of errors. Constructing new lines with an optimistic demand bias translates into a waste of taxpayer money, because this mode of transport is being developed in Europe within the public sector, without private participation and with revenues far from covering total costs.

What do economists say about the opportunity of investing in high speed networks in Europe? An exhaustive revision of the specific economic literature shows that the research effort devoted to the economic analysis of investing in high speed railways is almost insignificant considering the economic significance of this technology within the transport plans of member states and the European Commission, and its share in the state budgets of many countries.

The aim of this report is to contribute to the economic analysis of new high speed rail investment projects that are waiting for public funds. The economic evaluation of projects can help governments to obtain a clearer view of the expected net benefits of different lines of action, and identify the projects which really deserve the sacrifice of other social needs competing for the same public funds.

Constructing a new high speed rail line may reduce congestion and accidents in road and air transport over medium distances, where the train competes with the private vehicle and the airlines. If the volume of demand is high enough, the project may be socially profitable. In addition, when a high speed line is linked to a network, it multiplies its connectivity, making new origins and destinations accessible. This factor and the release of capacity in the conventional rail network or in congested airports increase the probability of a positive net present value.

Deciding to reject (or delay) the construction of a high speed rail line is not necessarily a position against progress. If the best information available *ex ante* proves that there are other transport options with a higher net social benefit, the most appropriate decision is to select such options and not the larger, more costly or newest technology.

The social pressure for the construction of high speed lines is not only explained by its known benefits but also by an institutional design that favors the construction of projects without having to pay for them directly. Incentives today lean towards the approval of mega-projects, which a country or a region, without supranational or state funds respectively, would not have undertaken on its own.

The research papers published in this report begin with the construction of a database from incomplete and disperse information on high speed lines all over the world. The report contains an analysis of the construction costs, maintenance, and exploitation of the lines in service or under construction, and it examines the demand data available. The economic evaluation of investment in high speed rail under different circumstance shows the conditions required for a minimum level of social profitability.

The texts included here have a common feature, which is the attempt to answer the question that motivated this research project: when is the investment in high speed rail profitable from a social perspective? The answer, as in so many aspects of economy, is not black and white. It depends on the local conditions where the new line is to be built and the expected volume of demand. Choosing an investment option without comparing it with relevant alternatives is, at best, contrary to good economic practice. The primary function of high speed railways is to solve a transport problem, and their advantage over other feasible alternatives has to be demonstrated on a case-by-case basis.

1
A Review of HSR Experiences Around the World

1.1 INTRODUCTION

High Speed Railways (HSR) is currently regarded as one of the most significant technological breakthroughs in passenger transportation developed in the second half of the 20th century. At the beginning of 2008, there were about 10,000 kilometers of new high speed lines in operation around the world and, in total (including upgraded conventional tracks), more than 20,000 kilometers of the worldwide rail network was devoted to providing high speed services to passengers willing to pay for lower travel time and quality improvement in rail transport.

For the last 40 years in Japan alone, where the concept of *bullet train* was born in 1964, 100 million passenger-trips are carried out per year. In Europe, traffic figures average 50 million passenger-trips per year, although they have been steadily growing since 1981 by an annual percentage rate of 2.6. Nowadays, there are high speed rail services in more than 15 countries,[1] and the network is still growing at a very fast pace in many others: it is expected to reach 25,000 kilometers of new lines by 2020 (UIC 2005a).

However building, maintaining and operating HSR lines is expensive; it involves a significant amount of sunk costs and may substantially compromise both the transport policy of a country and the development of its transport sector for decades. For these reasons, it deserves a closer look, well beyond the technological hype and the demand figures. The main objective of this chapter is to discuss some characteristics of the HSR services from an economic viewpoint, while simultaneously developing an empirical framework that should help us to understand, in more detail, the cost and demand sides of this transport alternative. This understanding is especially useful for future projects, since it will lead to a better analysis of the expected construction and operating costs, and of the number of passengers to be transported under different economic and geographic conditions.

Such understanding is particularly relevant because the economic magnitude of HSR investments and the described prospects for network expansion are not in accordance with the research efforts reported in the economic literature. The economic appraisal of particular corridors is limited to some existing and projected lines (see De Rus and Inglada 1993, 1997; Levinson et al. 1997; Atkins 2003; Coto-Millan and Inglada 2004; and De Rus and Roman 2005). General assessments are relatively scarce (Nash 1991; Vickerman 1997; Martin 1997; SDG 2004; De Rus and Nombela 2007; and De Rus y Nash, 2007); and many other papers were devoted to assess the regional and other indirect effects of HSR (Bonnafous 1987; Vickerman 1995; Blum, Haynes and Karlsson 1997; Plassard 1994, Haynes 1997, and Preston and Wall 2007).

Since most of the previous empirical assessments were based on individual country case

[1] Although the definition of HSR services will be discussed in section 1.2, the list includes Japan, South Korea, China, Taiwan, France, Germany, Italy, Spain, Portugal, Belgium, Netherlands, Norway, United Kingdom, Sweden, Denmark, and the United States.

studies, we will adopt an international comparative perspective. We assembled a database comprising all existing HSR projects around the world at the beginning of 2006.[2] It includes information about the technical characteristics and building costs of each project—even for those still at planning or construction stage, when available—plus detailed information regarding operating and maintenance costs of infrastructure and services for the lines already in operation. A special section devoted to the external costs of HSR is included, as well as data regarding traffic, capacity and tariffs on selected corridors.[3]

Our database includes information on 166 projects in 20 countries; 40 (24%) are projects already in operation, whereas 41 are currently under construction and 85 are still at planning stage, some of which pending further approval and/or funding. The projects in operation and construction have a total length of 16,400 kilometers, although some of them will not be finished before 2015.[4]

The statistical analysis and data comparisons obtained from such a large number of projects will allow us to address several questions about HSR around the world. The first one (section 1.2) is related to the economic definition of HSR. In section 1.3, we try to find out (on average) the cost of building a kilometer of (new) high speed line, and to identify the reasons why this cost differs across projects. Section 1.4 is devoted to extract, from actual data, some of the main characteristics of operating and maintenance costs of HSR lines in the world, whereas in section 1.5, we discuss the extended idea of HSR being the means of transport with the lowest external cost. Section 1.6 studies how the demand path for high speed services evolves around the world, and it tries to look for a pattern to predict how long it will keep on growing in Europe at the present rate. Finally, section 1.7 contains the general conclusions.

1.2 TOWARDS AN ECONOMIC DEFINITION OF HIGH SPEED RAILWAYS

For many years it has been customary in the rail industry to consider *high speed* just as a technical concept related to the maximum speed trains could reach when running on particular track segments. In fact, the European Council Directive 96/48 specifically established that *high speed infrastructure* comprised three different types of lines:[5]

- purposely built high speed lines equipped for speeds generally equal to or greater than 250 km/h,
- upgraded conventional lines, equipped for speeds of the order of 200 km/h, and
- other upgraded conventional lines, which have special features as a result of topographical or land-planning constraints, on which the speed must be adapted to each case.

In theory, these technical definitions are broad enough to encompass the entire rail infrastructure capable of providing high speed services. In practice, however, *speed* has not always been the best indicator, since commercial speed in many services is often limited due to, for example, proximity to densely urbanized areas (to ease the impact of noise and minimize the risk of accidents), or the existence of viaducts or tunnels (where speed must be reduced to 160-180 km/h for safety reasons).[6]

[2] The analysis carried out in this chapter and, in particular, the list of HSR projects are based on public information mainly provided by the *International Union of Railways* (see UIC 2006), and some of the rail companies currently operating HSR services.

[3] Information on the demand side (disaggregated traffic figures and prices) is still incomplete and constitutes the major drawback of our dataset.

[4] The only comparable database built with a similar purpose is The World Bank Railway Database (available at www.worldbank.org/transport/rail/rdb.htm). However our data specifically focus on HSR projects, not on the overall performance of rail operators worldwide.

[5] This Directive aims to ease the circulation of high speed trains through the various train networks of the European Union. Member States are asked to harmonize their high speed rail systems in order to create an interoperable European network (European Commission 1996).

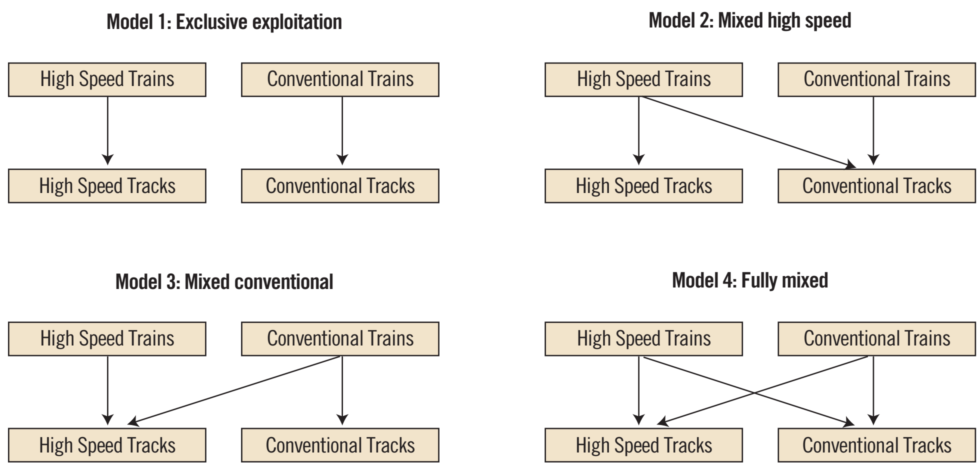
[6] The average commercial speed in several (supposedly) high speed services over the densest areas in North Eu-

Although HSR shares the same basic engineering principles with conventional railways—both are based on the fact that rails provide a very smooth and hard surface on which the wheels of the trains may roll with a minimum of friction and energy consumption—they also have technical differences. For example, from an operational point of view, their signalling systems are completely different: whereas traffic on conventional tracks is still controlled by external (electronic) signals together with automated signalling systems, the communication between a running HSR train and the different blocks of tracks is usually fully in-cab integrated, which eliminates the need for drivers to see lineside signals.

Similarly, the electrification differ: whereas most new high speed lines require at least 25,000 volts to achieve enough power, conventional lines may operate at lower voltages. Additional technical dissimilarities, regarding the characteristics of the rolling stock and the exploitation of services, also exist.[7]

All these differences suggest that, more than the speed factor, what actually plays a more relevant role in the economic definition of high speed services are both the relationship of HSR with existing conventional services, and the way in which the use of infrastructure is organized. As summarized in graph 1.1, four different exploitation models can be identified:

1) The *exclusive exploitation model* is characterized by a complete separation between high speed and conventional services, each one with its own infrastructure. This is the model the Japanese *Shinkansen* has been adopting since 1964, mostly due to the fact that the existing conventional lines (built in narrow gauge, 1.067 m) had reached their capacity limits, and it was decided that the new high speed lines would be designed and built in standard gauge (1.435 m). One of the major advantages of this model is that market organization of both HSR and conventional services are fully independent, something that later proved to be a valuable asset, when the public operator (*Japan National Railways*, JNR)



Graph 1.1 HSR models according to the relationship with conventional services

rope is often below the average speed of some conventional lines, running between distant stops through sparsely populated plain areas. New maximum speed tests have been recently (2007) announced by the TGV in France (www.sncf.com/news), but its commercial use may be restricted.

7 In recent years a new technology, based on magnetic levitation (*maglev*) trains that can reach up to 500 km/h, has been implemented in a limited number of projects (e.g. Shanghai). In spite of sharing the adjective *high speed,* the services provided by these trains are based on completely different principles—closer to air transport than to railways—and will not be considered in this chapter.

went bankrupt, and integrated rail services and infrastructures had to be privatized.[8]

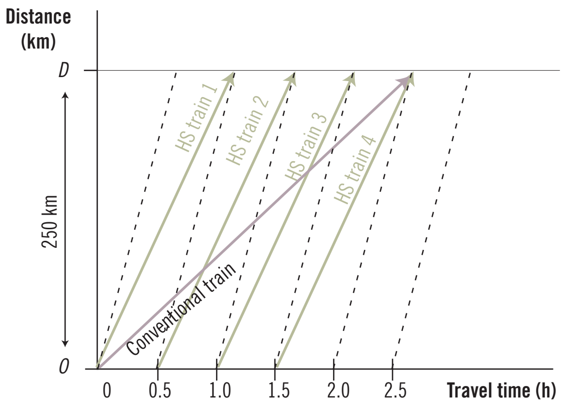
2) In the *mixed high speed model,* high speed trains run either on specifically built new lines or on upgraded segments of conventional lines. This corresponds to the French model, whose TGV (*Train à Grande Vitesse*) has been operating since 1981, mostly on new tracks, but also on re-electrified tracks of conventional lines in areas where the duplication was impractical. This reduces building costs, which is one of the main advantages of this model.

3) The *mixed conventional model*, where some conventional trains run on high speed lines, was adopted by Spain's AVE (*Alta Velocidad Española*). As in Japan, most of the Spanish conventional network was built in narrow gauge, whereas the rest of the European network used the standard gauge. To facilitate the interoperability of international services, a specific adaptive technology for rolling stock was developed in 1942—i.e., the TALGO trains—to enable it to use, at higher than normal speed, the specific HSR infrastructure (built in standard gauge).[9] The main advantages of this model are the saving of rolling stock acquisition and maintenance costs, and the flexibility for providing *intermediate high speed services* on certain routes.

4) Finally the *fully mixed model* allows for the maximum flexibility, since this is the case where both high speed and conventional services can run (at their corresponding speeds) on each type of infrastructure. This is the case of German intercity trains (ICE) and the Rome-Florence line in Italy, where high speed trains occasionally use upgraded conventional lines, and freight services use the spare capacity of high speed lines during the night. The price for this wider use of the infrastructure is the significant increase in maintenance costs.

The reasons why each of these models will determine in a different way the provision of HSR services depend on traffic management restrictions, which can be better understood with the help of graph 1.2.

On the vertical axis, we have represented the distance (250 km) between origin (O) and destination (D) rail stations, whereas the horizontal axis reflects the travel time (in hours). The inclined dotted lines represent potential time slots for (non-stop) trains running from O to D.[10] Note that the slope of the slots and the horizontal separation between each pair of them depend on the average commercial speed authorized for the O-D line (according to its technical configuration, gradient, number of curves, viaducts, etc.) However, the actual usage of these slots is mainly determined by the type of service provided to passengers. For example, high speed services (at 250 km/h) cover the distance between O and D in just one hour, whereas a conventional train would need 2.5 hours.



Graph 1.2 Time slots in railways and the provision of HSR services

[8] There are a few exceptions. Some *Shinkansen* lines cannot handle the highest speeds. This is because some rails remain narrow gauge to allow sharing with conventional trains, reducing land requirement and cost. In addition, in the congested surroundings of Tokyo and Osaka, the *Shinkansen* must slow down to allow other trains to keep their schedules and must wait for slower trains until they can be overtaken (Hood, 2006).

[9] The wheels in TALGO trains are mounted in pairs between, rather than underneath, the individual coaches. They are not joined by an axle and, thus, the trains can lightly switch between different gauge tracks.

[10] Note that for each intermediate stop, the dotted lines would jump to the right for a distance proportional to the time spent at the stop. In multiple track lines or in stations with multiple platforms, faster trains could overtake slower ones.

For this reason the network exploitation models in graph 1.1 now become crucial. The *exclusive exploitation* and the *mixed high speed* models, for example, allow a more intensive usage of HSR infrastructure, whereas the other models must take into account that (with the exception of multiple-track sections of the line) slower trains occupy a larger number of slots during more time and reduce the possibilities for providing HSR services. In graph 1.2, at least four high speed trains are stopped due to the operation of a single conventional train. Since trains of significantly different speeds cause massive decreases of line capacity, mixed-traffic lines are usually reserved for high speed passenger trains during daytime, while freight trains operate at night. In some cases, nighttime high speed trains are even diverted to lower speed lines in favor of freight traffic.

Since choosing a particular exploitation model is a decision affected by the comparison of the costs of building (and maintaining) new infrastructure versus the costs of upgrading (and maintaining) the conventional network, the definition of HSR immediately becomes not only a technical question but also a (very relevant) economic one. Three additional factors contribute to the definition of HSR in economic terms:

- The first one is the *specificity of the rolling stock*, whose technical characteristics must be adapted to the special features of high speed. HSR trainsets are designed to run without locomotives (both extremes of a train can function as the initial one), with minimal oscillations even on curves with elevated radial velocity, and without the need of tilting to compensate for the centrifugal push. The acquisition, operating and maintenance costs of this rolling stock represent a huge long-run investment for companies (often over 20 years), and critically determine the provision of high speed services.
- The second one is the *public support* enjoyed by most HSR undertakings, particularly in Europe where national governments have already compromised significant amounts of funds in the development of their high speed networks during the next decades. At the supranational level (European Commission 2001) there exists an explicit strategy for «revitalizing the railways» as a «means for shifting the balance between modes of transport against the current dominance of the road». This is justified in terms of the lower external costs of rail transport (particularly, HSR) when compared to road transport with respect to congestion, safety, and pollution.
- The third reason lies on the *demand side* for HSR services. Railways operators in many countries have widely acknowledged their high speed divisions as one of the key factors in the survival of their passenger rail services. In fact, HSR has been started to be publicized—particularly in France and Spain—as a different mode of transport, as a system with its own right that encompasses both a dedicated infrastructure with an increasingly more specialized and technologically advanced rolling stock. It brings with it an improvement over traditional rail transport (clock-face timetables, sophisticated information and reservation systems, catering, on board and station information technology services) and, in general, an overall increase in the added value for the passenger.

All these elements—infrastructure building costs, operating and maintenance costs, external costs and demand—will be analyzed in the remaining sections of this chapter.

1.3 THE COSTS OF BUILDING HSR INFRASTRUCTURE

Building new HSR infrastructure requires a specific design aimed at the elimination of all those technical restrictions that may limit the commercial speed below 250-300 km/h. These basically include roadway level crossings, frequent stops or sharp curves unfitted for higher speeds; however, in some cases, new signalling mechanisms and more powerful electrification systems may be needed, as well as junctions and exclusive trackways in order not to share the right-of-way with freight or slower passenger trains, when the infrastructure is jointly exploited (see the models in graph 1.1).

Such common design features, however, are not an indication of similarly in HSR construction.

Just the opposite; the comparison of construction costs between different HSR projects is difficult since each technical solution to implement these features not only differs widely (depending on topography and geography), but also evolves overtime.

According to UIC (2005b), building new HSR infrastructure involves three major types of costs:

— *Planning and land costs*, including feasibility studies (both technical and economic), technical design, land acquisition and other costs (such as legal and administrative fees, licenses, permits, etc.) These costs may be substantial in some projects (particularly, when costly land expropriations are needed), but they often represent a sunk component of between 5-10% of the total investment amount.
— *Infrastructure building costs* including all those costs related to terrain preparation and platform building. The amount varies widely across projects depending on the characteristics of the terrain, but usually represents between 10-25% of the total investment in new rail infrastructure. In some cases, the need of singular solutions (such as viaducts, bridges or tunnels) to geographic obstacles may easily double this amount (up to 40-50%, in more technically difficult projects).
— *Superstructure costs* include rail specific elements such as guideways (tracks) and sidings along the line, signalling systems, catenaries and electrification mechanisms, communications and safety installations, etc. Individually considered, each of these elements usually represents between 5-10% of the total investment.[11]

Although these three major types of costs are present in all projects, their variability is largely conditioned again by the relationship between the infrastructures to be built in each case and the pre-existing one. Attending to this criterion, at least five types of HSR projects can be distinguished (UIC, 2005b):

— *Large corridors isolated from other HS lines*, such as the Madrid-Seville AVE;
— *Network integrated large corridors*, such as Paris-Lille integrated with Paris-Lyon and the French high speed network;
— *Smaller extensions or complements of existing corridors*, such as Madrid-Toledo or Lyon-Valence, both developed to serve nearby medium-size cities;
— *Large singular projects*, such as the Eurotunnel, the Grand Belt or the bridge over the Messina Strait; and
— *Smaller projects complementing the conventional network*, including high speed lines that connect airport with nearby cities, or the improvements in conventional infrastructure to accommodate higher speed services, as in Germany or Italy.

Our database of 166 HSR projects around the world includes information about all these five types of projects. However, in the comparison of building costs, we only considered 45 projects. We excluded both the large singular projects and the smaller projects complementing the conventional network, due to their specific construction characteristics. Projects whose financial information was incomplete and all those that are still at planning stage, even when investment information was available, were excluded. The reason for the latter exclusion is that, at such stage, deviation over planned costs is often substantial, as pointed out in the literature about it (see Flyvbjerg, Skamris, and Buhl 2004, for example).

Graph 1.3 summarizes the average cost per kilometer of building HSR infrastructure found in our database. The values are expressed in euro million (2005) and include the infrastructure and superstructure costs, but not the planning

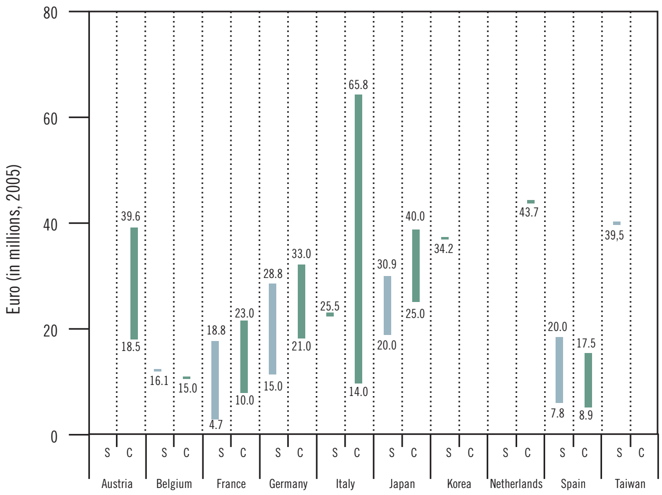
[11] In most projects the superstructure costs often include building standard stations and auxiliary depots which alone, according to their architectonic characteristics cannot be considered singular projects. In some cases, stations are singular buildings with an architectonic design and associated costs far beyond the minimum required for operating purposes. The allocation of these costs to the HSR line is arbitrary to say the least. There also are other minor elements (supervision, quality control, etc.) in each project that may represent between 1-5% of the total investment.

and land costs. Overall, the construction cost per kilometer in the sample of 45 projects varies between 6 and 45 million (with an average value of 17.5 million). When the analysis is restricted to projects in operation (24 projects) the range varies between 9 and 39 million (with a mean value of 18 million). With the exception of China, building HSR in Asia seems more expensive than in Europe, according to the data from Japan, Taiwan and South Korea, although the costs of these two latter countries include some items corresponding to upgrading conventional tracks.[12]

In Europe, there are two groups of countries: France and Spain have slightly lower building costs than Germany, Italy and Belgium. This is explained not only by the similar geography and existence of the less populated areas outside the major urban centers, but also by construction procedures. In France, for example, the cost of construction is minimized by adopting steeper grades rather than building tunnels and viaducts. Because the TGV lines are dedicated to passengers (the exclusive exploitation model of graph 1.1), grades of 3.5%, rather than the previous maximum of 1-1.5% for mixed traffic, are used. Although the land acquired to build straighter lines is more expensive, this is compensated by a reduction in line construction as well as operating and maintenance costs. In the other European countries high speed rail is more expensive because it is built over more densely populated areas, without those economies of space.

Finally, with respect to the projects currently under construction (21 projects, some of them due to finish by 2007), one can observe that, in most cases, they are in line with the building costs of projects in operation.[13] It is interesting to note that there is no evidence of economies of experience, particularly in Japan and France, the countries with a longer history of HSR projects, though the new projects are not homogeneous enough to make relevant comparisons.

In Japan, the cost per kilometer (excluding land costs) in the Tokyo-Osaka *Shinkansen* (started in 1964) was relatively low (€5.4 million in 2005 values), but in all the projects carried out during the following years, this figure was tripled or quadrupled. In France, each kilometer built for the TGV *Sud-Est* between Paris and Lyon, inaugurated in 1981, required an investment of €4.7 million (in construction costs), whereas the



Graph 1.3 Average cost per kilometer of new HSR infrastructure

Notes: S = Lines in Service; C= Lines under Construction (2006)

Source: HSR Database. Elaborated from UIC (2005b). Data excludes *planning and land costs*

[12] This is qualitatively consistent with the comparison performed by SDG (2004), although the costs included in UIC (2005b) are different. Several individual projects reported in SDG (2004)—such as the HSL Zuid (Netherlands) and the Channel Tunnel rail link—have construction costs per km in the range of €50-70 million.

[13] The only exception in graph 1.3 is Italy. This is because the lines under construction are mostly placed in the north of the country, more densely populated.

cost per kilometer of the TGV *Méditerranée*, inaugurated in 2001 was €12.9 million. These differences—due to intrinsic characteristics of each project—call once more for a cautious use of the comparison figures obtained in this and other papers.

1.4 THE COSTS OF OPERATING HSR SERVICES

Once the infrastructure is built, the operation of HSR services involves two types of costs: those related to the exploitation and maintenance of the infrastructure itself, and those related to the provision of transport services using that infrastructure. The different degrees of vertical integration existing between the infrastructure provider and the carrier that supplies HSR services are not discussed here.[14] In Europe, Council Directive 91/440 set out the objective of unbundling infrastructure from operations by either full separation or, at least, the creation of different organizations or units (with separate accounts) within a holding company. Outside Europe, many countries have still opted for the full vertical integration model, where all the HSR operating costs are controlled and managed by a single entity.[15]

1.4.1 INFRASTRUCTURE OPERATING COSTS

This category includes the costs of labor, energy and other material consumed by maintenance and day-to-day operations of the guideways, terminals, stations, energy supplying and signalling systems, as well as traffic management and safety systems. Some of these costs are fixed and depend on operations routinely performed in accordance with technical and safety standards. In other cases, as in track maintenance, the cost is affected by the traffic intensity; similarly, the cost of maintaining electric traction installations and catenaries is subjected to the number of trains running on the infrastructure. According to the UIC statistics (UIC, 2006), the proportions of the cost of labor within each kind of maintenance costs are: 55% for maintenance of electric traction installations, 45% for maintenance of tracks, and 50% for maintenance of equipment.

The database provides more detailed information for five European countries (Belgium, France, Italy, the Netherlands and Spain), where we are able to disaggregate the infrastructure maintenance costs for a new HSR line into five categories: maintenance of tracks, electrification costs, signalling costs, telecommunications and other costs, as shown in table 1.1.[16]

TABLE 1.1: Cost of HSR infrastructures maintenance by country

	Belgium		France		Italy		Spain	
Km, of single track	142		2,638		492		949	
Maintenance of track	13,841	43.7%	19,140	67.3%	5,941	46.0%	13,531	40.4%
Electrification	2,576	8.1%	4,210	14.8%	2,455	19.0%	2,986	8.9%
Signalling	3,248	10.3%	5,070	17.8%	4,522	35.0%	8,654	25.9%
Telecommunications	1,197	3.8%	0	0	0	0	5,637	16.8%
Other costs	10,821	34.2%	0	0	0	0	2,65	7.9%
Total maintenance cost	**31,683**	**100%**	**28,420**	**100%**	**12,919**	**100%**	**33,457**	**100%**

Note: Costs are expressed in 2002 euros per kilometer of single track.

Source: Elaborated from UIC (2005b).

[14] This section deals only with the private costs faced by the infrastructure management agencies and HSR operators. Section 1.5 is devoted to the discussion of some of the external costs associated with HSR.

[15] In countries where infrastructure is separately managed, access charges may represent an additional operating cost for operators, but they are mere transfer of funds, when considered from the perspective of the HSR system as a whole. For an analysis of the different options to introduce competition through vertical unbundling while maintaining vertical integration, see Gómez-Ibáñez and De Rus (2006).

[16] Note, however, that data comparability may be limited by other technical factors, very difficult to homogenize, such as required reliability index, the inspection intervals, track geometry, average load, etc., which may differ across countries and specific lines.

In general, in all cases the maintenance of infrastructure and tracks represent between 40-67% of total maintenance costs (both in high speed and conventional network), whereas the signalling costs vary between 10-35% in HSR, and between 15-45% in conventional lines. The relative weight of the electrification costs is almost the same in both networks.

In table 1.1 the cost of maintaining a high speed rail line ranges from 28,000 to 33,000 euros (2000) per kilometer of single track. Taking 30,000 euros as a representative value, the cost of HSR infrastructure maintenance of a 500-km HSR line would reach 30 million euros per year.

1.4.2. ROLLING STOCK AND TRAIN OPERATING COSTS

The operating costs of HSR services can be divided into four main categories: shunting and train operations (mainly labor costs), maintenance of rolling stock and equipment, energy, and sales and administration. This final cost item varies across rail operators depending on their expected traffic level, since it mainly includes the labor costs for ticket sales and for providing information at the railroad stations.[17] The other three components vary widely across projects depending on the specific technology used by the trains.

In the case of Europe, almost every country has developed its own technological specificities, suited to solve their specific transportation problems. In terms of types of trains employed to provide HSR services, France uses the *TGV Réseau* and the *Thalys* (for international services with Belgium, Netherlands and Germany), and in 1996, it introduced the *TGV duplex*, with double capacity. In Italy, the *ETR-500* and the *ETR-480* are used, whereas in Spain HSR services are provided by the *AVE* model. Finally, in Germany there are five different types: *ICE-1*, *ICE-2*, *ICE-3*, *ICE-3 Polycourant* and *ICE-T*.

Each of these train models has different technical characteristics—in terms of length, composition, mass, weight, power, traction, tilting features, etc.—but table 1.2 itemizes only those related to capacity and speed, and it gives an estimate of the acquisition cost per seat. Apart from the type of train, shunting (or track-switching) costs depend on the distance between the depot and the stations as well as the average pe-

TABLE 1.2: HSR technology in Europe: types of train

Country	Type of train	First year of service	Seats	Average distance (km)	Seats-km (thousands)	Maximum speed (km/h)	Estimated acquisition cost (€ / seat)
France	TGV Réseau	1992	377	495,000	186,615	300 / 320	33,000
	TGV Duplex	1997	510	525,000	267,750	300 / 320	—
	Thalys (*)	1996	377	445,000	167,765	300 / 320	—
Germany	ICE-1	1990	627	500,000	313,500	280	65,000
	ICE-2	1996	368	400,000	147,200	280	—
	ICE-3	2001	415	420,000	174,300	330	—
	ICE 3 Polyc.	2001	404	420,000	169,680	330	—
	ICE-T	1999	357	360,000	128,520	230	—
Italy	ETR 500	1996	590	360,000	212,400	300	37,000
	ETR 480	1997	480	288,000	138,240	250	42,300
Spain	AVE	1992	329	470,000	154,630	300	—

Source: HSR Database. (*) THALYS is used in France, Belgium, the Netherlands and Germany.

[17] We do not have detailed information on this item in our database. However, in some projects it can be estimated at around 10% of the passenger revenue.

riod of time trainsets stay at the depot. The remaining train operations include train servicing, driving, and safety and their costs consist almost exclusively of labor costs. Their amount varies across countries depending on the operational procedures used by the rail operator.[18]

Finally, the energy costs can be estimated from the average consumption of energy required per kilometer, which is a technical characteristic of each trainset. According to Levinson et al. (1997), energy consumption per passenger varies with the speed and increases rapidly when the speed is over 300 km/h; however, the price of energy at its source, and the way in which it is billed to the operator, may be relevant. In our database the energy consumption of HSR is 5% lower in France than in Germany, not only because of its cheaper (nuclear) source, but also because it is directly acquired by the rail operator instead of being included in the infrastructure canon, as in other countries. When the rail operator can negotiate its energy contracts, it finds more incentives to achieve higher energy savings.

1.5 THE EXTERNAL COSTS OF HSR

The environmental costs of high speed rail are not negligible. Both the construction of high speed infrastructure and the operation of services produce environmental costs in terms of land take, barrier effects, visual intrusion, noise, air pollution and contribution to global warming. Unfortunately, the information on these items provided by our database of HSR projects is very fragmented. For this reason, this section will rely on other sources in order to briefly discuss the most relevant stylized facts regarding the external costs of HSR.

The key question regarding environmental costs is the comparison with other modes. As long as price does not equal to marginal social costs in other transport modes, the deviation of traffic from air and road to rail increases efficiency if high speed rail has lower external effects.

With regard to pollution, the quantity of polluting gases generated to power a high speed train for a

TABLE 1.3: Comparison of operating and maintenance cost by HSR technology (euros)

Country	Type of train	Operating costs*			Maintenance costs		
		Per train (million)	Per seat	Per seat-km	Per train (million)	Per seat	Per seat-km
France	TGV Réseau	—	—	—	1.6	4,244	0.008
	TGV Duplex	—	—	—	1.6	3,137	0.005
	Thalys	—	—	—	1.9	5,039	0.011
Germany	ICE-1	—	—	—	3.1	4,944	0.009
	ICE-2	—	—	—	1.4	3,804	0.009
	ICE-3	—	—	—	1.6	3,855	0.009
	ICE 3 Polyc.	—	—	—	1.7	4,207	0.010
	ICE-T	—	—	—	1.8	5,052	0.014
Italy	ETR 500	—	—	—	4.0	6,779	0.018
	ETR 480	—	—	—	3.2	6,666	0.023
Spain	AVE	—	—	—	2.9	8,814	0.018

Source: HSR Database. Data in 2002 values.

* Under revision by the UIC.

[18] For example, in France, train servicing and driving for the South-East TGV and the Atlantic TGV require two train companions per trainset and one driver per train (which may include one or two trainsets). In other countries, this configuration is different.

given trip will depend on both the amount of energy consumed and the air pollution from the electricity plant generated to produce such energy. Due to the potentially high diversity of primary energy sources used in each country, it appears to be relatively complex to make comparisons about HSR air pollution emissions.

It is generally acknowledged, however, that when compared to competing alternatives, such as the private car or the airplane, HSR is a much less pollutant transport mode. According to INFRAS/IWW (2000), the primary energy consumed by high speed railways in liters of gasoline per 100 passengers-km was 2.5 (whereas by car and plane were 6 and 7 simultaneously). Similarly, the amount of carbon dioxide emissions per 100 passengers-km was 17 tonnes for airplanes and 14 tonnes for private cars, due to the use of derivatives of crude oil. For HSR the figure was just 4 tonnes.[19]

In the case of noise, the modal comparison is less brilliant although still very favorable to HSR. Railways noise is mostly conditioned by the technology in use but, in general, high speed trains generate noise as wheel-rail noise, pantograph/overhead noise and aerodynamic noise. It is a short time event, proportional to speed, which burdens during the time when a train passes. This noise is usually measured in dB(A) scale (decibels). The values obtained from measurements of noise level of different high speed train technologies ranged from 80 to 90 dB(A), which are disturbing enough, particularly in urban areas. Levinson et al. (1997) argue that in order to maintain the (tolerable) 55dB(A) background noise level at 280 km/h, a 150 meter corridor would be required.

This final distance is important because it has been generally omitted in the traditional comparisons of land occupancy between HSR and, for example, a highway, which tend to underestimate the values for railways. As a consequence, general complaints about the noise of TGVs passing near towns and villages in France have led to the construction of acoustic fencing along large sections of tracks to reduce the disturbance to residents.

With respect to safety, any comparison of accident statistics for the different transport modes immediately confirms that HSR is—together with air transport—the safest mode in terms of passenger fatalities per billion passenger-kilometers. This is so because high speed rail systems are designed to reduce the possibility of accidents. Routes are entirely grade-separated and have other built-in safety features. The safety costs are thus capitalized into higher construction and maintenance costs, rather than being realized in accidents.

Finally, the same idea applies to other external costs, such as alteration of landscapes and visual intrusion. These costs are seldom considered separately since they are always included with the items related to terrain movement and preparation. Nonetheless it is quite unlikely that, even with a proper accounting of these costs, the favorable position of HSR with respect to external costs could be reversed. This is a case-by-case issue, and the final balance depends on the value of the geographical area affected.

The first environmental protests against the building of a high speed line in France took place in May 1990 during the planning stages of the TGV *Méditerranée*. Protesters blocked a viaduct to complain against the planned route of the line, arguing that a new line was unnecessary, would serve mainly business travellers, and that trains could use existing tracks. Similarly, the Lyon-Turin line, which is to connect the TGV to the Italian TAV network, has been the subject of demonstrations in Italy. Similar concerns have arisen in recent years in the United States and the United Kingdom, where most HSR projects have not been completed yet.

Table 1.4 shows a comparison of the marginal external costs between competing modes in two European corridors. The marginal costs include acci-

[19] To the best of our knowledge, there are no specific studies relating the extensive use of nuclear power to produce electricity for the rail system (between 30-90% of total electricity production in Japan, France and Germany) and the environmental impacts of such source.

dents, noise, air pollution, climate change, urban effects and upstream/downstream effects, but not congestion or scarce capacity. High speed rails between Paris and Brussels have less than a quarter of the external cost of car or air. The higher load factors mean that high speed rail performs no worse on this corridor than conventional rail on the much longer Paris-Vienna corridor; on longer distances the advantage over air decreases since most of the environmental cost of air transport is incurred at take-offs and landings (chapter 3).

TABLE 1.4: External costs of car, rail and air (euros/1,000 passenger-km)

	Paris-Vienna	Paris-Brussels
Car	40.2	43.6
Rail	11.7	10.4
Air	28.7	47.5

Source: INFRAS/IWW (2000).

1.6 HSR DEMAND: EVOLUTION AND PERSPECTIVES

Since the earliest projects started their commercial operation in the 1970s, high speed rail has been presented as a success story in terms of demand and revenues. It has been particularly viewed in many countries as a key factor for the revival of railways passenger traffic, a declining business that had lost its momentum due to the fierce competition of road and air transport. In France or Spain, for example, high speed divisions are the only business units within the rail companies that can recover their operating costs (although not the infrastructure ones).

The demand figures for HSR are indisputable.[20] Until 2005, the pioneering Japanese *Shinkansen* lines accumulated more than 150 billion of passenger-km transported; in Korea, the high speed lines inaugurated in 2004 beat domestic air travel in just two years, gaining more than 40 million passengers per year.

With respect to Europe, it reached a record of 76 billion of passenger-km in 2005. During the 1994-2004 period, traffic evolution experienced an average annual growth of 15.6%, with two-digit figures in the initial years and a slight slowdown in more recent years.[21] In addition to other demand driving forces, namely prices, quality and income, this growth has been strongly dependent on the progress in building new HSR infrastructure. This rapid growth has enabled HSR to account for about 40% of the total passenger market over medium distances, with spectacular gains on some corridors.[22]

Table 1.5 describes in more detail the evolution of HSR traffic in Europe during the 1994-2004 period in terms of passenger-km. It can be observed that the largest share of traffic corresponds to the TGV in France, which represented initially 70% of all European services (currently, 55%). French HSR traffic has been growing more intensively in the Paris junction (TGV *Intersecteur*) that connects TGV *Nord* with TGV *Sud-Est*. The other corridors, particularly the older ones, have experienced a less impressive demand growth.

Such result suggests the possible existence of a sort of *maturity effect* common to other products and services. HSR demand starts growing at a very fast pace, stealing a lot of market share from competing modes and possibly inducing new travellers into the corridor. But after a few years, when the services are well established and running at schedule, demand growth rate declines.

The data in table 1.5 cannot be interpreted in terms of expected annual demand growth for new HSR lines as long as the growth rate showed in the table correspond to a network that expanded during the 1994-2004 period. The data provides aggregate information of demand trends.

[20] As mentioned before, the demand information contained in our HSR projects database is very aggregated, and the details on the tariffs are fragmented. The analysis in this section takes into account these restrictions.

[21] Compared to an average growth below 1-3% on conventional lines during the same period.

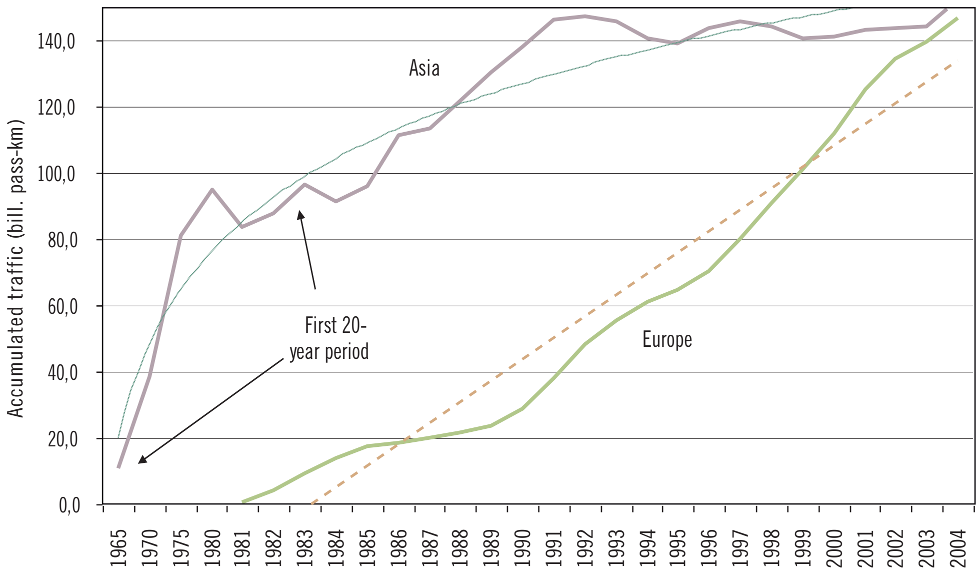
[22] For example, on the London-Paris corridor the HSR *Eurostar* has 70% of the rail/air traffic.

TABLE 1.5: Evolution of high speed rail traffic in Europe (1994–2004)

	France		Germany		Italy		Spain		Others		Europe	
	Pass-km (bn.)	Growth rate (%)	Pass-km (bn.)	Growth rate (%)	Pass-km (bn.)	Growth rate (%)	Pass-km (bn.)	Growth rate (%)	Pass-km (bn.)	Growth rate (%)	Pass-km (bn.)	Growth rate (%)
1994	21.9	—	8.2	—	0.8	—	0.9	—	0.3	—	32.1	—
1995	21.4	–2.3	8.7	6.1	1.1	37.5	1.2	33.3	0.4	33.3	32.8	2.2
1996	24.8	15.9	8.9	2.3	1.3	18.2	1.3	8.3	1.4	250.0	37.7	14.9
1997	27.2	9.7	9.3	4.5	2.4	84.6	1.5	15.4	2	42.9	42.4	12.5
1998	30.6	12.5	10.2	9.7	3.6	50.0	1.5	0.0	2.7	35.0	48.6	14.6
1999	32.2	5.2	11.6	13.7	4.4	22.2	1.7	13.3	2.8	3.7	52.7	8.4
2000	34.7	7.8	13.9	19.8	5.1	15.9	2.2	29.4	3.5	25.0	59.4	12.7
2001	37.4	7.8	15.5	11.5	6.8	33.3	2.4	9.1	3.8	8.6	65.9	10.9
2002	39.9	6.7	15.3	–1.3	7.1	4.4	2.5	4.2	4	5.3	68.8	4.4
2003	39.6	–0.8	17.5	14.4	7.4	4.7	2.5	0.0	4.1	2.5	71.1	3.4
2004	41.5	4.9	19.6	12.0	7.9	6.6	2.8	9.9	4.1	0.0	75.9	6.8

Source: HSR Database. Elaborated based on UIC (2005b) and companies' information.

Comparing the evolution of aggregated traffic in Asia and Europe (graph 1.4), the hypothesis of declining growth rates seems to be confirmed. HSR services in Japan started operations in 1965 and enjoyed a sustained traffic growth for the following 20 years (the trend is represented by a dotted line). During this period it gained around 100 billion passenger-km. However in the next 20-year interval (from 1984 to 2004), accumulated demand growth halved, and *only* 50 billion additional passenger-km used the *Shinkansen*. By comparison, most European HSR projects are still in their *first 20-year period,* and therefore it is natural to expect high growth rates (as confirmed by graph 1.4) at least until the high speed transport markets start to mature as in Japan.



Graph 1.4: Evolution of accumulated traffic: Asia vs. Europe

Source: HSR Database. Elaborated based on UIC (2005b) and companies' information.

1.7 CONCLUSIONS

This chapter should be viewed as an attempt to empirically identify some of the economic characteristics of high speed rail services, by constructing and analyzing an exhaustive database that comprises the relevant technical and economic information from all existing HSR projects in the world: 166 HSR projects from 20 countries; 40 (24%) are projects already in operation, whereas 41 are currently under construction, and 85 are still in the planning stage, some of which pending further approval and/or funding.

With this information at hand, the chapter starts by discussing the economic definition of *high speed rail*, showing that it is not speed but rather the network exploitation model what really determines this concept. Our next step consists in providing what could be considered a representative cost of building high speed infrastructure, taking into account both cost composition and the technical features of each. Although there is still a wide range of values, overall, the construction cost per kilometer (excluding planning and land costs) varies between 6 and 45 million of euros (in 2005). When the analysis is restricted to projects in operation (24 projects), the cost varies between 9-39 million.

To obtain an empirically-based approach to the true costs of high speed rail, a similar analysis is carried out regarding operating and maintenance costs of infrastructure (by country) and services (by type of train). The results vary again across projects ranging from 28 to 33 thousand euros (in 2000) per kilometer of single track. Excluding some extreme cases, the average cost of HSR infrastructure maintenance of a 500-km HSR line equals 30 million euros per year.

With respect to social costs, since the available information from the projects in our database is limited, we rely on other sources. HSR compares well with other transport modes in terms of some external costs such as pollution and the contribution to global warming, but the balance depends heavily on load factors and the primary energy source. In the case of noise, the modal comparison also favors the HSR but is highly dependent on the proportion of urban areas crossed by the HSR line.

HSR appears to be the safest mode in terms of passenger fatalities per billion passenger-kilometers. Some of the reduction in accident costs is internalized in higher construction and maintenance costs.

HSR also produces barrier effects, alteration of landscapes and visual intrusion. Some of these costs are mitigated and internalized in the construction costs, but the final effects is a case-by-case issue, and the final balance will depend on the value of the geographical area affected.

Finally we briefly discuss current demand of HSR in aggregated terms and try to draw some patterns about its future evolution, particularly within Europe. Our hypothesis is that the spectacular growth experienced by HSR services during its initial years later declines, as the market is more and more mature. At least this has been the evolution of the *Shinkansen* in Japan.

In sum, the main objective of this chaper is to explain the characteristics of the HSR technology from an economic viewpoint, providing some information on the cost and demand sides of this transport alternative. This understanding will be particularly useful for future projects since it will lead to a better analysis of the expected construction and operating costs, and of the number of passengers to be transported under different economic and geographic conditions.

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2
The Cost of Building and Operating a New High Speed Rail Line

2.1. INTRODUCTION

What is the (approximate) total cost of building, maintaining and operating a new high speed rail (HSR) line? Trying to answer this question is the main objective of this chapter. To address it, we will make an extensive use of the companion chapter 1, where a database containing information about 166 actual HSR projects in 20 countries is analysed in detail. This database provides a rough guide about the typical cost structure of any HSR project and suggests tentative estimates for some representative unit values of those costs. This information, together with some additional values gathered from other sources (Levinson et al. 1997; Atkins 2003; SDG 2004, De Rus and Nombela 2007), allow us to perform a simple simulation exercise capable not only of providing an answer to the initial question, but also of offering insights on the relevance of some elements in determining the total costs of a HSR line.

The cost structure of a HSR project can be generally divided into two major categories: costs associated with infrastructure and costs associated with rolling stock. Infrastructure costs include all the investment in construction and maintenance of the guideways (tracks), the sidings along the line, the terminals and stations at the ends of the line and along the line respectively, the energy supplying and signalling systems, train control and traffic management systems, related equipment, etc. Construction costs are incurred prior to starting commercial operations (except in the case of line extensions or upgrades of the existing network). Maintenance costs are related to the overhauling of infrastructure and include labor costs, materials, spare parts, etc. They occur periodically, according to planned schedules related to the depreciation of assets. In general, all infrastructure costs can be considered as fixed, in the sense that they mostly depend on the overall size of the infrastructure (line length, number of stations, etc.) instead of on traffic figures.

Rolling stock costs can be divided into three main subcategories: acquisition, operation and maintenance. With regard to the first one, the price of HSR trainsets is determined by its technical specifications, one of whose main factors is the capacity (number of seats). However, there are other issues that affect the final price, such as the contractual relationship between the manufacturer and the rail operator,[1] the delivery and payment conditions, the specific internal configuration demanded by the operator, etc. With respect to the operating costs, these mainly include the costs of labor (personnel) and energy consumed by the trains, as well as train formation (if it is necessary), in-train passenger services (food, drinks, etc.) and others, such as insurance costs. All these costs usually depend on the number of trains (fleet) operated on a particular line, which in turn, is indirectly determined by the demand. Since the technical requirements (for example, crew members) of trains may differ according to their size, sometimes it is preferable to estimate these costs as dependent on the number of seats or seats-km. In the case of the cost of maintaining rolling stock (including again labor, materials and spare parts),

[1] Some rail operators use internal departments for designing their rolling stock; others prefer contracting out.

it is also indirectly affected by the demand (through the fleet size), but mainly by the train usage, which can be approximated by the total distance covered every year by each train.

There are other costs involved in a HSR project. For example, planning costs are associated with the technical and economic feasibility studies carried out before construction. These (fixed) costs, as well as those associated with the legal preparation of the land (expropriation or acquisition to current landowners), can be somehow included in the construction cost category. On the other hand, there are some operating costs (general administration, marketing, internal training, etc.) that are fixed and cannot be easily assigned either to infrastructure or operations. In most projects these costs represent only a minimal fraction of the operating costs and, therefore, can be globally treated. Finally, it is important to mention here that we will not address the issue of external costs to answer the initial question posed in this chapter. The reason is that, even in the case that one could reach accurate estimates of these costs, the distribution of their burden over the agents involved in a HSR project is not always clear. This is not the case of the infrastructure and rolling stock costs, which can be both safely attributed to the project.

Although the cost structure of most HSR undertakings corresponds to the one we have just described, it is also true that the exact value of each cost category varies largely across projects in accordance to their specific characteristics. For this reason, this chapter proposes a general approach, based on a simulation exercise in which, departing from several justifiable parameter values (*reference case*), we calculate (the net present value of) the total costs of a simple HSR line (disaggregated into the described infrastructure and rolling stock costs categories). Then, by changing the values of the initial parameters, *ceteris paribus*, we can perform comparative statics, which provide us with useful insights on the overall validity of our exercise.

The use of simulation techniques in applied economics has been often criticized as excessively naïve. Although we acknowledge this criticism, the simulation exercise performed in this chapter will always try to remain as close as possible to reality, minimizing the number of simplifying assumptions while simultaneously keeping the numbers manageable. At the same time, the information provided in chapter 1 will be treated with caution, taking into account the observed differences across projects and countries. Whenever possible, we will distinguish between *best*, *medium* and *worst* alternative scenarios, and when in doubt, we will opt for the most cost-favorable option, so that our final estimates can be seen in each case as a lower bound to the actual cost of HSR.

Other papers on HSR use simulation techniques, either to make estimates about their social profitability (see chapter 3, for example) or to study counterfactuals that are not currently happening but could take place in a near future (as in chapter 4, or Ivaldi and Vibes 2005, regarding intermodal competition). They all share a basic economic model with simplifying assumptions where data from different sources is plugged into in order to get the simulation results.

After this introduction, the structure of the chapter is as follows. Section 2.2 describes the most relevant features of the project (the construction and the 40-year operation of a single HSR line connecting two cities without intermediate stops) and its most significant operating characteristics. Section 2.3 describes demand projections and how supply is calculated accordingly. In section 2.4 the infrastructure and rolling stock costs are simulated under several assumptions on demand, train capacity, speed, and line length, while simultaneously three alternative scenarios are considered (best, medium, and worst) for the estimates of the unit costs. Finally section 2.5 is devoted to a complete discussion of the results and their implications.

2.2 PROJECT CHARACTERISTICS

2.2.1 OVERVIEW AND TIMELINE

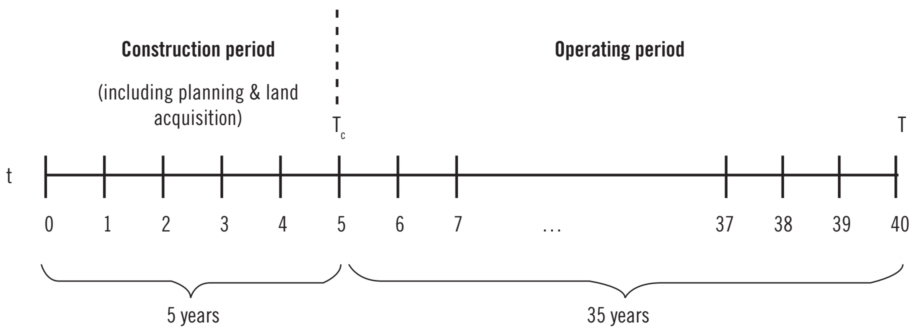
Consider that a new high speed line is going to be built to connect two similar-sized cities, *City O* (origin) and *City D* (destination), separated by a distance of 500 kilometers. Most of the infrastructure and rolling stock used in this project will be completely new (it is not an upgrade of an existing conventional line), although the existing passenger terminals in both cities will require only minor refurbishment.

The time needed for the planning and technical design of a HSR line varies largely across projects, depending on their specific legal and administrative arrangements. In some projects, with favorable legislation, efficient contracting procedures and adequate political pressure, it can take less than one year, whereas in other cases—particularly when legal conflicts arise on land occupation or there are other issues of public concern—the planning period may be delayed up to 20 years (Flyvbjerg, Skamris, and Buhl 2004).

Once the required technical and economic studies have been carried out, the actual deployment of the infrastructure and other side works is mainly conditioned by the characteristics of the terrain. In our simulation exercise, we will make the simplifying assumption that most of the area covered by the line is flat countryside, with only few difficult segments (either mountains or density and continuously urbanized areas) which may require viaducts and/or tunnels.[2] For that reason, and assuming that the planning and design stage is done with the maximum celerity, we will consider that total construction period (denoted as T_c) is 5 years.[3] Once built, the line starts commercial operations immediately and operates during 35 consecutive years, so that the project total duration is $T = 40$ years (from $t = 0$ to T), as depicted in graph 2.1.

Setting $T = 40$ is a decision that responds to the estimated evolution of the HSR technology. While a shorter period would seem rather uneconomical (most of the infrastructure costs would be hardly recovered), a much longer period would be unrealistic since the HSR technology is advancing so fast that in a few decades it is quite likely that the current equipment will be obsolete. In the real world, only a few Japanese *Shinkansen* lines (started in 1964) have enjoyed such a large lifespan so far, but during this period they have been largely improved at least twice (Hood 2006).

Finally, note that the construction (and planning) period involves much more than track building. It requires the design and building of depots, maintenance and other sites, as well as hiring and training of personnel, testing of material, and many other preparation issues. In our project, we will assume that all these tasks are adequately performed in time, that no major de-



Graph 2.1: Project timeline: construction and operation period

2 Note that, as mentioned in section 2.1, this is a cost-reducing assumption that favors the project. A more difficult topography would imply longer construction and planning period and, subsequently, higher costs.

3 We will also consider that, on average, the same number of kilometers is built every year. In practice, however, projects evolve at different speeds, depending on the technical limitations, the delivery of materials and the official termination dates of each stage.

lays occur and that the line is ready for commercial use at T_c.

2.2.2 OPERATIONAL CHARACTERISTICS

There are two closely related operational characteristics of the line—the average speed of the trains running over it and the total distance covered by them—that are very relevant from the point of view of construction and operation, and thus deserve a closer look. In addition, the ratio between line length and speed determines the travel time, which is a key factor in attracting demand.

- *Speed*

Obviously speed is a crucial piece in the characterization of a high *speed* line. However, the technical definition of speed is not unique[4] since there are several related terms whose economic implications have to be separately considered. First of all there is the *maximum track speed*, a technical parameter mainly related to infrastructure that, in the design stage, determines the radius of the curves and the gradient of the slopes. The ability of a train to trace closed curves without derailments or to climb steep mountains or hills is inversely related to its speed. For that reason, a HSR line faces tougher construction restrictions and may require a longer length the higher the maximum track speed of the project.

A second concept is the *maximum operating speed*, which is related to the technical characteristics of the trains and the way in which these are operated. This operating speed evolves with the technology and generally increases over time, only constrained by the maximum track speed. For example, in its early stages, the *Shinkansen* system's main line was hardly capable of speeds of up to 220 km per hour. But in its latest specifications, these *bullet trains* have earned their name by reaching speeds close to 600 km per hour (Hood 2006). Today, most European HSR services operate with trains capable of maximum speeds in the range of 280-300 km per hour.

Under normal operating conditions, and depending on the incidence of delays and the characteristics of the terrain, HSR services are usually provided at *average operating speeds* of 20-25 km per hour below their maximum operating speed, which is the optimal technical speed in relation to which the useful life of the rolling stock is calculated and the recommended maintenance plans are designed by the manufacturers.

The final (and most widely used) speed concept is the (average) *commercial speed*, which is simply calculated by dividing the total travel time over the line length. It should be noted that this is not only a technical concept (determined by the operating and track speeds), but an economic one as well: travel time is not only affected by technical considerations, but also by other (non-technical) elements, such as the commercial schedule, the number of intermediate stops, the quality assured to customers,[5] etc. In our simulation exercise we will use a commercial speed (s) of 250 km per hour and consider that it will not change during the operating lifespan of the project.[6]

- *Length*

HSR projects are very diverse across the world, and their lengths vary accordingly. Most countries start with single point-to-point lines that are later expanded by adding new corridors or by connecting the existing ones to larger networks. A typical example is the Madrid-Seville AVE (471 km), which—apart from smaller legs (such as La Sagra-Toledo, 22 km)—has been recently expanded with the Madrid-Lleida line (481 km) and other upcoming ones, all departing from Madrid (De Rus and Román 2005). The same centralized structure corresponds to the French TGV, which started with the Paris-Lyon line (417

[4] In chapter 1 we argue that speed is not just a technical concept, but also an economic one, since it is related to the infrastructure exploitation model chosen by the rail operator.

[5] For example, when there are punctuality commitments. In the Madrid-Seville line, in Spain, commercial speed is around 210 km per hour, but it can be increased on certain services to reduce delays.

[6] Whereas this final assumption is discussable (since technology improvements are likely), it is related to the simplifying assumption (see section 2.3.2) that the fleet is homogeneous and technology does not change until T=40.

km) that was later continued (Paris-Marseille, 750 km) and connected to the high speed network (TGV North, TGV Atlantic, etc.).

From the point of view of our simulation exercise, we have chosen a standard distance of 500 km between cities *O* and *D* by taking into account that with a commercial speed of 250 km per hour travel time would be approximately of 2 hours. This is compatible with the results in chapter 4 regarding the intermodal competitiveness of HSR services. They find that rail market share quickly decreases when travel time is below 1 hour (when road transport is much more attractive to passengers) and over 3 hours (since it would imply a distance that could be covered faster travelling by plane). In any case, since the length of the HSR line is a key variable that determines to a great extent the infrastructure costs, we will test alternative length assumptions in our simulation exercise.

2.3 DEMAND AND SUPPLY

2.3.1 DEMAND ESTIMATION AND DISTRIBUTION

From a microeconomic point of view, individual travel demand within the *O-D* corridor is an endogenous variable that depends on the relative generalized cost faced by the passengers on each alternative transport mode. From a broader perspective, aggregate demand depends on macroeconomic (such as the population density or the distribution of personal income) or cultural factors (traditions and history associated to rail travel) related to that corridor. For these reasons, and assuming that the relevance of intermodal competition in our corridor is minimal, annual traffic estimates can be simply calculated by projecting a reasonable initial figure along the operating period of the project.

Chapter 1 shows that the initial demand figures are quite different across countries. They are usually large in Japan and Korea (where the high speed lines inaugurated in 2004 gained more than 40 million passengers in two years) and exhibit a more timid start in Europe (between 1.5 and 5 million passengers in the first year, depending on the line). In general, chapter 3 proves that the lowest initial demand value for a 500-km HSR to be socially profitable is around 6-7 million passenger-trips. For simulation purposes we choose the slightly more conservative figure of 5 million passengers per year (Q_5, that is, starting at $t = 5$), and consider that only in very densely populated corridors larger figures (10, 20 million) will make sense.

A final but relevant simplifying assumption related to the demand is the fact that we consider that it is completely symmetrically distributed in three dimensions: between cities *O* and *D*, along the day (no peak-off/peak periods within the day), and along the year (no peak seasons within the year).[7]

With respect to the annual growth rates, reflecting the *maturity effect* also detected in chapter 4, we can consider that there is an expansion period (say, the first 5 years of operation) where the initial demand grows at a larger rate ($g_1 = 5\%$

TABLE 2.1: Traffic projections with alternative initial demand assumptions

Annual demand initial assumption	One-way traffic estimate (passengers per day)		
	Initial year (t = 5)	After 20 years (t = 25)	After 35 years (t = 40)
Q_5 = 2,500,000 pass.	3,425	6,942	10,815
Q_5 = 5,000,000 pass.	6,849	13,884	21,630
Q_5 = 10,000,000 pass.	13,699	27,767	43,261
Q_5 = 20,000,000 pass.	27,397	55,535	86,521

7 Again, these are cost-reducing assumptions, since the existence of demand asymmetries would increase the capacity needed on peak periods, which would not be used in off-peak ones.

from t = 6 to 11), while growing at a lower rate (g_2 = 3%) afterwards.

With all these values, and departing from four alternative initial annual demand estimates (2.5, 5, 10 and 20 million, respectively), table 2.1 shows the resulting one-way traffic projections (in terms of passengers per day) at three different points: the start of the operating period, 20 years later, and at the end of the project lifetime.[8] The variability is large; for example, if the initial demand is 2.5 million passengers per year, at t = 40 it would imply a daily (one-way) traffic of 10,815 passengers; for 20 million, the corresponding value would be eight times larger (86,521).

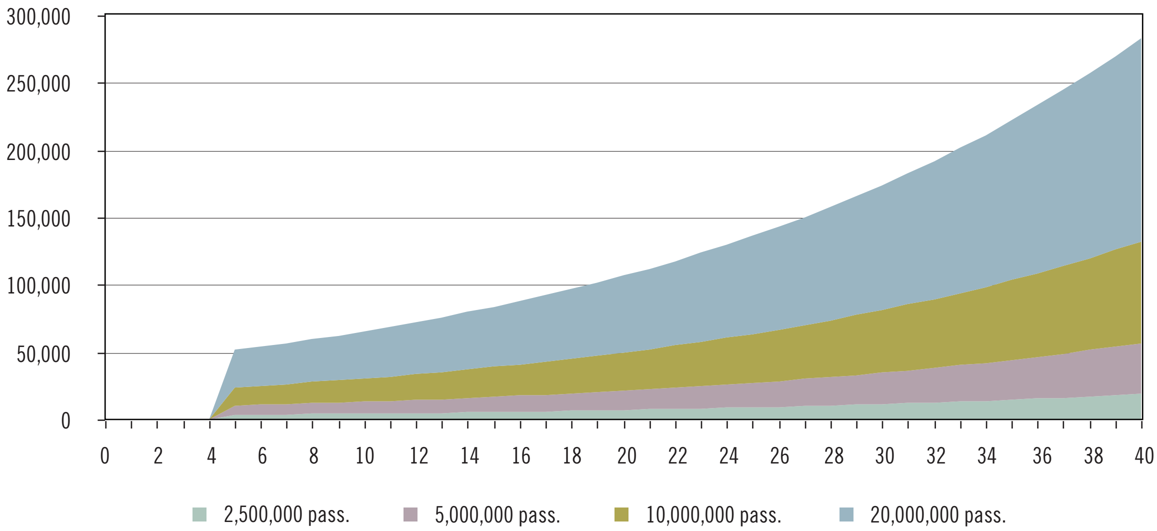
These differences would be even worse if, alternatively, the projections were made ignoring the *maturity effect,* that is, under the assumption that the demand grows at the same rate from t = 5 to t = 40 (that is, $g_1 = g_2$ = 5%). Graph 2.2 shows the corresponding (faster-growing) projections, where the final daily demands at t = 40 would range from 18,890 (starting with 2.5 million passengers per year) to 151,124 (starting with 20 million). Since these figures seem less realistic, our simulation exercise will be based on the projections depicted in table 2.1.

2.3.2. SUPPLY PARAMETERS: TRAIN CAPACITY AND FREQUENCY

If demand is measured as the daily number of (one-way) passengers, the corresponding definition of supply is the number of seats offered everyday from *O* to *D* (or vice versa). Then, train capacity and frequency become the key factors that determine the supply of HSR services in our *O-D* corridor.

- *Train capacity*

The capacity (number of seats) of a train designed for HSR services depends on both the technical specifications envisaged by the manufacturer and the specific internal configuration agreed with the prospective buyer. Nowadays most train



Graph 2.2 One-way traffic projections (under faster growth assumption)

Note: Vertical axis measures the number of passengers per day. Demand grows at 5% (t = 6-40).

[8] Daily traffic estimates are simply calculated by dividing annual demand between 365 days and between 2, since the *O-D* traffic is symmetric.

models can be easily adapted to project-specific needs (legal requirements, cultural differences, passenger density, intensity of use, etc.), and their costs vary accordingly. In general three *size groups* can be identified in the existing manufacturers catalogues: low-capacity trains (between 200-250 seats), medium-capacity trains (between 300-400 seats) and high capacity trains (more than 500 seats). The first group includes, for example, the ALARIS and TALGO units in Spain; the second group includes most models of the French TGV (including the THALYS), the Spanish AVE and some German ICE trains, while the TGV duplex and most Japanese units are in the last group. For our simulation exercise we assume an average value of $\bar{q}$ = 330 seats.

As mentioned above, there is a relevant simplifying assumption made here: we shall consider that all trains in the fleet are exactly equal, and that they all operate in single composition. We acknowledge it is one of our less realistic assumptions since in the real world, when demand grows over time the operator may respond by incorporating higher-capacity trains or by operating the existing ones in double composition, thus duplicating its supply. Despite its weakness, the assumption is necessary to keep the supply calculations simple.[9]

- *Frequency*

There are several alternative methods to calculate the number of seats (and, given their capacity, the number of trains) that the operator should provide to service the daily demand. Our calculations of the number of daily services and their frequency (defined as the number of services per hour) will be based on an average load factor of 75% (l), which gives us the basic relationship between supply and demand that will be maintained throughout the exercise.

In the real world, most existing HSR services are characterized by relatively high load factors (well above 70%), or at least larger than other equivalent rail services. This is explained by the fact that HSR lines are specifically designed for passenger traffic in dense traffic corridors, with minimal intermediate stops, and a marketing focus centered on the travel time and price. In our particular example—a direct service between *O-D* with a very regular and symmetric demand—the load factor must be large by definition. However note that a load factor close to 100%, for example, is impractical because it would imply that all trains would be always fully booked, and some travellers could not use them.

Apart from our assumption of l =75%, a few other values are needed. In particular, we will use the average commercial speed of s = 250 km per hour (which yields a travel time of 2 hours per direction), and the train average capacity of $\bar{q}$ = 330 seats (which implies that the effective occupation is $\bar{q}_e = 0.75 \cdot 330 = 248$ seats). In addition we consider that there is a boarding and train preparation time before each service of 15 minutes (0.25 hours) and that trains operate 18 hours a day (from 06:00 to 24:00).[10]

Using these values and departing from our projections of the (one-way) daily demand (denoted by q_t), the total number of daily services per direction is obtained from the ratio $q_t/\bar{q}_e$. The frequency (F) is then given by:

$$F_t = \frac{(q_t/\bar{q}_e)}{18},$$

in terms of number of services per hour. For example, for the reference case, if q_5= 6,849 passengers, F_5= 1.54 services per hour, which in turn implies a service every 39 minutes.[11]

9 It is unclear the net effect on costs associated to dropping this assumption. On one hand, with higher-capacity trains, the total number of trains needed is reduced; but, on the other hand, their operating and maintenance costs could be larger, particularly if they are more intensively used.

10 As a quick reference, table 2.2 provides a summary of the parameter values for the reference case.

11 This is a low value when compared to the real world. It corresponds to an initial demand of 5,000,000 passengers per year. In subsequent years, when the demand grows, the frequency (F_t) would also increase, reaching more reasonable values of one service every 15 or less minutes.

Since the demand is symmetric, and total travel time of a return trip (including boarding times) is 4h 30' (τ = 4.5 hours), the (minimum) number of trains (of capacity $\bar{q}$, at speed *s*, and with a load factor of 75%) needed daily in the *O-D* corridor would be given by the ratio $\frac{\tau}{1/F_t}$, that is

$$\tau \frac{q_t}{18\bar{q}_e}.$$

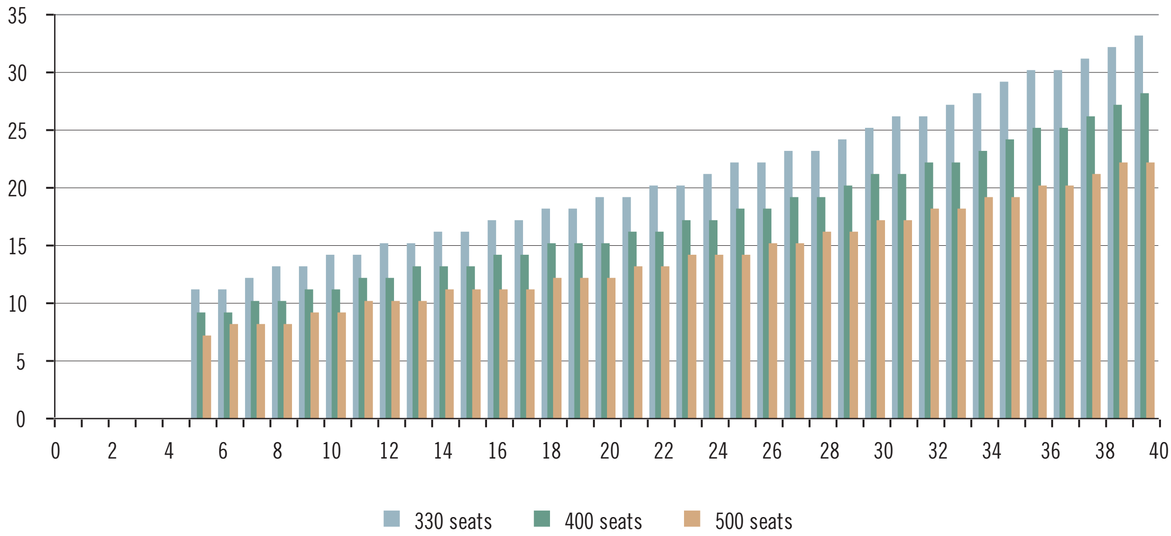
In order to face unforeseeable contingencies (delays, external damages, breakdowns, etc.) this minimum number is multiplied by an (exogenous) *contingency factor,* which we will set in 1.5.[12] Thus, the supply (in terms of the number of trains) would be finally given by:

$$RS_t = (1.5) \cdot \tau \frac{q_t}{18\bar{q}_e},$$

where RS_t stands for *rolling stock needed at t*.

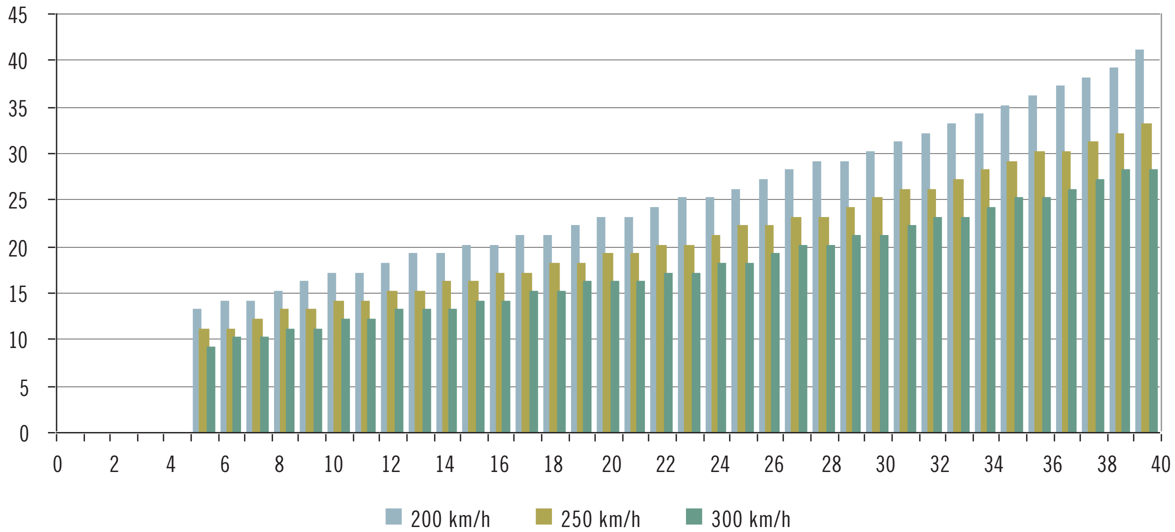
Graph 2.3 illustrates the supply calculations results and their evolution under alternative train capacity assumptions. Note that, for example, for the reference case (with $\bar{q}$ = 330 seats) our HSR service would start its operations with 11 trains, but in t = 40 the figure would be 33 due to the increase in the projected demand. With $\bar{q}$ = 400 and $\bar{q}$ = 500 the corresponding initial values would be 9 and 7, whereas the final ones would be 28 and 22, respectively. These figures fit reasonably well with international standards, which sets the number of trains used for lines in the range of 300-500 km (although with intermediate stops and shorter legs) between 30 and 80 (around 10-15 trains per 100 km of HSR line).

In practice, actual rolling stock provision in HSR lines around the world is directly affected by several project-specific parameters such as the average commercial speed or the specific technology used in each case. Other elements, such as the seasonality of demand or the existence of peak periods, were ruled out from this exercise.



Graph 2.3 Number of trains needed under alternative capacity assumptions

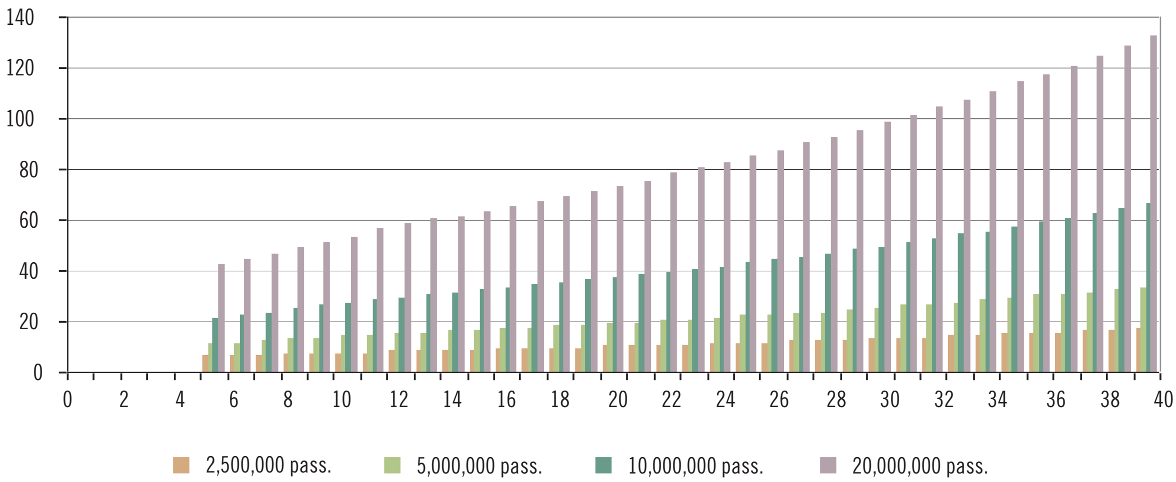
[12] This factor is quite firm-specific, and it is associated with the risk of failing to provide services vs. the cost of acquiring, operating and maintaining an over-sized fleet. The range of values found in the real world varies from 1.25 to 1.6, depending on the corridor.



Graph 2.4 Number of trains needed under alternative speed assumptions

With respect to the first one, total travel time is reduced when average commercial speed is increased and vice versa, thus affecting the supply calculations. Graph 2.4 illustrates these effects by recalculating the number of trains needed under different speed assumptions. Obviously, the figures in the reference case (250 km/h) are the same as those in graph 2.3 with $\overline{q}$ = 330. However, note that if speed is reduced to an average of 200 km/h (not an unrealistic assumption, nowadays) the number of trains needed at $t = 40$ would jump to 41; on the other hand, increasing the speed to 300 km/h would imply that 28 trains (only five less than in the reference case) would be needed.

Finally, graph 2.5 shows the strong dependence of the supply calculations with respect to the demand projections. It shows the number of trains needed every year under alternative values for initial annual demand (as in table 2.1). Note, for example, that departing from 2.5 million passengers per year, we will only need 6 trains in the first year (and 17 at $t = 40$). But if the initial de-



Graph 2.5 Number of trains needed under alternative initial annual demand assumptions

mand were 20 million, then the figures would be 42 and 142. Therefore a wrong demand projection could be more relevant for supply calculations than changes in train capacity or in average speed.

2.4. METHODOLOGY OF COST CALCULATIONS

2.4.1. OBJECTIVES

The main objective of this chapter is to provide an estimate of the total cost of building, operating and maintaining a HSR with technical characteristics and the supply and demand conditions described in the previous section. In order to provide a quick reference to our reference case, table 2.2 summarizes the main parameter values considered in our analysis.

Although all these values can be individually modified upwards or downwards—*ceteris paribus*—to illustrate their particular effect on our costs results, we will restrict our comparative statics exercises only to changes in the initial demand, the train capacity, the commercial speed, and the line length since these four factors summarize the most salient economic characteristics of any HSR line.

As described in section 2.1, cost calculations will be categorized into two main groups: infrastructure costs and rolling stock costs, respectively denoted as *IC* and *RSC*. Thus, formally, the total cost (*TC*) of our HSR project (evaluated at $t = 0$) is just given by the net present value:

$$TC = \sum_{t=1}^{T} \frac{IC_t + RSC_t}{(1+i)^t} \, . \qquad (2.1)$$

We now describe the components of each of these costs, and how each of them was calculated in our particular example.

2.4.2. INFRASTRUCTURE COSTS

Infrastructure costs (*IC*) can be grouped into construction costs (IC^C) and maintenance costs (IC^M). Both of them are relatively independent on the volume of the traffic and instead can be calculated as dependent on the line length (*L*), just by multiplying the number of kilometers by an average unit cost (denoted as *c* and *m*, respectively). Construction costs spread out over the construction period whereas the maintenance takes place during the operating period (see graph 2.1). Formally, the infrastructure costs can be denoted as

$$IC_t = IC_t^C + IC_t^M = \sum_{t=1}^{T_0} \frac{(c \cdot L)(1+\rho)}{(1+i)^t} + \sum_{t=T_0+1}^{T} \frac{m \cdot L}{(1+i)^t} \, , \qquad (2.2)$$

where we have additionally assumed that construction costs also include a surcharge (ρ = 10%) to take into account planning costs.

The actual values of the average costs per km (*c*, *m*) were estimated from the values found in chapter 1 database of actual HSR projects. In particular, to err on the side of precaution, we did

TABLE 2.2: The reference case: main parameter values

Line length (L) = 500 km	Train capacity ($\bar{q}$) =330 seats
Project timeline: t = 0 to t = 40 (T)	Load factor (l) = 75%
Construction period (T_c) = 5 years	Operating hours (daily) = 18 hours
Operation period ($T - T_c$) = 35 years	Average commercial speed (s) = 250 km/h
Initial annual demand (Q_5) = 5 mill. passengers	Boarding time (between services) =15 minutes
Growth rate 1 (g_1) = 5% (from t = 6 to 11)	Train contingency factor = 50%
Growth rate 2 (g_2) = 3% (from t = 12 to 40)	

TABLE 2.3: Infrastructure costs per year (reference case)

	Construction	Maintenance
Period	$t = 1$ to $t = 5$	$t = 6$ to $t = 40$
Line length (km)	500	500
Unit value (€ per km)		
Best scenario	9,000,000	12,919
Medium scenario	18,000,000	35,624
Worst scenario	39,000,000	71,650
Planning cost (%)	10%	—
Total value (€ per year)		
Best scenario	990,000,000	6,459,500
Medium scenario	1,980,000,000	17,812,000
Worst scenario	4,290,000,000	35,825,000

not considered just one value, but three: the lowest unit cost in the database (named, the *best scenario*), the highest unit cost in the database (the *worst scenario*) and the average value in the database (the *medium scenario*).[13]

Table 2.3 summarizes the results from these calculations for the reference case (where the line length is 500 km). The lowest construction (maintenance) cost per km is 9 million euros (12,919 euros, respectively), whereas the highest is 39 million and 71,650, respectively. Note in table 2.4 that total infrastructure costs are fixed costs that evolve linearly with the length of the corridor: for the largest case (650 km) construction costs might reach a peak of €5,517 million per year in the worst scenario.

A final element to take into account in the previous calculations is the residual value of the infrastructure at $t = 40$. This amount—once discounted to $t = 0$—reduces the total cost of the infrastructure. In general, since there are different assets (tracks, buildings, etc.), with different useful lives and depreciation rates, it is quite difficult to provide an accurate value of this residual value. To simplify calculations, we will just assume that it will be equal to 30% of the total construction cost for each particular scenario. Thus for the reference case in the best scenario with a total building costs of €990 x 5 years = €4,950 million, the residual value at $t = 40$ is €1,485 million. The corresponding residual values for the medium and worst scenarios will be €2,700 and €5,850 million, respectively.

2.4.3. ROLLING STOCK COSTS

Rolling stock costs (*RSC*) can be grouped into three categories: acquisition (RSC^A), operation (RSC^O) and maintenance (RSC^M) of the trains needed to run the services. With respect to the

TABLE 2.4: Annual infrastructure costs under different line lengths (euros)

	L= 250 km		L= 500 km		L= 650 km	
	Building	Maintenance	Building	Maintenance	Building	Maintenance
Best scenario	495,000,000	3,229,750	990,000,000	6,459,500	1,287,000,000	8,397,350
Medium scenario	990,000,000	8,906,000	1,980,000,000	17,812,000	2,574,000,000	23,155,660
Worst scenario	2,145,000,000	17,912,500	4,290,000,000	35,825,000	5,577,000,000	46,572,500

[13] Note that it is equivalent to implicitly assume a probability distribution where the three cases are equally likely.

acquisition costs they are simply calculated by multiplying the number of trains bought every year ($RS_t - RS_{t-1}$) by the unit cost per seat (a) and their average capacity ($\bar{q}$), so that their NPV is

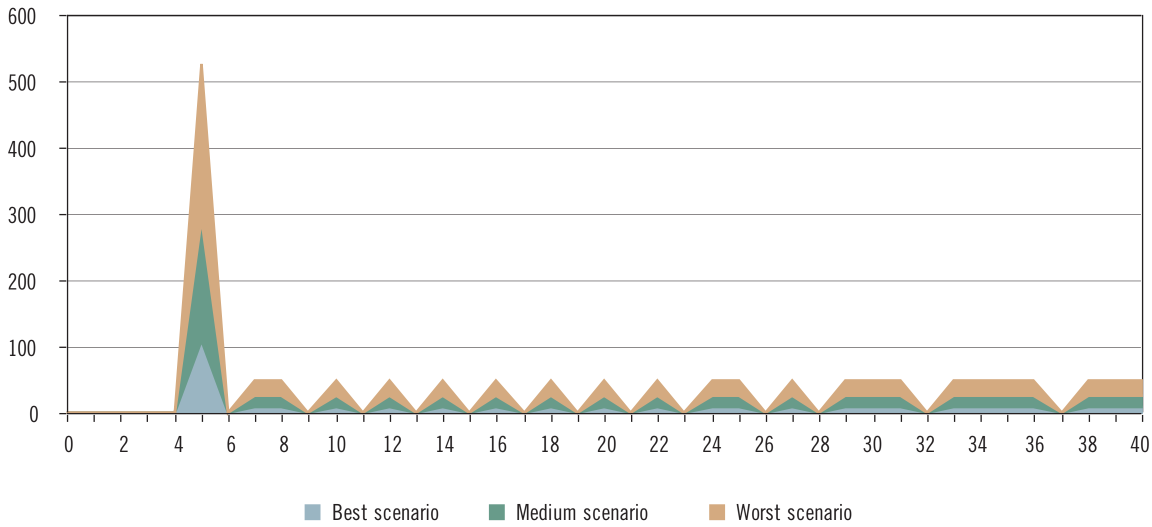
$$RSC^A = \sum_{t=1}^{T} \frac{(RS_t - RS_{t-1}) \cdot a \cdot \bar{q}}{(1+i)^t} \quad . \quad (2.3)$$

In practice, the process of contracting, designing, building, delivering and testing new rolling stock usually lasts several years; in our example, we will make the assumption that—since demand projections are known well in advance—rolling stock is delivered just-in-time. This implies, for example, according to our supply calculations, that 11 trains start to operate at $t = 5$ in the reference case. At $t = 6$, since $RS_6 = 11$, no new train is bought; however, at $t = 7$ an additional unit is acquired (since $RS_7 = 12$), and so on.

Another simplifying assumption is related to the useful life of the rolling stock. We will consider that, under adequate maintenance, each trainset is economically usable for at least 40 years (which corresponds to the average useful life in the industry nowadays). For this reason, no technical renewals or replacements are needed and all the new acquisitions are related to the growth in demand.

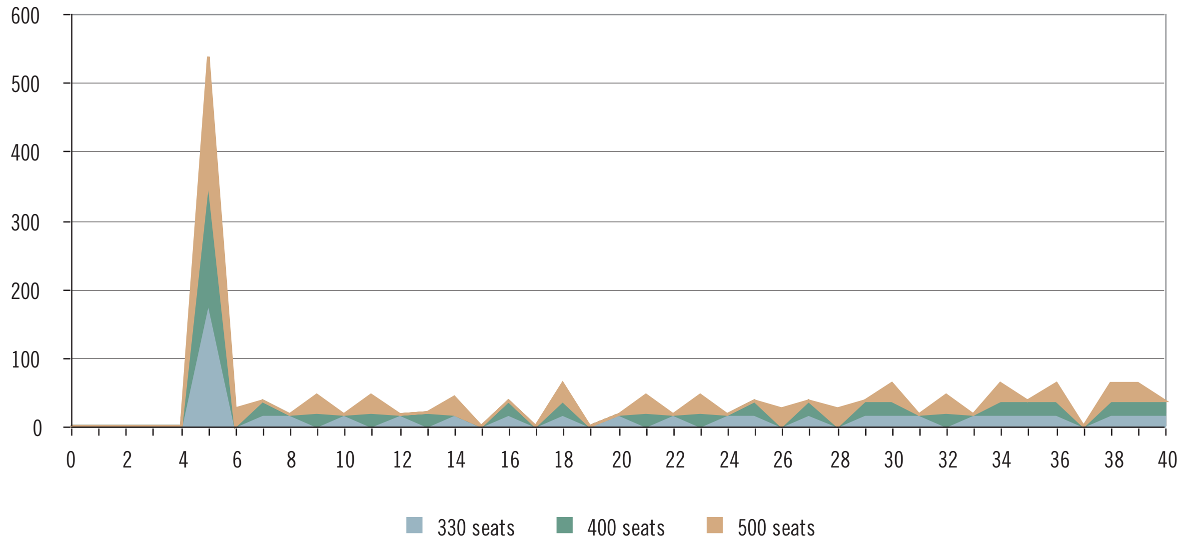
With respect to the effective cost calculations, the database in the companion chapter 1 provides three alternative acquisition unit costs in terms of euros per seat, which again we label as best scenario (lowest value = €30,000 per seat), medium scenario (average value = €50,000 per seat), and worst scenario (highest value = €65,000 per seat). Graph 2.6 summarizes the evolution of total acquisition costs from $t = 0$ to $t = 40$ for the reference case (330 seats per train) under the three alternative scenarios.

Obviously, the peak at $t = 5$ corresponds to the initial acquisition of rolling stock to start operations; afterwards, there are minor periodical acquisitions. This pattern is mimicked in graph 2.7, where we intended to test the potential existence of cost economies associated with train size. When the capacity of the trains increase so does their acquisition cost, but fewer trains are needed. Although the periodicity of the renewals can be changed (for example, a new train is added every three years instead of every two years), these two opposing effect tend to cancel each other out, thus reducing the possibility of economies of vehicle size.[14]



Graph 2.6 Acquisition costs per year under alternative scenarios (€ million)

[14] Wei and Hansen (2005) discuss this idea for the case of aircrafts. Their results also suggest that there are no large cost reductions associated with larger vehicle sizes.



Graph 2.7 Acquisition costs per year under alternative train capacities (€ million)

Note that in the previous figures we have just considered the gross acquisition cost. If we assume that the average useful life of each rolling stock unit is 40 years, and that its value is reduced 1/40 every year (linear depreciation), at $t = 40$ there will be some residual values that—once discounted to $t = 0$—should be reduced from the acquisition costs. These residual values depend on the year each particular unit is bought. For example, in the reference case, the residual value at $t = 40$ of the 11 trainset units acquired at $t = 5$ will be 5/40 of their acquisition cost; the additional unit bought at $t = 7$ will be worth 7/40 of its initial cost, and so on.[15] By adding the residual values of all the units bought from $t = 5$ to $t = 40$ we finally get the total residual values (at $t = 40$) of the rolling stock under each possible scenario: in the best one, it will be €149,242,500; in the medium scenario, €248,737,500, and in the worst scenario €323,358,750.

On the other hand, the operation and maintenance costs of the rolling stock are heavily dependent on the volume of traffic along the line which, indirectly, can be measured through the number of trains. In the case of the operation costs (RS^O), its main determinants are labor and energy. The number of technical crew members per train depends on its technical specifications and is usually set in transport regulations. On the contrary, there are no minimum standards on cabin attendants and auxiliary personnel, and their number depends on the level of service offered to passengers. Energy consumption is calculated in accordance with the technical specification of the rolling stock.

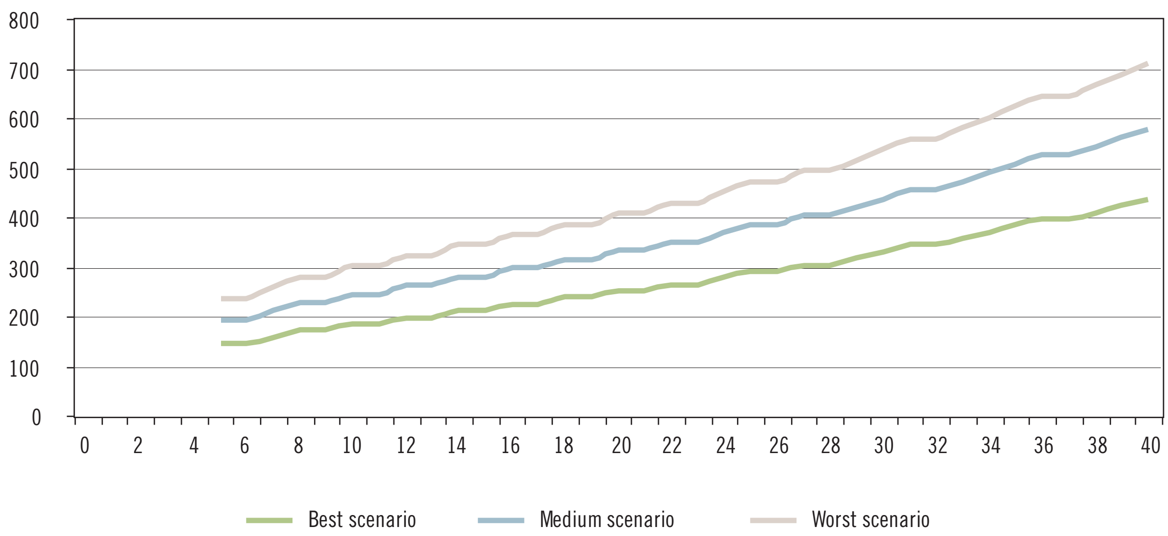
For these reasons, in our simulation exercise, we used the expression:

$$RSC^O = \sum_{t=5}^{T} \frac{r_o \cdot RS_t \cdot \bar{q}}{(1 + i)^t}, \qquad (2.4)$$

where r_o is the annual unit operation cost per seat (and the average train capacity). The evolution of total operation costs from $t = 0$ to $t = 40$ for the reference case is given in graph 2.8.

Interestingly, when the train size is increased (up to 400 and 500 seats), there are no clear cost advantages, as illustrated in graph 2.9 (drawn for the medium scenario only). In some years it is cheaper to operate larger sized trains, whereas in other years it is too expensive. It is important to

[15] Note, for example, that a rolling stock unit bought at $t = 40$ has a residual value of 40/40 (that is, 100%).



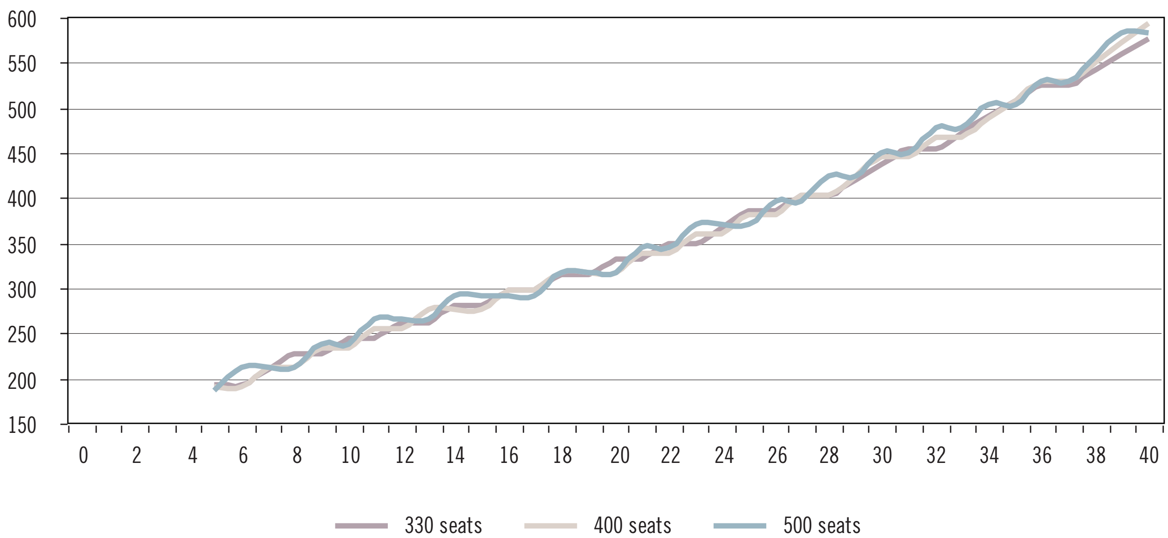
Graph 2.8 Operation costs per year under alternative scenarios (€ million)

recall here our simplifying assumption that all trains are equal in size, which is somehow unrealistic.

Finally, the maintenance costs of the rolling stock are not only related to traffic (measured through the number of trains) but also to train intensity usage. Thus a better estimate of the NPV of this cost would be given by

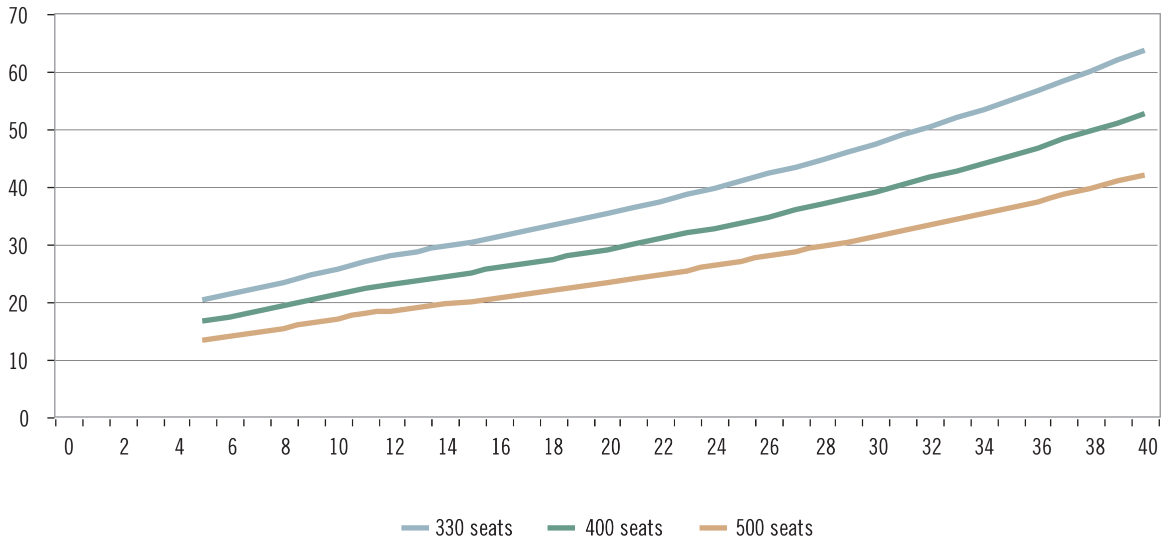
$$RSC^M = \sum_{t=5}^{T} \frac{r_m \cdot D_t \cdot RS_t}{(1+i)^t}, \qquad (2.5)$$

where r_m is the unit maintenance cost per train and kilometer, and D_t is the average distance travelled by each train.[16] According to chapter 1, r_m can be estimated around €2/km for trains running around 0.5 million kilometers per year. For chapter 1, our reference case, this value yields a



Graph 2.9 Operation costs per year under alternative train capacities (€ million)

[16] This average distance was calculated dividing the total distance covered by all trains every year (number of total annual services multiplied by line length) between the number of trains.



Graph 2.10 Maintenance costs per year under alternative train capacities (€ million)

total maintenance cost of 20,202,020 euros at $t = 5$ and 63,798,448 euros at $t = 40$. Note that, as depicted in graph 2.10, larger-size trains are cheaper to maintain, since the average distance they travel is lower.

2.5 CONCLUSIONS

By collecting together all the formulae and calculations in the previous sections, our estimate of the total cost (at $t = 0$) of building, operating and maintaining a HSR line would be obtained from the expression (2.1):

$$TC = \sum_{t=1}^{T} \frac{IC_t^C + IC_t^M + RSC_t^A}{(1+i)^t} + \sum_{t=1}^{T} \frac{RSC_t^O + RSC_t^M}{(1+i)^t}, \qquad (2.6)$$

that is,

$$TC = \sum_{t=1}^{T_0} \frac{(c \cdot L)(1+\rho)}{(1+i)^t} + \sum_{t=T_C+1}^{T} \frac{m \cdot L}{(1+i)^t} + \sum_{t=1}^{T} \frac{(RS_t - RS_{t-1}) \cdot a \cdot \bar{q}}{(1+i)^t} + \sum_{t=5}^{T} \frac{r_o \cdot RS_t \cdot \bar{q}}{(1+i)^t} + \sum_{t=5}^{T} \frac{r_m \cdot D_t \cdot RS_t}{(1+i)^t}. \qquad (2.7)$$

Although it just provides a lower bound to the actual cost, this expression summarizes the critical factors that must be taken into account when analyzing the costs of HSR lines. These include the line length (L), the number of trains needed to respond to the demand (RS), train capacity ($\bar{q}$), average distance (D) and the corresponding unit costs (c, m, a, r_o, r_m).

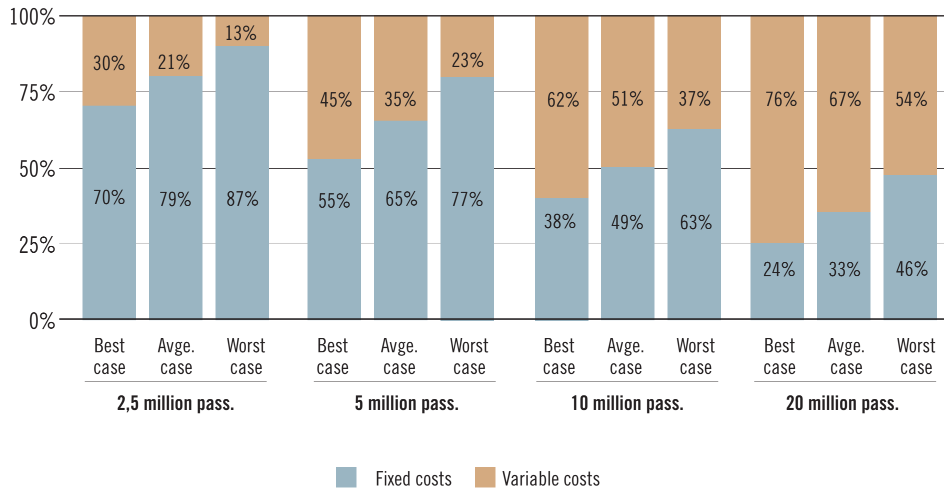
Table 2.5 summarizes the numerical estimates of this total cost considering a discount rate (i) of 5% under alternative assumptions on initial demand, train capacity, commercial speed and line length. We also considered three scenarios: the *all-the-best* scenario always uses the lowest value of the unit costs in each case; the *all-the-medium* scenario always uses the average value of the unit costs in each case; and the *all-the-worst* scenario always uses the highest value of the unit costs in each case. The implicit assumption behind these compound-scenarios is that there exists a perfect positive correlation between all the unit costs: if a country has a large construction cost, then its operating cost will be also large, and vice versa. In practice, this is not always the case since in several projects it is observed that the correlation could be even negative.

TABLE 2.5 Total costs (at *t*=0) of a HSR line under alternative assumptions (euros)

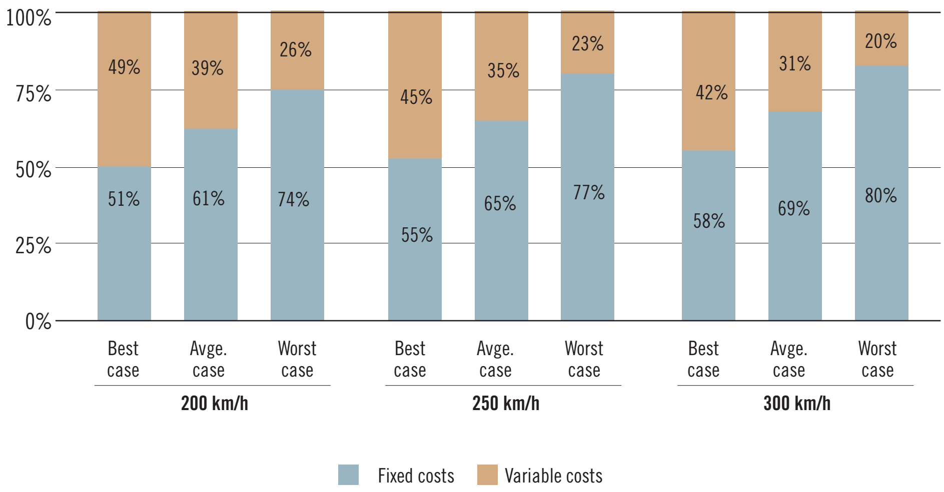
	All the best scenario	All the medium scenario	All the worst scenario
Initial demand assumptions			
2,500,000 pass.	6,000,067,777	10,785,250,118	21,065,618,421
5,000,000 pass.	7,730,285,037	13,029,676,448	23,777,416,675
10,000,000 pass.	11,187,484,570	17,513,729,139	29,194,942,065
20,000,000 pass.	18,108,860,949	26,491,173,260	40,041,479,687
Train capacity assumptions			
330 seats	7,730,285,037	13,029,676,448	23,777,416675
400 seats	7,648,681,646	12,945,753,435	23,691,415,005
500 seats	7,626,652,900	12,940,793,841	23,701,794,35
Commercial speed assumptions			
200 km/h	8,390,219,242	13,913,020,245	24,863,968,621
250 km/h	7,730,285,037	13,029,676,448	23,777,416,675
300 km/h	7,277,305,302	12,423,499,186	23,031,845,523
Line length assumptions			
250 km	4,080,508,403	6,803,021,727	12,243,154,507
500 km	7,730,285,037	13,029,676,448	23,777,416,675
650 km	9,909,604,536	16,751,534,490	30,680,581,170

Note: Results in bold correspond to the reference case.

According to table 2.5, the total cost of a 40-year HSR project lies between €7.7 and €23.7 billion in the reference case, depending on the scenario (best and worse, respectively). On average the NPV is 13.0 billion, which implies an average estimate of €25-30 million per kilometer. Table 2.5 also shows that when the initial demand is halved with respect to the reference case (that is, only 2.5 million passengers per year), the total cost is reduced (on average) just by a 20%, but if de-

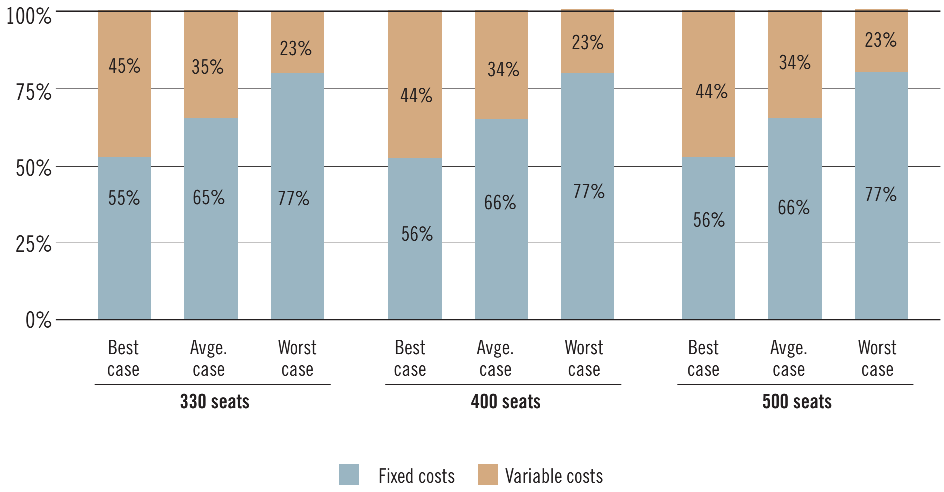


Graph 2.11a NPV cost distribution depending on initial demand

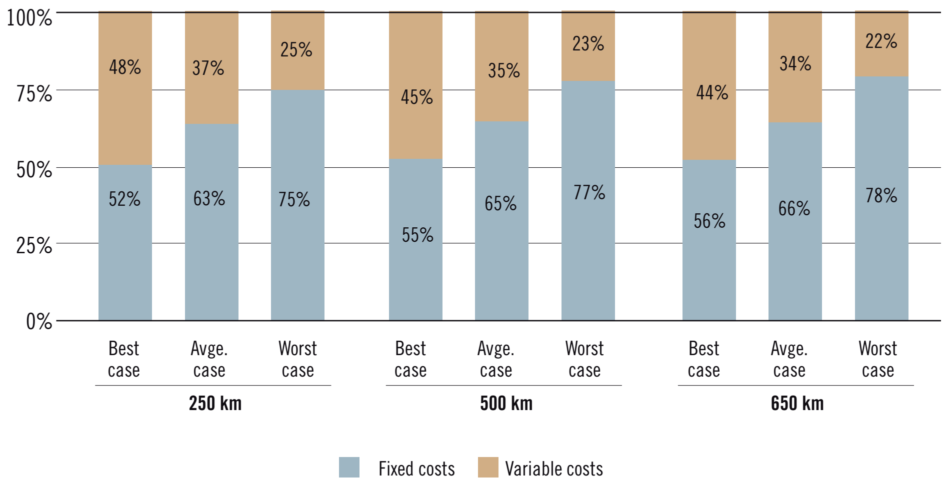


Graph 2.11b NPV cost distribution depending on commercial speed

mand is duplicated (10 million passengers) total cost can increase up to 31%. Similarly, it is interesting to note that neither the increase in train capacity nor the commercial speed have a large impact reducing the total costs of the project. Their effects on the supply tend to cancel out. On the contrary, changes in the length of the line are critical: shorter (larger) lines are dramatically cheaper (more expensive) to build and operate when compared to the reference case.



Graph 2.11c NPV cost distribution depending on train capacity



Graph 2.11d NPV cost distribution depending on line length

This final result is explained by the fact that most of the costs of the projects are fixed. This is confirmed in graphs 2.11a to 2.11d, where the NPV cost distribution between fixed and variable costs (under different assumptions) is displayed.

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3
In What Circumstances is Investment in HSR Worthwhile?

3.1 INTRODUCTION

By High Speed Rail (HSR) we normally mean rail technologies capable of speeds of the order of 300km/h on new dedicated track. Such systems offer journey times that are more competitive with other modes (and particularly air) than traditional train services, and very high capacity. But their capital cost is also high. The proposals of the European Commission for the Trans European Transport Network (TEN-T) envisage expenditure of 600 billion euros, of which 250 billion euros is for priority projects, and a large part of this expenditure is for high speed rail. Thus it is extremely important to have a robust appraisal methodology for these huge investments. It is not clear that this has been the case of the Trans European Networks. Individual projects are suggested by, and appraised by, member state governments, even though they are applying for the European Commission for assistance with funding. Research for the European Commission has appraised the TEN-T network as a whole, but has not appraised the individual elements of the program to ensure that they are all worthwhile (TML 2005).

The aim of this chapter is to consider the methodology for the appraisal of high speed rail proposals, and to produce some indication of the circumstances in which such proposals might be worthwhile. In the next section, we present an overview of the principal costs and benefits which need to be taken into account in a HSR appraisal. Then we illustrate the process for two particular contrasting examples: the study of HSR proposals in Great Britain, and an ex post evaluation of the Madrid-Seville line in Spain. In section 3.4, we formulate a model to incorporate the principal parameters influencing the outcome of an appraisal and in section 3.5, we use this model to draw conclusions on the circumstances in which high speed rail may be justified.

3.2 OVERVIEW OF COSTS AND BENEFITS

3.2.1 OPTIONS TO CONSIDER

Appraisal requires comparison of a base case with a series of *do-something* alternatives. It is necessary to be clear what the base case is, and to ensure that a realistic range of options is examined. A base case that literally assumes a *do-nothing* situation may be very unfavorable, particularly in the face of growing traffic; on the other hand the base case should not be padded out with unnecessary investments. In general the base case should be a *do-minimum* option, and other likely investments should be examined as alternative *do-something* options. These alternatives should be compared on an incremental basis to see whether the additional cost of moving to a more expensive option is justified.

In the case of high speed rail, the base case should therefore include such investment as it is necessary to keep the existing service running, and consideration should be given to how to deal with any exogenous growth in traffic. This might mean investing in additional rolling stock or revising fares structures and levels. More major changes should be considered as *do-something* alternatives. These might include upgrading existing infrastructure, purchase of a fleet of new tilting trains, or indeed construction of additional road or airport capacity. There will also be options regarding high speed rail—how far to extend the new line, to which alternative points to run the new trains, what service frequency and pricing policy to adopt. It is essential to examine sufficient alternatives to be confident that the best alternative is identified.

It is also necessary to consider the timing of investment. High speed rail might turn out to have the highest net present value, but if the demand for HSR and the other benefits from it are forecast to grow over time, then it might still be better to postpone the investment.

3.2.2 COSTS

HSR involves construction of new lines, stations etc., and purchase of new rolling stock, and additional train operating costs and externalities (mainly land take, visual intrusion, noise, air pollution, and global warming effects). Because the fixed cost of new infrastructure per kilometer is very high but creates very large capacity (assuming 12 trains per hour with 700 passengers per train give 8,400 passengers per hour), high speed rail systems are generally more economic the higher the traffic using the system. It follows that the strongest case for high speed rail is where traffic volumes are high. The traffic on the new system can be boosted if it is possible to construct a network such that passengers travelling between a number of city pairs use at least part of the same route with services, then branching off on to different high speed or conventional lines. Costs may also be reduced if the approach to city centers may be made on existing alignments. Traffic density may also be boosted by sharing the new capacity with freight traffic, but the infrastructure requirements for freight traffic are so different from high speed passenger that this adds to costs; in what follows we assume the HSR is built for passenger traffic alone.

Both construction of rail infrastructure and the operation of high speed trains lead to environmental costs in terms of land take, visual intrusion, noise, air pollution, and contribution to global warming. The first three of these impacts are likely to be much stronger where trains go through heavily populated areas. Since high speed trains are invariably electrically powered, air pollution and global warming impacts depend on the primary fuel used to generate the electricity; in countries with extensive hydro or nuclear electricity, these impacts will be negligible, whereas where coal, oil and gas are used they will be more significant, as will other forms of air pollution.

An estimate of the energy consumption of high speed rail in comparison with other modes is shown in table 3.1 (CE Delft 2003). Whilst HSR may involve twice the energy consumption per seat km of an average train, it may be substantially offset by higher load factors (the French TGV operates with an average load factor of 67%, whereas for conventional trains load factors are typically no more than an average of 40-45%. The reason for the difference is that the limited number of stops of the TGV makes it possible to enforce compulsory seat reservation and yield management techniques to a greater extent than on trains which also handle significant numbers of short distance passengers.) High speed rail clearly gives a substantial saving in energy over air, but the advantage over car, which arises because high speed rail typically operates at a higher load factor than car, is more marginal.

What matters in assessing the overall environmental impact of the HSR is not only the load factor but also the source of the traffic. For traffic diverted from conventional rail, the environmental impact is likely to be somewhat worse, whilst for totally generated trips the impact is obviously worse. (However, to the extent that generated trips are mainly trips taking advantage of low off-

TABLE 3.1: Energy consumption (MJ/Seat Km)

Gasoline car on highway	0.47
Diesel car on highway	0.34
Passenger aircraft on 500 km flight	1.80
Intercity Train	0.22
High Speed Train	0.53

Note: Based on CE Delft (2003) Appendix A. Graphs for car are based on new cars in 2000 and assume 5 seats per car.

Source: CE Delft (2003).

peak fares to fill empty seats, reducing generated traffic may simply lead to lower load factors and no improvement in environmental performance.) For trips diverted from car, and especially air, the impact is likely to be an improvement (particularly with respect to energy consumption and greenhouse gases in the case of air). The benefits HSR brings from reduced externalities on other modes are considered further in the next section.

3.2.3 BENEFITS

The principal benefits from HSR are:

- time savings;
- additional capacity;
- reduced externalities from other modes;
- generated traffic; and
- wider economic benefits.

Each of these elements will be discussed in turn.

Compared to a conventional train running at 160 km/h, a high speed train will save some 35 minutes on a journey of 450 km (SDG 2004). Where the existing infrastructure is of poorer quality or is congested, the time savings may be substantially greater. When it comes to valuation, time savings are generally split into business, commuter and leisure. There is extensive research on the valuation of time savings; the current valuations used in rail schemes in Britain are as shown in table 3.2. The high value for business time is based on the fact that much business travel takes place during working hours and directly reduces labor productivity, although questions have been raised on whether the full business value of time should be applied in this case on two grounds:

- many long distance business trips start and end outside normal working hours; and
- when travelling by train it is possible to work on the way (Hensher 1977).

However, research has shown that firms are willing to pay the sort of rate deduced from current valuations even under such circumstances, presumably because of the benefits they perceive in shortening long working days and having staff less tired (Marks, Fowkes, and Nash 1986).

The most recent review of evidence on values of time undertaken for the British government (ITS 2003), and which led to the adoption of the values shown in table 3.2, gave careful consideration to what was likely to happen to the value of time over time. The advice given by the British Department for Transport is that working time values, which are based on the wage rate, should rise in proportion to GDP, whilst non-working time values have an elasticity of 0.8 to GDP. Thus long term growth of values of time is assumed to be in the range of 1.5-2% per annum.

Additional capacity is obviously only of value if demand is exceeding the capacity of the existing route. But in those circumstances, additional capacity may be of value not just in allowing for growth between the cities served by the high speed line, but also by relieving existing lines of traffic for other types of service, such as suburban passenger or freight. Where the effect is to allow rail to carry traffic, which would otherwise use other modes, the benefits may be quantified as the net user benefits plus net reduction in externalities minus the net cost of the change of mode. There is also clear evidence (Gibson, Cooper, and Bell 2002) that running rail infrastructure less close to capacity benefits reliability; it may also lead to less overcrowding on trains. Both of these features are highly valued by rail travellers and especially business travellers (Wardman 2001). It should be noted that capacity constraints also make the alternative of upgrading existing infrastructure more problematic; for instance, running higher speed tilting trains on infrastructure shared with slower traffic may not be feasible.

Typically a substantial proportion, but not all, of the new traffic attracted to rail will be diverted

TABLE 3.2: Value of time savings for rail passengers in the UK

Standard Valuations	(£ per hour, 2002 market prices)
Leisure	4.46
Commuting	5.04
Business	39.96

Source: DfT: WEBTAG Unit 3.5.6 (www.webtag.org) from other modes—mainly car and air (British studies, such as Atkins 2003, suggest that this may be of the order of 50%, with the remainder being totally new trips). To the extent that infrastructure charging on these modes does not cover the marginal social cost of the traffic concerned, there will be benefits from such diversion. Estimation of these benefits requires valuation of marginal costs of congestion, noise, air pollution, global warming, and external costs of accidents and their comparison with taxes and charges.

INFRAS/IWW (2000) provides estimates of marginal external cost per passenger km for two European corridors, including accidents and environmental cost but excluding congestion. These are reproduced in table 3.3, and show the high speed rail between Paris and Brussels to have less than a quarter of the external cost of car or air. Higher load factors mean that HSR´s performance on such corridor is no worse than that of conventional rail on the (much longer) Paris-Viena corridor. On longer distances, the advantage over air diminishes since most of the environmental costs of air transport are incurred during take-offs and landings.

In the case of air, the absence of fuel tax means that there is normally no charge for environmental externalities, although this is crudely allowed for in some countries (including Britain) by a departure tax. (Value added tax [VAT] at the standard rate should not be seen as an externality charge since it does not influence relative prices, except when charged on some modes and not others; in some cases in Europe VAT is charged on domestic rail and air fares, in some on rail but not air and in others on neither).

TABLE 3.3: External costs (euros/1,000 pass-km)

	Paris-Vienna	Paris-Brussels
Car	40.2	43.6
Rail	11.7	10.4
Air	28.7	47.5

Note: The measured externalities include accidents, noise, air pollution, climate change, urban effects, and upstream/downstream effects, but not congestion or scarce capacity.

Source: INFRAS/IWW (2000).

The other key issue for air is charging for slots at congested airports. The allocation of slots by grandfather rights and charging structures, based on average costs of running the airport (or less where there are subsidies), mean that charges may not reflect congestion costs imposed on other planes, the opportunity cost of slots or the costs of expanding capacity. A further benefit of high speed rail may therefore be the release of capacity at airports for use by other, typically longer distance flights. Regarding accidents, there has never yet been a fatality on a purpose-built HSR, and the record of conventional rail is much better than car, though not bus or particularly air (Evans 2003).

Generated traffic leads directly to benefits to users, which are generally valued at half the benefit to existing users according to the rule of a half. But there has been much debate as to whether these generated trips reflect wider economic benefits that are not captured in a traditional cost benefit analysis. Leisure trips may benefit the destination by bringing in tourist spending; commuter and business trips reflect expansion or relocation of jobs or homes or additional economic activity.

The debate on these issues centers on whether these changes really are additional economic activity or whether such activity is simple relocated. In a perfectly competitive economy with no involuntary unemployment, theory tells us that there would be no net benefit. In practice, there are reasons why there may be additional benefits. Firstly, if the investment relocates jobs to depressed areas, it may reduce involuntary unemployment. The experience of Lille, which has been regenerated by its location at the crossroads of high speed lines between Paris, Brussels and London is often cited as an example. High speed rail tends to favor central locations, so if the aim is to regenerate major cities then it may be beneficial. However, if the depressed areas are at the periphery, this is the opposite of what is desired. High speed rail may also allow for expanded market areas and the exploitation of economies of scale, reducing the impact of imperfect competition, and encouraging the location of jobs in major urban centers where there are external benefits of agglomeration (Graham 2005). Any such impacts are most likely to be found in the case of service industries (Bonnafous 1987).

Chapter 5 concludes that HSR may have additional benefits for the above-mentioned reasons, but that the effects are very variable and difficult to predict. They are likely to be much less important than the direct transport benefits of HSR; typically they will also apply to alternative transport infrastructure investments, so that whilst they improve the case for transport investment as a whole, they do not necessarily benefit HSR against other modes.

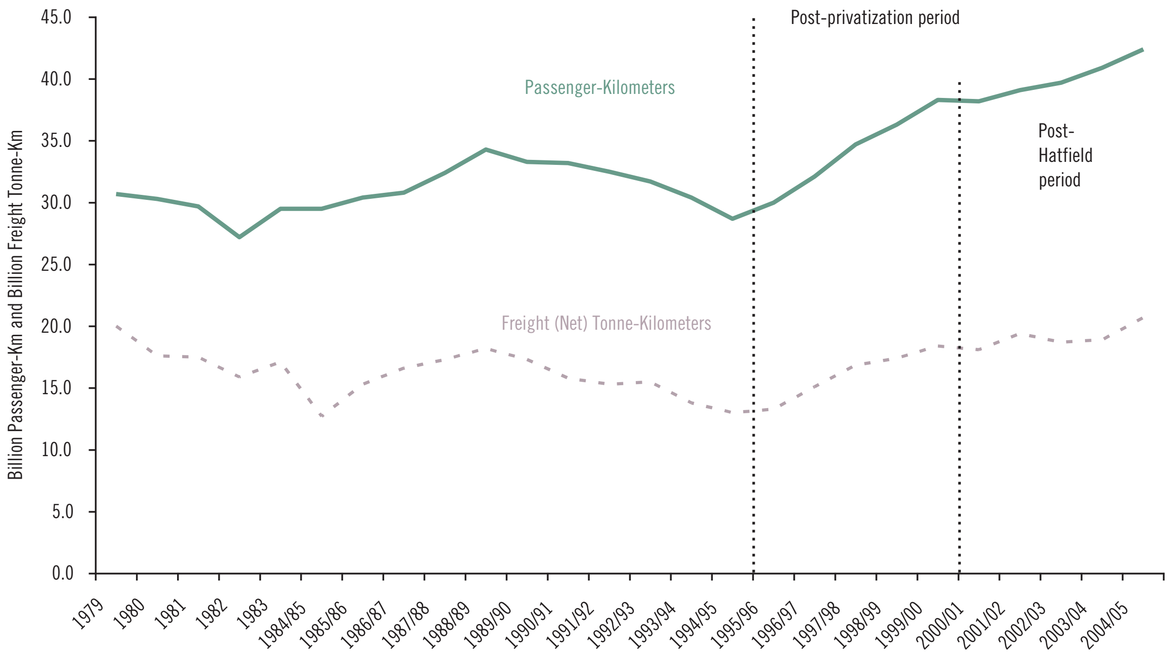
Another key factor influencing the outcome of an appraisal is the choice of discount rate. Low discount rates favor capital intensive investments such as HSR. Practice varies substantially within the European Union. In Britain the current practice is to discount at a pure time preference rate of discount of 3.5%, reducing to 3% after 30 years, but to allow for capital shortages by requiring a benefit/cost ratio of at least 1.5 and preferring projects where it is at least 2. DG Regio recommends a 5% social discount rate. Given that HSR is very capital intensive and has a long life with growing benefits over time, a low discount rate will favor investment in HSR.

3.3 EMPIRICAL EXAMPLES

In this section we will examine two empirical case studies, in radically different circumstances and with widely differing results. Firstly we look at a study of a new North-South high speed rail line in Britain, undertaken for the Strategic Rail Authority by a consortium led by the consultants W.S. Atkins (SRA). Then we look at a study of the actual Madrid-Seville line.

3.3.1 BRITISH HSR PROPOSALS

The Atkins study took place in a context of rapid growth in rail passenger and freight traffic in recent years (graph 3.1), leading to severe overcrowding on both long distance passenger services and London commuter services, and a lack of capacity for further growth in freight. Thus a major objective of the scheme was to relieve exist-



Graph 3.1 Rail Passenger and Freight Volumes (1979 to 2004/05)

Note: The Hatfield accident in October 2000 led to severe speed restrictions being imposed which temporarily halted traffic growth.

Source: Transport Trends, 2002 Edition. Departmant for Transport and National Rail Trends, SRA.

ing routes, as well as provide faster more competitive services between the major cities. This rather general remit led to the need to generate and study a wide range of options. Altogether some fourteen options were studied in depth, the main issues being whether to have a single route north from London which might split further north to serve cities up the east and west sides of the country, or to have two separate routes, and how far north to go. The obvious starting point would be a new route from London to the heavily populated West Midlands. The further north the line was extended, the less heavily used the new sections would be, but this effect might be offset by the fact that these extensions attract additional traffic on to the core part of the network. It is a characteristic of Britain geographically that a single line could serve the major cities of London, Birmingham, Leeds, Newcastle, Edinburgh, and Glasgow, whilst a conventional or high speed branch would serve Manchester.

It was forecast that the new line, if built to its extremities, would attract nearly 50 million passenger trips per year in 2015, although most of these would only use part of the route. This high figure reflects the high population density of Britain, and the large number of origin-destination pairs that the line would serve. Of these around two thirds would be diverted from existing rail routes, and the remainder split almost equally between diversion from other modes and newly generated trips. Most of the forecast diversion occurred from car—the forecast of diversion from air was surprisingly low given the experience of the impact of HSR on air traffic elsewhere.

The original appraisals were undertaken with a life of 30 years and a discount rate of 6%; the British government has subsequently modified its practice to have a life of 60 years and a discount rate of 3.5%. Despite the simultaneous introduction of a big allowance for optimism bias in the estimates of costs (67% in the case of capital costs plus a 25% program bias), the result is a substantially higher ratio of benefits to costs in subsequent appraisals. Results of the appraisal of two options are shown in table 3.4. Option 1 (minimum investment) is the line from London to the West Midlands, which is the obvious first phase of any high speed rail program in Great Britain, and it is seen to be well justified in its own right. But option 8 (maximum investment), the extension through Manchester on the West Coast route and right through Scotland via the East Coast, is also shown to be justified, with an incremental benefit-cost ratio representing good value for money. It is obviously important, however, to examine the issue of timing and phasing. The study showed that, if feasible, immediate construction of the whole line was the best option.

A number of other factors have added to the case since the original appraisal. Firstly is the failure to upgrade the East Coast Main Line, an investment that was assumed to be part of the base case in the study. Whilst this should certainly still be considered as an option, given the delays and cost overruns with the upgrading of the parallel West Coast route compared to the more satisfactory experience in the construction of the wholly new high speed line to the Channel Tunnel, it is less likely to be favored now. At the same time, the government has announced its intention of introducing nationwide road pricing within the next ten years, adding to the forecast high speed rail traffic.

Although net revenue more or less covers operating costs for both options, the capital cost can only be justified by non-financial benefits and released capacity. A breakdown of the composition of costs and benefits for option 1 is given in table 3.5. Some 78% of benefits take the form of time savings and reduced overcrowding with 19% due to increased net revenue and only 3%

TABLE 3.4: Appraisal of options 1 and 8 (£bn, present value)

	Option 1	Option 8
Net revenue	4.9	20.6
Non-financial benefits	22.7	64.4
Released capacity	2.0	4.8
Total benefits	**29.6**	**89.8**
Capital costs	8.6	27.7
Net operating costs	5.7	16.3
Total costs	**14.4**	**44.0**
NPV	15.3	45.7
B/C	2.07	2.04

Source: Atkins (2003) Summary report, Addendum, table 2.1 with transcription errors corrected.

taking the form of reduced road congestion and accidents. The value of the released capacity was not included in this analysis, but adds some 7% to the overall benefits.

On balance it was thought that the non-quantified environmental benefits were slight. It is an interesting question whether more of the user benefits could be captured as revenue by more sophisticated yield management techniques than the simple fare structure model. Such yield management methods are already in use on other high speed services, including Eurostar services between London, Paris, and Brussels. They might also boost benefits by increasing diversion from air; in the study this was found to be rather small on the assumption that rail fares would on average exceed those by air for traffic between London and Scotland.

In summary, then, this study of Britain found a strong case for high speed rail, based on the high patronage that could be attracted by a single line linking most of the major conurbations of Britain, in the context of growing demand leading to severe overcrowding and shortages of capacity on the existing infrastructure. In the following section we look at a contrasting situation—that of Spain.

TABLE 3.5: Cost benefit analysis results, option 1 (% of Total Benefits or Costs)

Benefits – Revenue	
HSR Revenue	64%
Classic rail revenue	–45%
Net rail revenue	19%
Benefits – Users	
Journey time/reduced overcrowding	76%
Accidents	2%
Total User Benefits	78%
Benefits – Non-users	
Journey time/veh operating costs	3%
Total Non-User Benefits	3%
Present Value Benefits	**100%**
Costs	
Capital	69%
HSR operating	41%
Classic operating	–9%
Present Value Costs	**100%**

Source: Atkins (2003) unpublished full report.

3.3.2 THE SPANISH EXPERIENCE[1]

The construction of the first high speed line in Spain was carried out between 1987 and 1993. The Madrid-Seville line started its operations in April 1992, with a demand highly influenced by the Universal Exhibition held in Seville in 1992 (EXPO) and with the pricing policy applied by RENFE. The Madrid-Seville corridor includes several routes[2] (commuting, long-distance and services provided to other destinations using high-speed infrastructure but with *Talgo* technology).

High speed train is the transport option with the lowest generalized cost in this corridor, but not the fastest mode. Air transport has the lowest travel time in the Madrid-Seville corridor, after accounting for access and waiting times. The advantage of the HSR with respect to air transport appears when tariffs of both modes are compared. These differences in the generalized costs have induced changes in the modal split to the benefit of HSR. Diverted traffic comes mainly from conventional train and air transport.

Regarding the impact of the Madrid-Seville HSR on other transport operators, the main effects which must be considered are those on air transport (Iberia and airports), on conventional railways, and on road transport. For air transport between Madrid and Seville, the introduction of the HSR induced a demand downshift of 50%, diminishing the load factor and flight frequency. The Seville airport suffered a reduction of 25% in its use, as Madrid-Seville represented 50% of airport traffic. Given the investments which were carried out in the airport of Seville to accommodate the peak of demand induced by the exhibition EXPO-92, and more recent investment at

1 See De Rus and Inglada (1993, 1997).
2 Price discounts of up to 30% (Madrid-Seville) and 50% (Madrid-Ciudad Real) were introduced to compensate the reduction in demand after EXPO closure (in October, 1992). These discounts contributed to higher load factors.

Barajas airport in Madrid, it is unlikely that this diversion will significantly reduce congestion although it will certainly reduce pollution from air transport.

For conventional railway transport, RENFE was also affected by the introduction of the new product. The Madrid-Seville, Madrid-Malaga and Madrid-Cordoba links were amongst the main twenty lines of the company. Conventional trains have lost the major part of their traffic in this corridor; therefore an efficient solution might be to consider the closure of the conventional infrastructure. However, the impossibility of carrying goods on the new infrastructure makes this scenario unfeasible.

HSR long distance services and bus transport are hardly substitutes at current prices. In commuter services, and taking into account the low prices introduced by RENFE, bus operators are certainly affected by HSR.

Given the demand volumes in this corridor, the main benefits obtained from the investment in high speed rail are derived from time savings obtained when users shift from slower transport modes, and gains from generated traffic. It has also been argued that one of the key benefits of HSR was the increase of land value in Ciudad Real. Nevertheless, this benefit is a consequence of the improvement in accessibility to this city, which is already accounted for in the reduction of travel time between Madrid and Ciudad Real. To include this effect in the analysis would lead to double counting.

To evaluate the economic effects of HSR, it is required first to have an estimation of the demand for the period which is going to be considered for the analysis. To obtain this estimate, surveys carried out by RENFE in the Madrid-Seville corridor were consulted, and real data of HSR for the period 1992–1994 and four months in 1995 were used. Additional information was supplied by Iberia, RENFE, and bus companies operating in the corridor. The main components of the demand (generated and diverted traffic) were obtained for each market segment (commuters, long distance and Talgo) and each transport mode.

The evolution of demand for the 30-year project life (40 years in the sensitivity analysis) is estimated assuming that the Spanish GDP will grow from 1997 onwards at a rate of 2.5%, the elasticity of demand with respect to GDP is assumed to be 1.25, and that HSR fares will not be reduced below average variable costs.

Using this demand estimation, the social profitability of the HSR was estimated. Benefits of the HSR are obtained from 1992 onwards, after the starting of the service. Costs and benefit present values are discounted with a 6% social discount rate.

The HSR costs have a fixed component (infrastructure), semi-fixed (trains) and variable (operating costs). In this evaluation it is considered that prices (net of tax) of the infrastructure, trains and operating costs measure opportunity costs except in the case of labor. HSR infrastructure was built between 1987 and 1992, its costs (including taxes) was 500 billion pesetas at 1996 currency value. HSR benefits are mainly obtained from time savings and generated traffic.

Benefits and costs of the first HSR line in Spain are summarized in Table 3.6. The NPV is –258 billion pesetas at 1987 prices, using a social discount rate of 6%. Table 3.5 shows the sensitivity of results to different assumptions: life of the project (40 years); shadow pricing of labor; increase of 25% in generalized costs of car, train and bus; and GDP growing at a 3% rate. These changes do not affect the main findings of this evaluation.

A simple financial analysis of the project shows a NPV of –314 billion pesetas in 1987, which indicates that an economic evaluation of HSR, considering all social costs and benefits, reveals an 18% improvement on its performance. As table 3.5 shows, the main source of benefits of the HSR is generated traffic (44% of the total benefits of the project).

Benefits of diverted traffic are not limited to time savings (22.5% of total benefits). The reduction in operating cost in other transport modes is also important. The shift to HSR of journeys by car forms 8.9% of the total benefits; cost savings from railway and air transport yield benefits of

TABLE 3.6: Benefits of Madrid-Seville high speed train
(millions of 1987 pesetas)

	Social benefit of HSR*	GDP growth rate (3%)	Project life (40 years)	Shadow prices for labour	Increase of 25% in generalized costs of car, train and bus
Costs					
Infrastructure	–237,761	–237,761	–237,761	–200,575	–237,761
Residual value	17,636	18,546	5,816	17,636	17,636
Trains	–58,128	–61,003	–61,700	–58,128	–58,128
Maintenance	–41,410	–41,410	–45,022	–41,410	–41,410
Operation	–135,265	–140,575	–155,216	–135,265	–135,265
Time savings derivated traffic					
Conventional train	37,665	39,950	44,852	37,665	55,119
Car	4,617	4,898	5,469	4,617	9,779
Bus	1,958	2,079	2,321	1,958	2,867
Air transport	0	0	0	0	0
Generated traffic costs savings	**86,718**	**92,080**	**102,951**	**86,718**	**92,703**
Conventional train	18,505	19,629	21,906	18,505	18,505
Air transport	19,020	20,157	22,460	19,020	19,020
Bus	1,680	1,783	1,990	1,680	1,680
Car operating costs	17,412	18,471	20,618	17,412	17,412
Congestion	4,896	6,284	7,486	4,896	4,896
Accidents	4,128	4,363	4,867	4,128	4,128
Net present value of HSR	–258,329	–252,509	–259,533	–221,143	–228,819

* Project life (30 years), GDP growth (2.5%), social discount rate (6%).

9.4 and 9.6% respectively. The savings in bus operator costs are not significant. Benefits from the reduction in congestion and accidents are only 4.6% of the benefits.

It has been argued that the linking of the Spanish high speed rail with the European HSR network would improve, in a significant way, the social profitability of the project. However, journey times in HSR from Seville (and even Madrid) to many European cities are too long to challenge the comparative advantage of air transport in long-distance journeys.

Construction costs for HSR in Spain are typically much lower than in Britain due to reduced population density. But the key reason for the poor performance of the Madrid-Seville line is the low traffic volume, which has only recently reached 5 million passengers p.a. more than 10 years after opening. The recognition that traffic volumes are the key to the case for HSR leads us to examine the issue of breakeven traffic volumes in more depth in the next section.

3.4 BREAKEVEN TRAFFIC VOLUMES

3.4.1 THE MODEL

In this section we outline a simple model designed to give a rough idea of the breakeven traffic volume for HSR and go on to apply it to see how this volume varies with circumstances.

Let us consider the case of a project consisting of the construction and operation of a new high speed railway line. This project has a life of T years. The construction firm builds the rail infrastructure and superstructure, and the operator buys the rolling stock during some initial period, which will be considered as the year of reference ($t = 0$) and thereafter when it requires replacement. From $t = 0$ to $t = T$, the railway operator charges a regulated fare and each year receives Q users, assumed to be constant during the life of the project.[3]

Investment costs (construction and the present value of rolling stock), expressed as opportunity costs, are equal to I, evaluated in constant terms of year $t = 0$. During the life of the project, the operator[4] incurs some annual costs of maintaining and operating the rail track, stations, signalling and other fixed plants, and the operating costs of labor and energy consumed in train operation. Some maintenance costs (track, stations, rolling stock) are fixed ($C_t(t)$) and thus invariable to the level of traffic Q, and others are demand related, depending on the number of users ($C_q(Q)$). All costs are computed at opportunity costs.

Investment in HSR consist of building a new line and operating high speed rolling stock which reduces the time component of the generalized cost for all passengers switching from the conventional mode to the new mode and, thus, affecting other secondary markets, whose products or services are complements or substitutes of the HSR service, including those users who continue using the conventional mode,[5] road users, for example, because congestion is eased. This investment generates some net benefits in the primary market, and some indirect benefits in secondary markets.

Total costs of the project are:

$$I + \int_0^T (C_t + C_q(Q))e^{-rt}\, dt \quad , \qquad (3.1)$$

where:

I: investment costs;

C_t: annual fixed maintenance and operating cost;

$C_q(Q)$: annual maintenance and operating cost variable with Q;

T: project life;

r: social discount rate.

The introduction of a HSR line means a discrete reduction of the generalized cost of travel. Given that HSR is an indivisible investment, the change in social surplus is the following:[6]

$$\begin{aligned} \Delta W = \int_0^T \int_{g_1}^{g_0} Q(g)e^{-rt}dg\,dt + \int_0^T [\bar{p}(Q_1 - Q_0) - \\ - C_t - C_q(Q_1) + C_C(Q_0)]e^{-rt}dt - I + \qquad (3.2) \\ + \sum_{i=1}^{N} \int_0^T S_i(q_{i1} - q_{i0})e^{-rt}dt \quad , \end{aligned}$$

where:

g_0: generalized cost *without* the HSR project;

g_1: generalized cost *with* the HSR project;

$\bar{p}$: regulated fare;

Q_0: demand *without* the HSR project;

Q_1: demand *with* the HSR project (includes diverted and generated traffic);

C_t: annual fixed maintenance and operating cost;

$C_q(Q)$: annual maintenance and operating cost variable with Q;

$C_C(Q)$: annual avoidable cost of the conventional mode;

3 We drop this assumption later.
4 The HSR can be vertically integrated or separated. All high speed rail lines in the world currently operate as vertically integrated firms. Vertical unbundling is one of the key elements of EU railway policy, and proposals are under consideration to allow open access for new entrants into the international rail passenger market.
5 We ignore here environmental impacts, such as land-take, barrier effect, noise, and visual intrusion, which should also be accounted for on the cost side of HSR, as well as on the benefit side when HSR is a substitute of a highway or an airport.
6 We are not maximizing welfare but obtaining a change in welfare when the government decides to build a new high speed railway line.

I: infrastructure construction costs;

N: other markets in the economy;

S_i: excess of benefits over costs of a unit change in q_i;

q_{i0}: level of activity in market i without the project;

q_{i1}: level of activity in market i with the project;

T: project life;

r: social discount rate.

Expression (3.2) shows how the introduction of the HSR line affects transport users and producers in the primary markets, with annual benefits measured by the definite integral between the initial generalized cost (g_0) and the new one (g_1), once the HSR line is introduced. Producer surplus can be measured through annual revenue and avoidable cost changes. Then, HSR investment cost (I) has to be deducted from the discounted flows of these benefits.

The demand function for transport Q(g) is a derived demand, and one should be careful when adding the indirect effects of the reduction in travel time in competitive markets, where firms use transport as an input to avoid double counting (see Jara-Díaz 1986); so, we will limit our attention to secondary markets, where products and services are related to the primary market through complementarity or substitutability links, or in the case of monopolistic firms using the HSR service as an input.

The third line of expression (3.2) accounts for indirect or secondary benefits. There are N secondary markets in the economy, which may have their level of demand affected by the new project. The change in the level of activity in these secondary markets would affect the NPV of the project as long as there is an excess of benefits over costs of a unit change of q, represented by S_i which could be positive or negative (Harberger 1972; Mohring 1976).

Therefore the justification of adding indirect effects to HSR primary benefits not only requires that other markets are affected ($q_{i1} - q_{i0} \neq 0$) but the change in the level of activity in these markets has to have a positive sign when $S_i > 0$, and negative when $S_i < 0$. In the case of $S_i = 0$, the change in the secondary market can be ignored. It is worth noticing that the significance of the indirect effects in expression (3.2) depends on the existence of distortions in the economy. Externalities, taxes, subsidies, unemployment, and the existence of market power create additional sources of benefits (and costs) in secondary markets. The importance of these indirect effects is an empirical matter,[7] which depends on the magnitude and sign of the distortions and the cross-effects in secondary markets due to the reduction in transport costs.[8]

3.4.2 SIMPLIFYING THE MODEL

HSR technology can be characterized as a faster transport mode than conventional railway and road transport, and a more convenient alternative than air for certain distances. Although the economic evaluation of a particular project requires disaggregate information on passengers shifting from other modes and generated traffic, it is possible to simplify the problem working with some assumptions.

The main purpose of these assumptions is to concentrate on the HSR benefits derived from time savings and generated demand, leaving aside the benefits from the provision of additional rail capacity and from the net reduction of accidents, congestion and environmental impacts due to diversion from road and air modes, which are more sensitive to the local conditions of each corridor. The idea is to make the basic model workable with real data, concentrating efforts on the uncontroversial effects of HSR investment in order

[7] This is especially relevant for freight transport. The British Department of Transport suggests an additional 6% of net benefits in UK due to the expansion of demand in monopolistic sectors which benefit from transport reduction projects (see Department of Environment, Transport and the Regions 1999).

[8] These constitute net benefits which are yet to be measured in the primary market.

to establish some basis for the rational discussion on the economic desirability of this investment.

The assumptions are the following: indirect effects (positive and negative) cancel out in the aggregate; the net reduction in externalities is negligible; first year net benefits grow at a constant annual rate during the project life; producer surpluses do not change in alternative modes; market prices are equal to opportunity costs; and there are no benefits to users other than time savings and willingness to pay for generated trips. The condition to be satisfied for a positive NPV can then be expressed as follows:

$$\int_0^T [B(Q) - C_q(Q)]e^{-(r-\theta)t}\, dt - \int_0^T C_t\, e^{-rt} > I \quad , \qquad (3.3)$$

where:

B(Q): annual social benefits of the project;

$C_q(Q)$: annual maintenance and operating cost variable with Q;

C_t: annual fixed maintenance and operating cost;

I: investment costs;

T: life of the project;

r: social discount rate;

θ: annual growth of benefits and costs which depends on Q.

Assuming $r > \theta$, and solving expression (3.3), for the project to be socially desirable, the following condition is obtained:

$$\frac{B(Q) - C_q(Q)}{r - \theta}(1 - e^{-(r-\theta)T}) - \frac{C_t}{r}(1 - e^{-rT}) > I \quad . \qquad (3.4)$$

Dividing by I and rearranging terms:

$$\frac{B(Q) - C_q(Q)}{I} > \frac{r - \theta}{1 - e^{-(r-\theta)T}} + \frac{C_t}{I}\,\frac{r - \theta}{r}\,\frac{1 - e^{-rT}}{1 - e^{-(r-\theta)T}} \quad . \qquad (3.5)$$

The economic interpretation of expression (3.5) is quite intuitive assuming that the project life is very long (T tends to infinity). In this case, the net benefits of the first year (annual benefits minus variable costs depending on Q) expressed as a proportion of the investment costs should be higher than the social discount rate minus the growth rate of net benefits plus a proportion ($r - \theta$ / r) of fixed annual maintenance costs. In the case of a finite project life, the only change is a more demanding benchmark for profitability.[9]

According to expression (3.5), the economic return of a HSR is higher: the larger is the first year net benefit, which depends on the initial demand; the lower are investment, maintenance and operating costs; the lower is r and the higher is θ; the higher is the share of annual fixed costs (C_t) in first year total annual costs ($C_q + C_t$); and the longer is the project life.

The social profitability of HSR infrastructure depends crucially on the net benefit of the first year of the project. When externalities and indirect effects are not significant, first year annual benefits come mainly from time savings and benefits from generated traffic,[10] net of variable costs. These net benefits depend on the volume of demand to be served, the time savings on the line

[9] $\frac{1}{1 - e^{-(r-\theta)T}} > 1$, $\frac{1 - e^{-rT}}{1 - e^{-(r-\theta)T}} > 1$ when $r > \theta$ and $0 < T < \infty$. Both expressions tend to 1 when $T \to \infty$.

[10] Willingness to pay for the difference in comfort is another source of benefit, though the empirical evidence is scarce.

with respect to existing modes and the average user's value of time.

Note that, as commented above, it is important not just to check that the net present value of the project is positive, but also that the timing is appropriate. Where benefits grow over time the optimal timing is given by the point at which the first year rate of return first exceeds the rate of discount. This test corresponds to applying equation (3.5) but $\theta = 0$.

The growth rate (θ) in expression (3.5) affects benefits and demand related costs in the same way. This is an ad hoc assumption only justified by the lack of better evidence. Another possibility is to introduce a separate variable to account for changes in the value of time over time and labor costs. This would require choosing different growth rates for other cost categories which are not expected to vary proportionally with income.

Given the assumptions outlined above, $B(Q) - C_q(Q)$ in equation (3.5) can be expressed as the change in users' surplus (diverted and generated) and the producer surplus:

$$\frac{1}{2}(g_0 - g_1)(Q_0 + Q_1) + p_1 Q_1 - p_0 Q_0 - C_q + C_C \,, \tag{3.6}$$

where:

g_0: generalized cost *without* HSR;

g_1: generalized cost *with* HSR;

p_0: price of the conventional mode;

p_1: price of the HSR;

Q_0: first year diverted demand to HSR;

Q_1: first year total demand (diverted and generated) *with* HSR;

C_q: annual maintenance and operating cost variable with Q;

C_C: annual variable cost of the conventional mode.

By definition, the generalized cost is $g = p + vt$. The change is in the total value of time saved by the average passenger; therefore, (3.6) can be expressed as the sum of the total value of time saved by the diverted demand, plus the willingness to pay of generated trips, plus the net change in resource cost:

$$v\Delta tQ_0 + \frac{1}{2}(p_0 + vt_0 - p_1 - vt_1)\Delta Q + p_1\Delta Q + C_c - C_q \,. \tag{3.7}$$

Rearranging and multiplying and dividing by Q_0:

$$v\Delta tQ_0 + C_c + \frac{1}{2}(v\Delta tQ_0 + \Delta pQ_0)\frac{\Delta Q}{Q_0} + p_1 Q_0 \frac{\Delta Q}{Q_0} - C_q \,. \tag{3.8}$$

Since the conventional mode breaks even (as assumed), and costs are fully avoidable when traffic diverts to HSR, then $C_c = p_0 q_0$ and $p_1 Q_0 = C_c + |\Delta p| Q_0$; therefore, (3.8) is equivalent to:

$$v\Delta tQ_0 + C_c + (\frac{1}{2}v\Delta tQ_0 + C_c + \frac{1}{2}\Delta pQ_0 + |\Delta p|Q_0)\frac{\Delta Q}{Q_0} - C_q \,. \tag{3.9}$$

Simplifying and letting α represent the ratio $\frac{\Delta Q}{Q_0}$:

$$v\Delta tQ_0 + C_c + (\frac{1}{2}v\Delta tQ_0 + C_c + \frac{1}{2}|\Delta p|Q_0)\alpha - C_q \,. \tag{3.10}$$

Considering that $v\Delta t$ is always greater than Δp (otherwise the number of passengers would not increase), (3.10) can be finally approximated by:

$$[v\Delta tQ_0 + C_C](1 + \alpha) - C_q \,, \tag{3.11}$$

where:

v: average value of time;

Δt: average time saving;

Q_0: first year diverted demand to HSR;

C_C: annual variable cost of the conventional mode;

α: proportion of generated passengers *with* the project with respect to Q_0.

For (3.11) be equivalent to (3.10) it is required that $v\Delta t = |\Delta p|$ and, therefore, (3.11) overestimates the benefit from generated traffic by the difference $v\Delta t - |\Delta p|$ which, if significant, would bias the evaluation in favor of the project.

Substituting (3.11) back in (3.5) and rearranging it, it is straightforward to figure out the minimum value of Q_0, which would be necessary for a positive NPV:

$$Q_0 > \frac{1}{v\Delta t(1+\alpha)}\left[\frac{r-\theta}{1-e^{-(r-\theta)T}}I + C_q + C_t\frac{r-\theta}{r}\frac{1-e^{-rT}}{1-e^{-(r-\theta)T}} - C_C(1+\alpha)\right]. \tag{3.12}$$

3.4.3 DEMAND THRESHOLDS FOR SOCIAL PROFITABILITY

We have limited information concerning the actual values of key parameters in (12). Having a HSR line in operation requires incurring some fixed (and partially sunk) costs: the investment costs in infrastructure, which consists of tracks and sidings along the line, buildings and technical equipment for terminals and stations, line signalling, traffic management and control system. These components need maintenance and operation (energy, materials and labor) and a reservation system; and although these costs are in some way dependent on the volume of traffic, they cannot be completely avoided when demand is lower than expected, and therefore they are considered fixed in this chapter.

Besides dedicated infrastructure, investment in high speed rolling stock is required, as well as maintenance and operating costs such as energy and labor expenses needed for having these trains in operation. These costs are demand-related but they could be partially considered as fixed in the short term. In this chapter, we will consider all these costs as variable, i.e., related to the level of demand.

It is not easy to obtain cost values for HSR projects because the range of variation is wide, and costs vary according to local conditions: density of crossed urban areas, number of tunnels, bridges, and so forth. We worked with a range of typical cost values in standard circumstances (based on the HSR in operation in Europe), and used different values of time, from several European studies in the recent past. Then, we applied a sensitivity test using the most favorable assumptions regarding key parameters.

Data on infrastructure construction costs shows how the cost per kilometer varies from €12 million per kilometer in Spain to 32 in Germany and over 45 in the Netherlands (Department of Environment, Transport and the Regions 2004). In spite of the difficulties associated to the limited evidence concerning cost data, it is possible to work within certain realistic ranges for standard projects.[11] Table 3.7 shows the actual costs for a standard 500-km HSR (see Barrón de Angoiti 2004).

The lower value of construction costs in table 3.7 is representative of the line Madrid-Seville (Spain) or the TGV Atlantique (France); the highest value would reflect the construction costs of lines like Naples-Rome and Florence-Turin (Italy); in the middle lie the TGV Méditerenée (France) and the

[11] There is also evidence of a systematic bias in the estimation of costs and demand in large infrastructure projects. Flyvbjerg, Skamris, and Buhl (2004) found that 90% of projects have cost overruns. Overruns are general in space and constant for the past 70 years.

TABLE 3.7: Estimated costs of a 500-km HSR line in Europe (2004)

	Cost per unit (€thousand)	Units	Total cost (€million)
Capital costs			
Infrastructure construction* (Km)	12,000-40,000	500	6,000-20,000
Rolling stock (Trains)	15,000	40	600.0
Running costs (p.a.)			
Infrastructure maintenance (Km)	65	500	32.5
Rolling stock maintenance (Trains)	900	40	36.0
Energy (Trains)	892	40	35.7
Labor (Employees)	36	550	19.8

* Terminal value = 50% of the investment in infrastructure.

Source: UIC.

ICE Frankfurt-Cologne (Germany), which is closer to the upper limit.

One key parameter is the expected average time saving per passenger (Δt). SDG (2004) provides some evidence from case studies on HSR development, transport markets and appraisal processes in the UK and six other countries. The *base case* is a conventional rail service with an operating speed of 130 km/h (representative of many main lines in Europe). For distances in the range of 350-400 km, a typical HSR yields 45-50 minutes savings. When conventional trains run at 100 km/h, potential time savings are one hour or more. On the other hand, if the conventional train's operating speed is 160 km/h, time saving is 35 minutes over a distance of 450 km.[12]

These average values imply that all passengers travel the whole length of the line. Given the existence of intermediate stations along the line and different trip lengths, these values overestimate the actual time savings. Moreover diverted traffic also comes from road and air transport. Time savings are lower when passengers divert from air transport, though higher when passengers shift from road transport. In this chapter we assume that the average time saving per passenger goes from half an hour to an hour and a half, which probably includes any potential case in Europe.

Other key parameters are the value of time and the social discount rate. We use average values of time ranging from 15 to 30 euros. For the sake of robustness, the maximum value chosen is above the state-of-the-art values (see, for example, Nellthorp et al. 2001). This range includes different possibilities of trip purposes and initial transport mode combinations, and the possibility of an extra willingness to pay for quality not included in the reported values of time. Avoidable costs in the conventional mode (C_c) are initially assumed to be a half of (C_t+C_q) in the high speed train.[13] The social discount rate is 5% in real terms, as recommended by the European Commission for the evaluation of infrastructure projects.[14]

Expression (3.12) allows the estimation of demand thresholds changing the average time savings, the value of time and other relevant parameters. Graphs 3.2a to 3.2d represent isoquants for particular values of *Q* that allow a NPV equal to zero. These values correspond to a 500-km line, an optimal distance for a HSR project. Any isoquant shows the level of demand required for a positive NPV for different vΔt and investment costs (including rolling stock), under alternative

[12] These figures underline the importance of the chosen *base case* in cost-benefit analysis.

[13] Cost savings in conventional modes were found to be one third of C_t+C_q in the Madrid-Seville evaluation (De Rus and Inglada 1997).

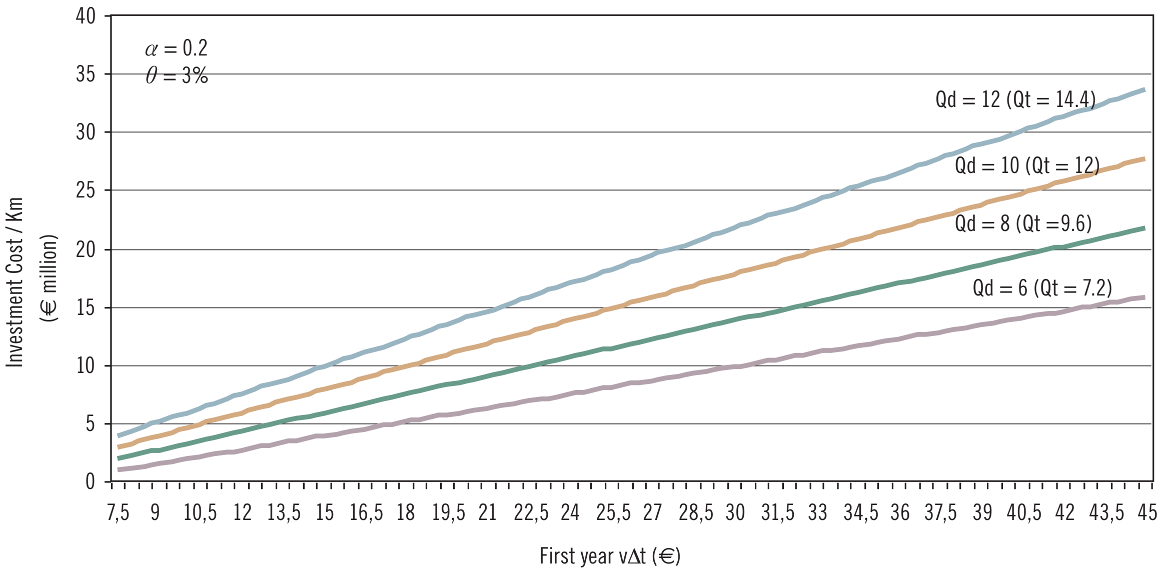
[14] See European Commission (1997).

scenarios for generated traffic and annual growth of net benefits.

The isoquants can be interpreted in different ways, but one interesting approach is to check which minimum levels of demand are required for a particular range of expected values of investment (rolling stock included) and expected total value of time savings per average passenger. The isoquants in graphs 3.2a to 3.2d show that for a 500-km line, even in the best cases of low investment costs, high annual growth of net benefits and a high proportion of generated passengers, it is difficult to find a case for a HSR investment below a first year demand of at least 6 million passengers; in terms of optimal timing, such investment should not be undertaken until traffic has grown to somewhat more than that.

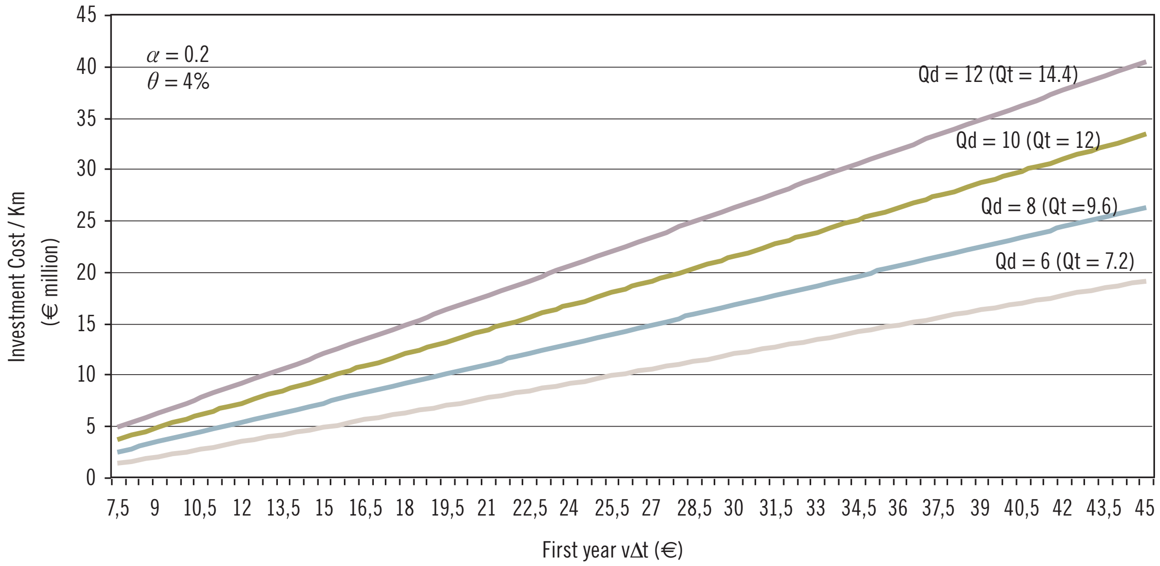
Tables 3.8 and 3.9 show a sensitivity test for first year demand thresholds leading to an NPV = 0. Investment costs per kilometer are 12, 20, 30, and 40 million euros. The average benefit per passenger is 20, 30, and 45 euros. The percentages of generated demand relative to diverted demand are 20, 30, 40, and 50. Annual growth of net benefits is 2, 3, and 4%. The social discount rates are 5 and 3% alternatively. These tables reinforce the fact that we only find a case for HSR at a total demand below 6 million passengers p.a. in circumstances where low construction costs and a low discount rate are combined with high values of time savings per passenger. With high construction costs but otherwise favorable circumstances, a total first year demand of at least 9 million trips p.a. is needed; in unfavorable circumstances, the requirement may be considerably more than that.

As we stress throughout this chapter, the estimated demand thresholds are obtained assuming that benefits come from time savings of diverted traffic from competing modes. When the provision of new rail capacity is needed, and there is significant congestion in roads and airports, additional benefits of HSR investment will reduce the required first year demand for a positive NPV. The construction of new HSR lines increases capacity for both passengers and freight, both by providing the new infrastructure itself and by releasing capacity in existing routes. In the British case study, these benefits appear to have accounted for around 10% of the benefits, which will be equivalent to adding 10% to the level of demand, so the change they bring is not dramatic. In those cases where serious bottlenecks



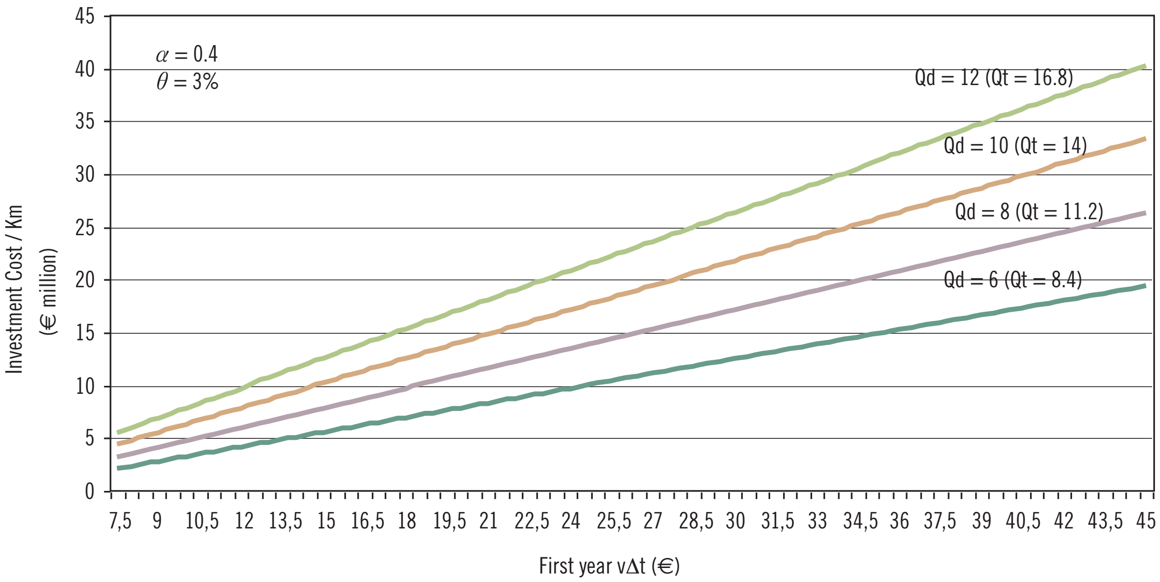
Graph 3.2a First year demand required for NPV = 0 ($\alpha = 0.2$ $\theta = 3\%$).

Note: Qd: diverted demand; Qt: total demand Qt=Qd(1+α); α: proportion of generated traffic; θ: annual growth of net benefits; v: average value of time; ∆t: average time saving per passenger.



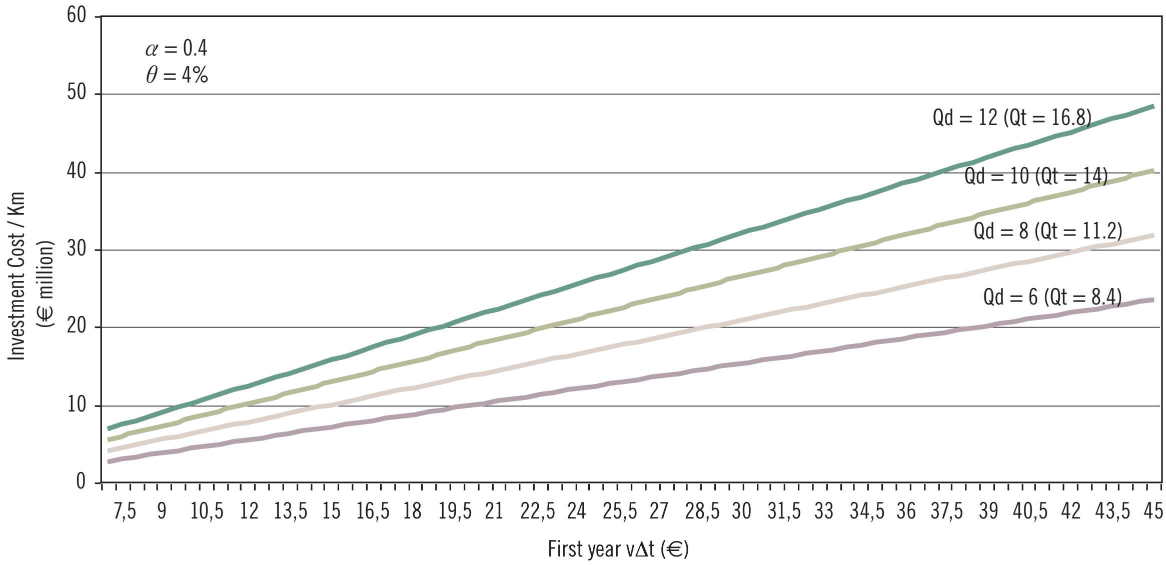
Graph 3.2b First year demand required for NPV = 0 ($\alpha = 0.2$ $\theta = 4\%$).

Note: Qd: diverted demand; Qt: total demand Qt=Qd(1+α); α: proportion of generated traffic; θ: annual growth of net benefits; v: average value of time; Δt: average time saving per passenger.



Graph 3.2c First year demand required for NPV = 0 ($\alpha = 0.4$ $\theta = 3\%$).

Note: Qd: diverted demand; Qt: total demand Qt=Qd(1+α); α: proportion of generated traffic; θ: annual growth of net benefits; v: average value of time; Δt: average time saving per passenger.



Graph 3.2d First year demand required for NPV = 0 ($\alpha = 0.4$ $\theta = 4\%$).

Note: Qd: diverted demand; Qt: total demand Qt=Qd(1+α); α: proportion of generated traffic; θ: annual growth of net benefits; v: average value of time; Δt: average time saving per passenger.

TABLE 3.8: First year demand thresholds for NPV=0
(r=5% T=40 C_t=32.5 C_q=91.5 C_c=62)

					Q_t								
					α								
		20%			30%			40%			50%		
					θ								
		2%	3%	4%	2%	3%	4%	2%	3%	4%	2%	3%	4%
I	vΔt												
12	20	14.9	12.8	10.8	14.6	12.5	10.5	14.3	12.2	10.2	14.0	11.8	9.9
12	30	10.0	8.5	7.2	9.8	8.3	7.0	9.5	8.1	6.8	9.3	7.9	6.6
12	45	6.6	5.7	4.8	6.5	5.5	4.7	6.4	5.4	4.5	6.2	5.3	4.4
20	20	23.5	20.0	16.9	23.2	19.7	16.6	22.9	19.4	16.3	22.6	19.1	15.9
20	30	15.7	13.4	11.2	15.5	13.2	11.0	15.3	12.9	10.8	15.1	12.7	10.6
20	45	10.5	8.9	7.5	10.3	8.8	7.4	10.2	8.6	7.2	10.0	8.5	7.1
30	20	34.3	29.1	24.5	33.9	28.8	24.1	33.6	28.5	23.8	33.3	28.2	23.5
30	30	22.8	19.4	16.3	22.6	19.2	16.1	22.4	19.0	15.9	22.2	18.8	15.7
30	45	15.2	12.9	10.9	15.1	12.8	10.7	15.0	12.7	10.6	14.8	12.5	10.5
40	20	45.0	38.2	32.0	44.7	37.9	31.7	44.4	37.6	31.4	44.1	37.3	31.1
40	30	30.0	25.5	21.4	29.8	25.3	21.2	29.6	25.0	20.9	29.4	24.8	20.7
40	45	20.0	17.0	14.2	19.9	16.8	14.1	19.7	16.7	14.0	19.6	16.6	13.8

Q_t: total demand (millions of passenger-trips)
α: proportion of generated traffic
θ: annual growth rate of net benefits
v: average value of time (€/hour)
Δt: average time saving per passenger (hours)
I: investment cost per kilometer (construction + NPV of rolling stock, € million)
r: interest rate
T: life of the project (years)
C_t: annual fixed maintenance and operating costs (€ million)
C_q: annual maintenance and operating cost variable with Q (€ million)
C_c: annual variable cost of the conventional mode (€ million)
C_c=1/2(C_t+C_q)

TABLE 3.9: First year demand thresholds for NPV=0
(r=3% T=40 C_t=32.5 C_q=91.5 C_c=62)

				Q_t										
				α										
				20%			30%			40%			50%	
				θ										
			2%	3%	4%	2%	3%	4%	2%	3%	4%	2%	3%	4%
I	12	vΔt	20	11.1	10.0	7.7	10.8	9.7	7.4	10.5	9.4	7.1	10.2	9.1	6.8
			30	7.4	6.7	5.1	7.2	6.4	4.9	7.0	6.2	4.7	6.8	6.0	4.5
			45	4.9	4.4	3.4	4.8	4.3	3.3	4.7	4.2	3.2	4.5	4.0	3.0
	20		20	17.2	15.0	11.8	16.9	14.7	11.5	16.5	14.4	11.2	16.2	14.1	10.9
			30	11.4	10.0	7.9	11.2	9.8	7.7	11.0	9.6	7.4	10.8	9.4	7.2
			45	7.6	6.7	5.2	7.5	6.5	5.1	7.4	6.4	5.0	7.2	6.2	4.8
	30		20	24.8	21.2	16.9	24.4	20.9	16.6	24.1	20.6	16.3	23.8	20.3	15.9
			30	16.5	14.2	11.2	16.3	13.9	11.0	16.1	13.7	10.8	15.9	13.5	10.6
			45	11.0	9.4	7.5	10.9	9.3	7.4	10.7	9.2	7.2	10.6	9.0	7.1
	40		20	32.3	27.5	22.0	32.0	27.2	21.6	31.7	26.9	21.3	31.4	26.6	21.0
			30	21.6	18.3	14.6	21.4	18.1	14.4	21.1	17.9	14.2	20.9	17.7	14.0
			45	14.4	12.2	9.8	14.2	12.1	9.6	14.1	11.9	9.5	14.0	11.8	9.3

Q_t: total demand (millions of passenger-trips)
α: proportion of generated traffic
θ: annual growth rate of net benefits
v: average value of time (€/hour)
Δt: average time saving per passenger (hours)
I: investment cost per kilometer (construction + NPV of rolling stock, € million)
r: interest rate
T: life of the project (years)
C_t: annual fixed maintenance and operating costs (€ million)
C_q: annual maintenance and operating cost variable with Q (€ million)
C_c: annual variable cost of the conventional mode (€ million)
C_c=1/2(C_t+C_q)

make it very difficult to introduce upgraded services on existing routes, the case for HSR investment is stronger. The case will also be stronger in circumstances where high speed rail provides major environmental benefits or indirect economic benefits.

3.5 CONCLUSIONS

The case for building new High Speed Rail (HSR) infrastructure depends on its capacity to generate social benefits which compensate for the construction, maintenance and operation costs. Decisions to invest in this technology have not always been based on sound economic analysis. A mix of arguments, besides time savings—strategic considerations, environmental effects, regional development, and so forth—has often been used with inadequate evidence to support them.

Whether HSR investment is socially profitable depends on the local conditions, which determine the magnitude of costs, demand levels and external benefits such as reduced congestion or pollution from other modes. Given the costs, the expected net social benefit of the investment in HSR relies heavily on the number of users and its composition (diverted and generated passengers) and the degree of congestion in the corridor affected by the investment. HSR projects require a high volume of demand with enough economic value to compensate for the high cost involved in providing capacity and maintaining the line. It is not only that the number of passengers must be large, a high willingness-to-pay for the new facility is required: many users who obtain high benefits when switching to HSR or making more journeys.

HSR investment does not only save time but also increases capacity for passengers as well as for freight, both by providing capacity itself and by releasing capacity on existing routes. In those routes characterized by serious bottlenecks, the opportunity to upgrade the existing services is a factor which may well increase the added value of HSR.

We explored under what conditions net welfare gains can be expected from new HSR projects. In this chapter, we use some simplifying assumptions with the aim of obtaining a benchmark: the minimum level of demand from which a positive social net present value could be expected when new capacity does not provide additional benefits beyond time savings from diverted and generated demand.

It appears that only under exceptional circumstances (a combination of low construction costs plus high time savings, perhaps because the existing rail infrastructure and services on competing modes are very poor) could a new HSR line be justified with a level of patronage below 6 million passengers per annum on opening; with more typical construction costs and time savings a figure more like 9 million passengers per annum is needed.

Judging from the British example, allowing for the release of capacity on existing lines may only reduce this figure by some 10%; allowing for optimal timing may increase it. Of course in a network, individual links may be justified with lower levels of demand, provided that the increase in traffic density on the network as a whole produces an equivalent additional traffic volume. Also the demand thresholds reported in this chapter assume benefits grow in the same order as GDP. Where there is both underlying growth in demand and growth in the value of time savings, it may understate benefit growth. Significant environmental or indirect economic benefits would also strengthen the case, but it appears that—when allowance is made for the increased environmental costs of trips diverting from conventional rail—net environmental benefits may be somewhat marginal, whilst indirect economic benefits are both highly variable and uncertain.

Our results suggest that, given typical rail demand volumes in Europe, investment in HSR infrastructure on a single corridor can rarely be justified on the basis of time savings and the net willingness to pay of generated traffic alone. Instead the investment could be justified by a combination of factors: the need to bypass bottleneck sections, the existence of network benefits arising from serving a variety of traffic flows with a single link, and the presence of congestion or environmental problems in competing transport modes. These are indeed features of much of the French and German high speed networks and of proposals for Britain but are less likely to be found in countries with lower population density away from the core of Europe.

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4
Measuring the Intermodal Effects of High Speed Rail

4.1 INTRODUCTION

From the point of view of the transport system as a whole, High Speed Rail (HSR) may act as a substitute or as a complement of other transport modes. It acts as a competitor when provides alternative transport services in the same point-to-point market already served by air companies, (private or public) road transport, maritime services (such as in the Channel Tunnel) or even conventional rail services. On the other hand, HSR complements other modes when it enhances intermodal transport at interchange infrastructure (airports, ports, bus stations), behaving as a feeder/receiver for/from *transfer* markets (at regional or urban levels) not covered by HSR. However although both roles become crucial when evaluating the overall economic impact of this technology, a larger part of the existing literature has generally focused on the competitive edge of HSR (Pavaux 1991).

On any given city-pair corridor, most of the relative advantage of high speed rail services is traditionally attributed to its lower travel time, which favors direct journeys over medium distances, whereas larger journeys tend to be dominated by air transport, and shorter ones are mostly carried out by road or conventional rail. When the journey involves more than one mode, the choice of HSR critically depends on its integration within the overall transport system.[1] However, as pointed out in SDG (2004), «the exact range of journeys over which high speed rail is competitive (...) clearly varies depending on assumptions about time required for station and airport access, check in, etc.» As a consequence, it may be deduced that the market advantage of HSR and, presumably, its effects on other transport modes also varies with all the components of the generalized cost for passengers (the relative price of transport, the quality and reliability of other modes, and the integration of HSR within the transport system) which are particular to specific routes.

The empirical evidence accumulated after more than 30 years of operation of high speed lines (25 years in Europe) should suffice to provide a complete analysis of the true determinant of the intermodal effects of HSR. However, apart from some seminal contributions (e.g., Nash 1991), the published experiences that have attempted to provide an integrated framework to explain the intermodal effects of HSR are relatively scarce (as compared to what might be expected), mostly due to two main reasons: firstly, operators and governments are mostly interested in the *ex-ante* research to justify these expensive schemes but seem to lose interest in the evaluation of the project once it has been constructed, and secondly, the research findings are often commercially confidential, particularly in Europe, since it is expected that national rail markets will be open to competition in the near future.

Although this gap has been filled during the last years, the recent empirical literature analyzing intermodal effects of HSR is dominated by the

[1] These are well-known results in transport demand literature involving modal choice. An extensive and specific survey of intermodal demand modelling related to high speed rail can be found in chapter 3 of COST318 (1998).

papers by López-Pita (2001a, 2001b), López-Pita and Robusté (2003, 2005) and López-Pita et al. (2006), which provide a detailed technical study of the impact of high speed rail on other modes in terms of market shares for the most relevant corridors. Janic (1993, 2003) compares the operational performance of HSR and air passenger transport across several countries, insisting on their substitute vs. complement roles. Levinson et al. (1997) analyze the San Francisco-Los Angeles corridor providing costs estimates for a potential high speed service. At the European level, the most comprehensive official document so far is the COST318 (1998) study, which discusses several case studies on the interaction between high speed and air passenger transport. Park and Ha (2006) analyze the Korean case, whereas González-Savignat (2004) is one of the few papers that specifically focuses on the competition between HSR and private transport. More recent works have modelled the relationship between HSR on one hand, and traditional or low-cost airlines on the other, as in Friebel and Niffka (2005) for Germany, Ivaldi and Vibes (2005), Crisalli et al. (2007) or Adler, Nash, and Pels (2007). Still, the most data-extensive study on this issue was carried out by the UIC (2003), analyzing the influence of low-cost air companies and long-distance coaches on the demand of passenger rail services in several European corridors. Finally, Martín and Nombela (2007) provide intermodal share estimations for Spain in the 2010-horizon.

The objective of this chapter is to contribute to this growing literature by providing a formal approach that could clarify some of the determinants that explain the intermodal effects of HSR. For that reason, our contribution is twofold. First, after this introduction, we summarize some of the most relevant empirical findings related to the intermodal effects of HSR worldwide, discuss the substitute/complement role of high speed and analyze, through examples from the existing routes, the current situation in several countries. Then, in section 4.3, we provide a theoretical model that could be viewed as a methodological approach to be used for carrying out this sort of intermodal analysis. The model proceeds as follows: in a first step, as in Ivaldi and Vibes (2005), travellers choose a transport mode and an operator to travel on a route between an origin and a destination, which is modelled as a market with differentiated services competing against each other. Second, on the supply side, we endogenize the costs of the transport operators, thus accounting for the various competitive pressures impinging on their activity, depending on the type of route they operate. Section 4.4 explains how this model could be solved and empirically implemented, the data requirements and the limitations it could face. Section 4.5 proposes a simulation exercise where operators' own-price demand elasticities as well as marginal costs and margins are evaluated. We show how this exercise can be implemented with very little data, and we suggest that, on the very specific route we consider as example (the Paris-Amsterdam line), and when compared with other competing transport modes, HSR faces the less elastic demand curve and enjoys the highest price-cost margins. Section 4.6 is finally devoted to conclusions.

4.2 INTERMODAL EFFECTS OF HSR: A SUMMARY OF EMPIRICAL FINDINGS

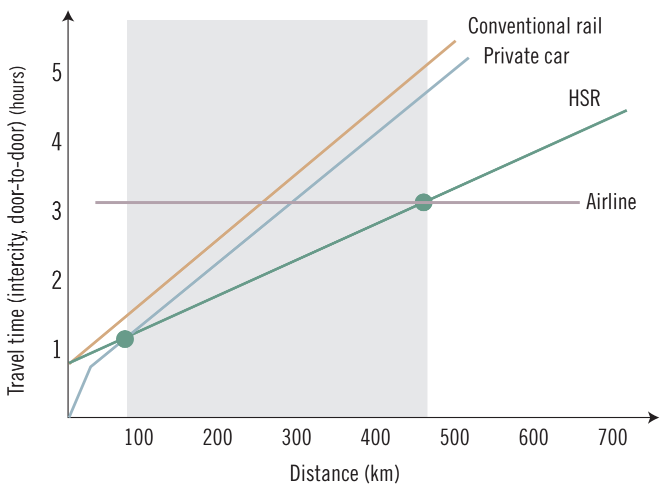
When choosing among alternative transport modes, rational passengers make their decisions by comparing the generalized cost of each mode. This cost includes not only the fare and other monetary costs, but also total travel time, and many other factors related to the perceived quality of the service (such as reliability, comfort, amenities, safety, etc.) (see Quinet and Vickermann 2004). From a broader perspective, and when the journey involves more than one mode, integration within the overall transport system may also affect the perceived quality of each mode, and thus, the modal choice. Rail terminals, for example, are often well located in terms of accessibility to city centers and densely populated areas, whereas airports tend to be on the outskirts of cities, with worse accessibility. Rail is also in a stronger position when serving large conurbations, and demand levels are sufficiently high to warrant frequent services.

4.2.1 THE COMPETITIVE ADVANTAGE OF HSR: THE EFFECT OF TRAVEL TIME

All these characteristics are particularly relevant for analyzing the intermodal effects of high speed rail services, where most existing comparisons just relate market share to speed and distance. SDG (2004) states for example that «(...) for journeys of less than about 150 km, high speed rail offers little advantage over conventional rail and may, depending on the location of stations, be less convenient for most passengers; for journeys of approximately 150-400 km, rail is faster than air travel even if there is no high speed line, and HSR will instead serve to make that advantage more robust; for journeys of more than 400 km, high speed is necessary for rail to become the fastest mode and thereby make significant mode switches realistic; and for journeys of more than about 800 km, even with dedicated high speed infrastructure available for the entire route, air travel is faster.»

However, as reckoned in several case studies (for example, Yao and Morikawa 2003), these distances are not absolute and may vary slightly across corridors and along time. In 1964, the Tokaido Express Rail (*Shinkansen*) was operated as the first high speed train in Japan. In its early stages, the *Shinkansen* system's main line was capable of speeds of up to 220 km per hour and did not offer much advantage over air transport. But in its latest specifications, the *Shinkansen* was the first high speed train to reach the speed of 591 km per hour,[2] and thus become a very attractive alternative even for shorter routes. For example, in the Tokyo-Nagoya corridor (366 km), air services have been highly reduced, as total travel time, including airport dwelling time, might be approximately 2h 30min by air, and slightly more than 1 hour by train.

In general, as represented in graph 4.1, the time-distance relationship just reflects the relative speed of each mode and the range of distances over which each one implies a lower generalized cost for the passenger. Only when the comparison refers to a standardized intercity door-to-door journey,[3] and total travel time is considered (including access and waiting time),



Graph 4.1 The modal competitive advantage of HSR

Source: Adapted from Sellnick (2006).

[2] We do not include here the (much faster) magnetic levitation technology (*maglev*), since its commercial use is still very limited.

[3] For private car, graph 4.1 was drawn assuming an average speed of 110 km per hour on an intercity highway plus 30 minutes (2x15) of urban traffic congestion. For rail (both conventional and high speed), it assumes total scheduled time plus 30 minutes of access time. In the case of air transport, total travel time was considered as 3 hours regardless of distance since flying time variations for short distances are minimal.

it can be safely said that HSR has a competitive advantage (the shaded area) only for *medium* distance journeys, in the range of 100-500 km, depending on the corridor.[4] In general, it is very difficult for air transport services to compete effectively in the short-haul transport market against other modes. In the 500 km-plus long-haul transport market, however, most air transport services can successfully compete with high speed rail.

Travel time is indeed the key factor explaining rail vs. air modal share in most existing studies that have empirically examined the intermodal effects of high speed rail. Table 4.1 summarizes some of the most recent findings showing that, in general, where the high speed train offers a journey time of three hours or less, it captures at least 60% of the combined rail and air market. Conversely, this share goes down very sharply as journey time increases beyond three hours.

In all the corridors in the table, the effect of total journey time on rail share closely follows the pattern drawn in graph 4.1, although perhaps the Brussels-London route might be expected to achieve a higher share and the Paris-Amsterdam route a lower share. The strength of air competition on the first route and the weakness of that same competition in the second one may explain these results. It is also noticeable that rail has captured virtually the entire market on the Paris-Brussels route and, in fact, there is very little air activity between these two airports.

Table 4.1 shows that rail market share is not always a linear function of absolute travel time. Other studies have focused instead in travel time differences with respect to air competitors. This approach is particularly useful for analyzing the impact of HSR over different passenger segments. In COST318 (1998) it is stated, for example, that «business travellers will hardly consider the rail alternative over medium distances if it cannot accommodate the trip in a single day when air can.» This requires a round trip journey time of less than six hours and a minimal difference in

TABLE 4.1: Travel time and rail market share on selected corridors

Corridor (km)	Year	Travel time	Rail share (*)
Tokyo-Osaka (515)	2005	2h 30min	81%
Tokyo-Okayama (643)	2005	3h 16min	57%
Tokyo-Hiroshima (814)	2005	3h 51min	47%
Tokyo-Fukuoka (1069)	2005	4h 59min	9%
Paris-London (257)	2005	2h 40min	66%
Paris-Amsterdam (514)	2004	4h 10min	45%
Brussels-London (204)	2005	2h 20min	60%
Paris-Geneva (339)	2003	3h 30min	35%
Paris-Brussels (183)	2006	1h 25min	100%

* Rail market share was calculated with respect to the combined air-rail market.

Source: Adapted from López-Pita et al. (2006).

access and waiting times. In France, where rail has become very competitive with air in many HSR corridors, the public operator SNCF officially aims at attracting around half of the business passenger market. On average, in 2002-2005, it consolidated a market share (with respect to air) of 19% in «professional trips» plus 7% in «other private trips, not leisure» (Bernard 2006).

From the point of view of airlines, they reckon that the adverse impact of HSR services is initially severe and often increases during the following 2-5 years. For example, COST318 (1998) asserts that the introduction of the AVE between Madrid and Seville (471 km) in 1992 reduced in six months the number of weekly flights from 71 to 40, and the airlines lost more than 20% of market share in one year. The Paris-Lyon south-east route (450 km) was opened in 1981 as the very first route of the TGV, and immediately had a significant intermodal impact. By 1997, once other high speed routes had been also introduced, airlines' share in domestic passenger transport markets had decreased by almost half, from 30% to 16%, especially in medium distance routes (as predicted in graph 4.1). In some longer routes the impact after three years of HSR services was also significant: in the Paris-Marseille corridor (700 km), the air transport share dropped from 45-55%

[4] Other factors, such as network configuration, congestion, etc. may affect the relative generalized costs (see De Rus, Campos, and Nombela 2003).

to 35-45%, and in the Paris-Nice route (900 km) it fell from 55-65% to figures around 50-60%.

In the longer run, it has been argued that this retrenchment by the airlines, as well as having environmental and congestion benefits at airports, will tend to reinforce the rail demand effect. Wilken (2000) points out that in France the introduction of HSR caused a sharp reduction in the number of regional flights, and there was also a movement towards smaller planes. In the two years after HSR introduction in the Paris-Lyon corridor, the change in aircraft movements between their airports was only 0.53% per year, compared to a 9.3% increase per year between Paris and Bordeaux, which at the time had no high speed services.

Another example corresponds to the Paris-London corridor, where trains are winning the competition against aircrafts. By August 2004, the HSR had captured 68% of this market (Givoni 2005), although the airlines continued to offer about 60 flights a day between Heathrow and Charles de Gaulle airports. In general, although the airlines are likely to lose from this competition, they will not exit the market if such routes are important at the network level and are used to feed traffic into the more profitable (mainly long-haul) routes. Other alternative will be the low-cost and charter flights segments, which can possibly compete more advantageously with HSR.

With respect to the effects of the introduction of HSR on road and conventional rail market shares, the comparable evidence across countries is more limited due to the lack of accurate passenger travel statistics of road users. In general, as showed by table 4.2, the impact of high speed trains on conventional services in Europe, after a decade of intermodal competition, was almost definitive: on average their share fell below 4%, partly because many of them were just suppressed on overlapping corridors, and partly because most of them were used only by low-income passengers that could not afford or were not willing to pay for a seat on HSR services. The change in the road market share was less impressive but significant in all three examples depicted in the table. As in the case of air transport, it was heavily dependent on the amount of travel time reduction, as generally predicted by several empirical studies (see González-Savignat 2004, for example).

TABLE 4.2: Modal market share before and after HSR (selected routes)

Paris-Lyon	Before HSR (1980)	After HSR (1997)
Road	29%	21%
Rail	40%	3%
HSR	0%	70%
Air	31%	6%
Madrid-Seville	**Before HSR (1991)**	**After HSR (2002)**
Road	44%	30%
Rail	16%	1%
HSR	0%	61%
Air	40%	8%
Hamburg-Frankfurt	**Before HSR (1985)**	**After HSR (2000)**
Road	57%	45%
Rail	23%	3%
HSR	0%	48%
Air	10%	4%

* Road combines bus and private car passenger transport; Rail is *conventional* rail.

Source: Adapted from Gallois (2005) and López-Pita et al. (2006).

Finally in Japan and Korea, a large part of the HSR share in many corridors was *stolen* from road transport. Yao and Morikawa (2003) suggest that the increase in speed and frequencies in HSR services during the last decade has led to a reduction of at least 10% in the number of bus travellers nationwide for distances below 500 km. Park and Ha (2006) reports a reduction of 18-25% in express bus services two years after the introduction of HSR between Seoul and the cities of Deagu and Busan. In both countries the impact of high speed trains on air travel was also relevant, but not as large as in Europe.

4.2.2 THE COMPETITIVE PRESSURE OF OTHER MODES: THE EFFECT OF PRICES

Although HSR competitive position against other modes is basically determined by travel time, it is also affected by other components of the generalized cost, which together define the attractiveness and availability of a rail service in comparison to a rival air service on a particular corridor.

In most European countries, high speed rail services are publicized not only in terms of attractive fares, but also in terms of higher reliability (even with punctuality compromises) and greater comfort (on-board amenities, distance between seats, etc.). Table 4.3 shows, for example, that the ratio of airfares over railfares for comparable tariffs over selected corridors always favored the rail, which is on average almost 50% cheaper.

The emergence of low-cost airlines in Europe during the last five years was initially seen as a serious threat to the price advantage of rail services, particularly in the leisure market. However, according to an empirical study carried out by the UIC (2003), most of the risk is limited to conventional rail services, whereas competition with HSR services is restricted to a few corridors in France and Germany. This latter result was recently confirmed by Friebel and Niffka, (2005), who also point out that most of the low-cost airlines' market share is *stolen* from conventional airlines. Furthermore, some rail companies have learned to react to this menace by launching their own *low-cost* services, with fewer on-board services and a greater focus on the price.

With respect to frequency, its increase has been long identified as one of the best strategies of railroads against alternative transport modes. In most cases, the control of infrastructure and overall traffic planning by the railways allows them (in contrast to most airlines in airports) to adapt their schedules more easily to changing demand conditions. Leboeuf (2006) says that, under no congestion conditions, high speed trains are apt to be operated like shuttles. In Japan, for example, the timetable on main lines is based on departures every 4 to 12 minutes from 6 a.m. to 11 p.m. In most European HSR corridors there are more than 25 services per day, an advantage rarely matched by air competitors due to airport capacity limits and air traffic congestion.

TABLE 4.3: Airfares vs. HSR fares on selected European corridors

Ratio: Airfare / Railfare	Business (First class)	Non-business (Second class)
Paris-Marseille	1.77	2.63
Madrid-Seville	1.29	1.81
Frankfurt-Hamburg	1.43	2.17
Rome-Milan	2.32	2.00

Source: Adapted from López-Pita and Robusté (2005) and Leboeuf (2006).

4.2.3 THE GROWING ROLE OF HSR AS A COMPLEMENT TO OTHER TRANSPORT MODES

Although this is a topic that is just emerging in the literature and, so far, has not been formally considered in detail, a final element that could determine the effects of HSR on other transport modes is the degree of intermodality it allows. As pointed out by López-Pita and Robusté (2003), the collaboration between the railways and the plane with respect to airport access goes back to the 1950s with the establishment of rail links to facilitate travel by this mode of transport to airports. But the idea of complementarity between air services and high speed trains at airports is much more recent, dating back to 1985, when the French government decided to build the Interconnection high speed line linking the TGV-South-East, TGV-Atlantic, and TGV-North lines in the Paris suburbs since it was also intended to serve Charles de Gaulle airport. This first high speed station entered commercial service in November 1994.

From the viewpoint of users, HSR and air transport services are complementary if the combination instead of a single transport mode is preferred for travelling between two cities. From the viewpoint of transport operators, HSR is a complement to air transport if it replaces short-haul feeder flights connecting into and out of long-haul flights by using feeder trains according to a compatible (balanced) timetable. Generally, the literature identifies three types of complementary networks, if commercially viable, that may exist:

1) HSR may partially replace air transport in collecting and distributing passenger flows between a hub airport and particular spokes. One

such example is Frankfurt airport, where many short-haul domestic air transport services have been replaced by equivalent HSR services (see Grimme 2006).

2) More generally, HSR may completely substitute air transport by providing feeder services between a hub and spokes, while air transport exclusively connects hub airports to each other. One example could take place is the connection between Paris and Rome by air services, which would be fed by HSR instead of short-haul air transport services (Givoni and Banister 2006).
3) Air transport services may connect hub airports with spokes while HSR provides exclusive surface connections between hub airports themselves. One example of this case is the already-mentioned HSR line connecting Paris Charles de Gaulle airport and Lyon airport, which is partially fed by air passengers.

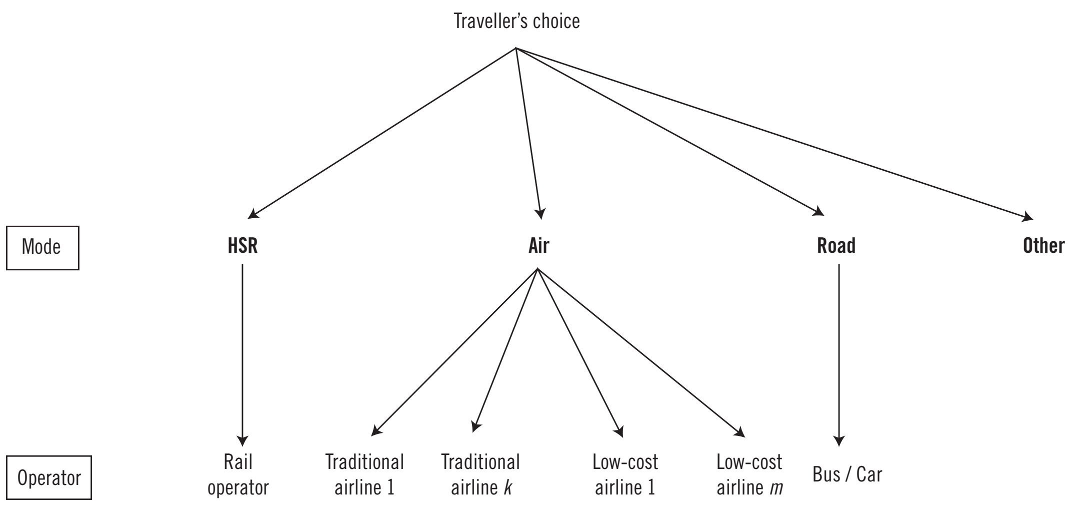
Although the figures are promising (4% of passengers at Paris-Roissy airport currently arrive or depart by means of high speed trains, according to López-Pita 2006), the arrival of high speed to some European airports has just begun to develop intermodality in the transport system. An improved connection of airports to the rail network and a better operational integration between railroads and airlines are still required around the world. For this reason, in the model developed in the next sections we will mainly focus on the role of HSR as a competing transport mode.

4.3 EXPLAINING THE INTERMODAL EFFECTS OF HSR: A THEORETICAL APPROACH

According to the empirical evidence analyzed in previous sections, the intermodal effects of HSR depend, from the point of view of passengers, on the relative generalized cost for each mode, a term which includes not only the fares, but also the travel time and other elements related to the overall quality of the service. In this section, we depart from the literature on differentiated products to propose a model that describes the passenger's modal and operator choice, the firms' price and cost decisions, and the overall equilibrium in a market where intermodal competition plays a disciplinary role on rivals.

4.3.1 TRAVELLERS' MODAL CHOICE

We develop here a model of demand for transport services that accounts for the type of transport mode as well as the type of operator offering the service. Different transport services are seen as differentiated products offered by operators competing in an oligopolistic market, which is usual-



Graph 4.2 The traveller's decision among alternative transport modes

ly a route between two cities. According to what was described in previous sections, transport services are differentiated in several dimensions composing the generalized price, which includes: (1) travel time, (2) fare, and (3) various quality variables such as the comfort and amenability, onboard services and extras, ease of interconnection, service on board, whether the service is direct or not, etc.

The chain of decisions made by a representative traveller at the moment of choosing a transport operator is presented in graph 4.2. First the individual chooses among the set of transportation modes, which includes air transportation, high speed rail, private car, or an alternative decision. Note that the alternative decision may be to travel with conventional rail or not to travel at all. In a second step, the traveller may choose a specific operator inside a transportation mode. The air transportation set includes traditional airline operators as well as low-cost airlines.

This particular decision tree, standard in transport demand literature since McFadden (1975), suits perfectly to our integrated approach to the intermodal effects of HSR transport. Depending on which route is considered, we could as well consider an additional decision node inside the airline transportation set, where travellers choose between traditional and low-cost airlines, and then choose the type of operator they want to travel with. This may be potentially relevant on routes where the share of business travellers is high, as these passengers are particularly sensitive to the quality of service offered on board. Since considering a three-step decision procedure would complicate significantly the exposition, and since its relevance is strongly dependant on the type of data available, we leave this possibility for further research.

Our theoretical analysis departs from a precise definition of the utility of the transport user. It is inspired by the literature on differentiated products and oligopolistic markets. In particular, the specification closely follows the exposition of the nested *logit* model in Berry (1994), and the intermodal competition model of Ivaldi and Vibes (2005). The key elements of the travellers' utility are the characteristics of the transport services they choose as well as the travellers' preferences. All characteristics and preferences are assumed to be observed by the participants in the market but are not necessarily observed by an external analyst. The researcher only observes the market outcomes of prices and quantities sold by each firm, as well as other service characteristics.

We group the transport decisions j into $G + 1$ exhaustive and mutually exclusive sets, where $g = 0, 1, \dots, G$. Thus a decision consists in travelling from origin to destination for instance with a particular low-cost carrier, while a transport set would be for instance air transportation. The outside decision, $j = 0$, is assumed to be the only member of group 0. The utility of traveller i for transport service j depends on the characteristics of the service and the traveller's. We can denote this utility as

$$U(x_j,\ \xi_j,\ p_j,\ \zeta_{ig},\ \varepsilon_{ij})\ . \tag{4.1}$$

The variables in the utility function are as follows: x_j and ξ_j denote, respectively, observed and unobserved (by the researcher) service characteristics. Observed characteristics include those described above (i.e., travel time and quality variables); unobserved ones are those that may be specific to one particular operator, and that cannot be systematically measured or observed; p_j is the vector of prices; ζ_{ig} and ε_{ij} are random variables reflecting individual i's deviation from the mean valuation; the term ζ_{ig} is traveller's i utility, common to all services belonging to group g, whereas the term ε_{ij} is traveller's i's utility, specific to transport service j.

For ease in exposition, we assume that the utility in (4.1) can be rewritten linearly as

$$u_{ij} = \delta_j + \zeta_{ig} + (1 - \sigma)\varepsilon_{ij}\ , \tag{4.2}$$

where the first term, δ_j, is the mean valuation for service j, common to all travellers. It depends on the price of service j, p_j, its observed characteristics, x_j, and its unobserved characteristics, ξ_j:

$$\delta_j = x_j\beta - \alpha p_j + \xi_j\ . \tag{4.3}$$

Note that α and β are parameters to be estimated. A third parameter to estimate, $0 \leq \sigma \leq 1$, deserves additional explanations. It measures the correlation of the travellers' utility across transport services belonging to the same group. If $\sigma = 1$, there is perfect correlation of preferences for services belonging to the same group. In this case, products are perceived as perfect substitutes. As σ decreases, the correlation of preferences for services within the same group decreases. If $\sigma = 0$, there is no correlation of preferences; travellers are equally likely to switch to services in a different group as to services in the same group in response to a price increase. Thus this framework allows modelling correlation between groups of similar services in a simple way.

Each traveller chooses the service j that maximizes his/her utility. In particular, a traveller chooses a travel alternative j from group g only if $u_{ij} > u_{ij'}$, $\forall\ j' = j$. If we assume that the expression $\zeta_{ig} + (1 - \sigma)\varepsilon_{ij}$ follows an extreme value distribution, we can write the market share of service j inside the total group g as

$$s_{j/g} = \exp\left(\delta_j / (1 - \sigma)\right) / D_g \ , \qquad (4.4)$$

where D_g can be written as

$$D_g = \sum_{j \in G_g} \exp\left(\delta_j / (1 - \sigma)\right) \ , \qquad (4.5)$$

Similarly the probability of choosing one of the group g services is

$$s_g = \frac{D_g^{1-\sigma}}{\sum_g D_g^{1-\sigma}} \ . \qquad (4.6)$$

Hence we can write the absolute market share of service j as

$$s_j = s_{j/g} s_g = \frac{\exp\left(\delta_j / (1 - \sigma)\right)}{D_g^{\sigma} \sum_g D_g^{1-\sigma}} \ . \qquad (4.7)$$

Assuming that the mean utility of the outside travel decision is 0, i.e., $\delta_0 = 0$, and that this service is the only member of group zero, i.e., $D_0 = 1$, the market share of the outside travel service is then

$$s_0 = \frac{1}{\sum_g D_g^{1-\sigma}} \ . \qquad (4.8)$$

To make this model amenable to the data, a practical procedure suggested by Berry (1994) proceeds as follows: taking the logs of the market shares s_j and s_0 as well as the group share s_g in (4.7), (4.8), and (4.6) respectively, and substituting, we obtain the following expression that can be directly estimated:

$$\ln(s_j) - \ln(s_0) = x_j\beta - \alpha p_j + \sigma \ln s_{j/g} + \zeta_j \ . \qquad (4.9)$$

An estimation of α, β, and σ can be obtained using a simple linear regression of the difference in log market shares on services characteristics and the log of the within group share. Note that shares can be obtained as $s_j = q_j / q$, and $s_{j/g} = q_j / q_g$, where q_j is the demand of service j in the market, while q denotes the total size of the market, and q_g is the size of the segment g. Note also that demand can be measured directly as the number of travellers, or the number of travellers-kilometers carried. Finally note that the within group share, $s_{j/g}$ is potentially endogenous, suggesting the need for additional exogenous variables that are correlated with the group share.

4.3.2 TRANSPORT OPERATORS' PROFITS

Let us now turn to the supply side. Since we have already seen how travellers make their optimal travel decision, we need to define how transport operators behave, that is, how they maximize their profit to determine their optimal pricing rule. We will thus obtain a simple economic rule that ties transport fares to operators' marginal costs, depending on demand elasticity.

Before entering into these details, we need to introduce the operators' cost function. We will assume that transport operators may face different incentives to reduce operating costs, depending on the degree of competition they face. Consider for instance a route that is operated by a HSR operator and several airlines (traditional and/or low-cost). The HSR operator competes against group *g* operators, while an airline of group *g* competes at the same time against the HSR operator as well as the other airlines. We therefore consider that a transport operator is given higher incentives to reduce operating costs and improve its technology if more operators of the same type (group) are present on the same route. This can be accounted for through the structure of the cost function.

4.3.2.1 The primal cost function

To produce a volume of service q_j, firm *j* requires quantities of labor, l_j, materials, m_j, and capital, k_j. Denote as w_l, w_m, and w_k, the price of labor, materials and capital, respectively. Also denote by c_j the observed operating cost of firm *j*. An important feature of our model is that the actual operating cost may differ from the minimum operating cost. Inefficiency may prevent operators from reaching the required output level q_j at the minimum cost, and this may result in upward distorted costs. Firms can also undertake cost reducing activities to counterbalance their inefficiency. They can engage in process research and development; managers may spend time and effort in improving the location of inputs within the network. They can as well attempt to find cheaper suppliers, bargain better procurement contracts, subcontract non-essential activities, monitor employees, solve potential conflicts, etc. Whatever these cost reducing activities may be, we will refer to them as effort. Denote by θ_j and e_j firm *j*'s inefficiency and effort levels, respectively. Note that these two variables are unobservable.

Each operator faces a long-run cost function, conditional on inefficiency and effort, of the form:

$$C_j\,(q_j,\ w_j,\ z_j \mid e_j,\ \theta_j,\ \omega)\ , \qquad (4.10)$$

where z_j is a vector of service characteristics that affects operating costs, and ω is a vector of parameters to be estimated. Note that z_j may include the vector x_j, i.e., the service characteristics affecting travellers' demand may also affect operating costs. In transport economics, the usual variables used by econometricians to capture the observable heterogeneity across operators' costs include variables such as the size of the operator's network, and the average stage length. In general, which variables will enter vectors x_j and z_j depends on data availability. Note also that while inefficiency θ_j is exogenous, cost reducing effort e_j is a choice variable for firm *j*, and will therefore depend on the competitive pressures impinging on the activity of the firm.

We describe now the firms' pricing and effort decisions. Before entering into the analysis, it is worth reminding that the pricing structure itself is independent of the nature of the competitive pressures impinging on the activity of the firm.[5] Thus although prices and effort are determined simultaneously, the firms' decisions will be presented separately, for ease of exposition.

4.3.2.2 Competitive pressure and cost reduction

This section focuses on the construction of the structural cost function. We propose to account for the competitive pressures impinging on the operators' incentives to reduce costs through the cost function (4.10) that is conditional on inefficiency θ_j and the effort level e_j. Deriving the equilibrium level of effort and plugging it back into the conditional cost function allows us to derive a structural cost function that can be estimated. The aim of this approach is twofold. First, we can test whether the different transport operators are involved in different cost reduction activities, depending on which transport mode they operate, as well as the degree of competitive pressure inside the particular market (route) they operate. Second, accounting for these changes in incen-

[5] The way we incorporate the technical inefficiency and effort parameters allows the incentive-pricing dichotomy principle to hold (Laffont and Tirole 1993). This means that the same pricing formula applies whether we assume strong or weak competitive pressures.

tives through the cost structure enables us to reduce the source of misspecification, and avoid biases in the estimation of the technological parameters.

As mentioned before, a firm can exert effort e_j to reduce its operating cost c_j. The cost reduction activity induces an internal cost $\psi(e_j \mid \mu)$ where μ is a parameter to be estimated. Taking into consideration the operating cost reduction and the internal cost of effort, the operator sets the optimal effort level e_j that maximizes its profit. Firm j's profit is the difference between revenue $R_j = p_j q_j(\cdot)$ and total cost $c_j(e_j,.) + \psi(e_j \mid \mu)$:

$$\begin{aligned}\pi_j (x_j, p_j, w_j, z_j, \Theta) &= p_j q_j (x_j, p_j, \xi_j, d) - \\ &- c_j (q_j, w_j, z_j \mid e_j, \theta_j, \omega) - \psi(e_j \mid \mu) \quad ,\end{aligned} \tag{4.11}$$

where $\Theta = (d, \omega, \mu)$ is a vector of parameters to be estimated, and $z = (\xi_j, \theta_j, e_j)$ is a vector of unobservable (by the econometrician) variables to be evaluated.

Each operator j determines the optimal effort level e_j that maximizes its profit in (4.11). The first order condition is:

$$-\frac{\partial c_j (q_j, w_j, z_j \mid e_j, \theta_j, \omega)}{\partial e} = \psi'(e_j \mid \mu) \quad , \tag{4.12}$$

which implies that the optimal effort level is attained by equating the marginal cost reduction and the marginal disutility of effort.

We now consider two competitive situations. First a situation M which refers to a situation where an operator is a monopolist inside its group g on a specific route. Second a situation C which refers to a framework where more than one firm of the same mode operate a given market. We expect firms to provide higher effort levels under competitive pressure, i.e., $e_j^C > e_j^M$. Note that, to be able to derive and identify two different closed forms for the cost function, we need to normalize $e_j^M = 0$, and let e_j^C be determined by condition (4.12).[6]

Given these two effort levels, we can rewrite the primal cost expression in (4.10) as

$$c_j^R (q_j, w_j, z_j \mid e_j^R, \theta_j, \omega) \quad , \tag{4.13}$$

where R denotes the type of competitive regime, that can be either M or C. Note that equation (4.13) entails two different cost structures that are conditional on the specific market studied.

4.3.2.3 Optimal pricing

Each transport operator in the market is supposed to be a price setter. Each operator j determines the optimal price p_j; that maximizes the profit function:

$$\begin{aligned}\pi_j (x_j, p_j, w_j, z_j, \Theta) &= p_j q_j (x_j, p_j, \xi_j, d) - \\ &- c_j^R (q_j, w_j, z_j \mid e_j^R, \theta_j, \omega) - \psi(e_j^R \mid \mu) \quad ,\end{aligned} \tag{4.14}$$

where the associated first-order condition is

$$p_j = MC_j^R - \frac{s_j (x_j, p_j, \xi_j, d)}{\partial s_j (x_j, p_j, \xi_j, d) \,/\, \partial p_j} \quad , \tag{4.15}$$

where $MC_j^R = \partial c_j^R (q_j, w_j, z_j \mid e_j^R, \theta_j, \omega) \,/\, \partial q_j$ is the marginal cost conditional on the type of competitive regime R.

Note that, from section 4.3.1, $\partial s_j(\cdot)/\partial p_j = -\alpha \partial s_j(\cdot)/\partial \delta_j$, so the first-order condition (4.15) can be rewritten as depending on $\partial s_j(\cdot)/\partial \delta_j$. Differentiating s_j in equation (4.7), we obtain

$$\partial s_j(\cdot)/\partial \delta_j = \frac{1}{1-\sigma} s_j \left[1 - \sigma s_{j/g} - (1-\sigma) s_j\right] . \tag{4.16}$$

Hence, the pricing equation (4.15) is reinterpreted as

$$p_j = MC_j^R + \frac{1-\sigma}{\alpha\left(1 - \sigma s_{j/g} - (1-\sigma) s_j\right)} . \tag{4.17}$$

[6] This assumption is justifiable given that what matters in our analysis is the difference $e_j^C - e_j^M$. Note that we do not force e_j^M to be positive when estimating it.

Interestingly, the margin set by the operator depends on the correlation σ of the travellers' utility across transport services belonging to the same transport group g. As emphasized before, if $\sigma = 0$, there is no correlation of preferences and travellers are equally likely to switch to products in a different group as to products in the same group in response to a price increase. To set prices, the operators care about the market share s_j, but do not care about the market share within group $s_{j/g}$.

As σ increases, the market share within group becomes more important. When $\sigma = 1$, operators face perfect correlation of preferences for services belonging to the same group, i.e., different transport services are perceived as perfect substitutes. In this case, prices are set equal marginal costs. Hence, altogether, prices, market shares, and market shares within groups allow identifying σ. Note that, from equation (4.17), the own-price elasticity of service j demand can be computed as

$$\eta_j = \alpha p_j \left(s_j - \frac{1}{1-\sigma} + \frac{\sigma}{1-\sigma} s_{j/g} \right), \quad (4.18)$$

and, correspondingly, the cross price elasticities are finally given by:

$$\eta_{j,k} = \frac{\partial q_j}{\partial p_k} \frac{p_k}{q_j} = \alpha p_k s_k , \qquad j \neq k, \quad j \in g, \quad k \notin g , \quad (4.19)$$

$$\eta_{j,k} = \frac{\partial q_j}{\partial p_k} \frac{p_k}{q_j} = \alpha p_k s_k \left(\frac{\sigma}{1-\sigma} \frac{s_{k/g}}{s_k} + 1 \right), \qquad j \neq k, \quad j, k \in g . \quad (4.20)$$

4.4 IMPLEMENTING THE MODEL: A METHOD TO MEASURE INTERMODAL EFFECTS

We propose now an empirical application of our model. We first consider a Cobb-Douglas technology for our cost function. Once the structural cost form is obtained, our model is ready to be estimated. We then comment on the estimation procedure. We suggest that the three demands, pricing, and cost equations should considered altogether, and we propose an additional discussion on the information that is required to identify the model. Finally, we comment on the data that are needed for the analysis.

4.4.1 COBB-DOUGLAS TECHNOLOGY

We assume a Cobb-Douglas specification for the cost function presented in (4.13). This specification retains the main properties desirable for a cost function, while remaining tractable. Alternative more flexible specifications, such as the *translog* function, lead to cumbersome computations of the first order conditions when effort is unobservable.[7] The cost function is then specified as:

$$c_j = \omega_0 \, w_{lj}^{\omega_l} \, w_{mj}^{\omega_m} \, w_{kj}^{\omega_k} \, q_j^{\omega_q} \, z_j^{\omega_z} \exp[\, \beta_L (\theta_j - e_j) + \delta_j \,] , \quad (4.21)$$

where δ_j is an error term. We impose homogeneity of degree one in input prices, i.e., $\omega_l + \omega_m + \omega_k = 1$. The reader should remember that θ_j and e_j are both unobservable. The inefficiency θ_j is characterized by a density function $f(\theta)$ defined over an interval $[\theta_L, +\infty]$, where θ_L denotes the most efficient transport operator. Second, the effort e_j is defined as follows. It has the following convex cost of effort function, with $\psi(0) = 0$, $\psi'(e_j) > 0$, and $\psi''(e_j) > 0$:

$$\psi(e_j) = \exp(\mu e_j) - 1, \quad \mu > 0 \ . \quad (4.22)$$

[7] In particular, in order to solve for equation (4.12), plug it into equation (4.10), and estimate equation (4.13) applying parametric techniques, we need a Cobb-Douglas specification.

Using the functional forms of operating costs (4.21), the cost of effort (4.22), and the first order condition for effort (4.12), we can express the effort level for regime *C*. The first-order condition that determines the effort level e^C can now be written as:

$$c_j = \mu \exp(\mu e_j) \quad . \tag{4.23}$$

Substituting (4.21) in (4.23), we can solve for e^C as:

$$e_j^C = \frac{1}{1+\mu}(\omega_0 + \omega_q \ln q_j + \omega_l \ln w_{l_j} + \omega_m \ln w_{m_j} + \omega_k \ln w_{k_j} + \omega_z \ln z_j + \theta_j - \ln\mu + \delta_j) \ , \tag{4.24}$$

while $e_j^M = 0$.

As suggested by the new theory of regulation, the effort level of a firm increases with θ_j, i.e., a more inefficient operator optimally exerts more effort than a less inefficient operator, $\partial^2 c/\partial\theta_j \partial e_j < 0$. Moreover operators provide less effort when effort is more costly, i.e., when the cost reducing technology parameter μ is larger. Substituting back e_j^C and e_j^M into (4.21) allows us to obtain the final forms to be estimated $c^C(\cdot)$ and $c^M(\cdot)$. We get:

$$\ln c_j^C = c_0 + \omega_l' \ln w_{l_j} + \omega_m' \ln w_{m_j} + \omega_k' \ln w_{k_j} + \omega_q' \ln q_j + \omega_z' \ln z_j + \gamma\theta_j + \delta_j' \ , \tag{4.25}$$

and

$$\ln c_j^M = \ln\omega_0 + \omega_l \ln w_{l_j} + \omega_m \ln w_{m_j} + \omega_k \ln w_{k_j} + \omega_q \ln q_j + \omega_z \ln z_j + \theta_j + \delta_j \ , \tag{4.26}$$

where $\gamma = \mu/1 + \mu$, $c_0 = \omega_0 + (1/1 + \mu)(\ln\mu - \omega_0)$, $\omega' = \gamma\omega$, and $\delta' = \gamma\delta$.

It is interesting to note that $\lim_{\mu\to\infty} \omega' = \omega$, suggesting that, as the cost of effort grows, the effort level falls, and expression (4.25) converges to (4.26). This implies that if effort is not properly identified, the estimates of the cost elasticities are biased. The cost function to be estimated is then:

$$\begin{aligned}\ln c_j = {} & \upsilon_j^C(c_0 + \omega_l' \ln w_{l_j} + \omega_m' \ln w_{m_j} + \omega_k' \ln w_{k_j} + \\ & + \omega_q' \ln q + \omega_z' \ln z_j + \gamma\theta_j + \delta_j') + \\ & + \upsilon_j^M(\ln\omega_0 + \omega_l \ln w_{l_j} + \omega_m \ln w_{m_j} + \omega_k \ln w_{k_j} + \\ & + \omega_q \ln q + \omega_z' \ln z_j + \theta_j + \delta_j) \ ,\end{aligned} \tag{4.27}$$

where υ_j^C takes value 1 if the competitive regime is of *C* type, and 0 otherwise, while υ_j^M takes value 1 if the competitive regime is of *M* type and 0 otherwise. In the course of the estimation, several vectors υ_j^C and υ_j^M will be assumed, depending on which market (route) is considered, and therefore which competitive regime affects the cost reducing activity of competitors. From equation (4.27), one obtains immediately the marginal costs MC_j^R in equation (4.17).

4.4.2 ESTIMATION

The system to be estimated is made of the demand equation (4.9), the pricing equation (4.17), and the cost equation (4.27). The demand parameters to be estimated are α, β, and σ; those from the cost equation are ω and μ. The observed variables are demand q_j, fares p_j, service characteristics x_j affecting the mean valuation, costs c_j, input prices w_j, and service characteristics z_j affecting costs. The econometric error terms are the parameters ξ_j, θ_j, and δ_j. Note that θ_j is at the same time an error term and an inefficiency parameter to be estimated.

Since prices p_j and demand q_j are potentially endogenous, the system needs to be estimated with instrumental variables techniques. The cost function (4.27) includes a non-observable parameter, θ_j, which is, from the viewpoint of the econometrician, an unobservable random variable in the same sense as δ_j and ξ_j. It plays a central role in the analysis since it is at the same time the parameter measuring operators' inefficiency and the source of heterogeneity across them. We assume that θ_j is characterized by a Half-Normal density function $f(\theta)$ which needs to be estimated. The main advantage of such framework is its ease of exposition, which is important for us, since, on the cost side, we are more concerned with the discussion around the cost reducing activity of the operators than with exogenous inefficiency. Note that, when estimating this cost-function, one needs to compute the integral of the joint density function of θ_j and δ_j over $[0, +\infty]$.[8] Finally, note that the system is identified and all parameters can be recovered, given the homogeneity of degree 1 in input prices.

4.4.3 THE REQUIRED DATA

We consider that transport operators may enter and compete freely on any route of their choice. Their pricing policies and cost reducing effort may change from one route to another, depending on the competitive environment they face, as well as other key variables as discussed in the previous sections. As a result, the degree of competition between different transport mode, or inside a specific transport mode may vary from one route to another.

The relevant observation to conduct the empirical analysis should therefore be at the route level. Ideally, the econometrician should gather observations on several routes where both HSR and airlines are present. The dataset may be a cross-section or a panel. In case of a panel dataset, the time unit should be the maximum period during which transport fares proposed by all operators competing on the same route, demand, and number of competitors are constant, i.e., the equilibrium is unchanged.

As specified above, the minimum information required to conduct the empirical analysis entails observing on each route, and for each operator, fares, demand, marginal costs, the time travel, and at least one variable on the quality of the service. As mentioned in section 4.1, these variables are usually difficult to obtain. While prices for all operators can nowadays be observed on a daily basis without much problem, difficulties start at the moment of obtaining information on demand. The econometrician may therefore have to get the data from data directly from the operators, but making all the data coincide (same route, same time period) is currently an almost insuperable task.[9]

4.5 SIMULATION

The methodology proposed in this chapter serves as an integrated approach that allows a full analysis of the intermodal effects of HSR. To complete it, we propose in this section a simple simulation exercise on a specific city-pair route, i.e., Paris-Amsterdam (514 kilometers) in order to test the results of our economic model.[10] We focus on the pricing, own-price elasticity, and cross-price elasticities expressions presented in equations (4.17)-(4.20) respectively.

In spite of lacking detailed data on costs and prices, this route is appropriate to our test since various transport operators of different modes compete over the distance. These operators are *Thalys* (high speed rail), *Vueling* (low-cost airline), *Air France* and other companies (traditional airlines), *Eurolines* (bus), and various conventional rail operators. (SNCF in France, SNCB in Belgium and NS in the Netherlands). We therefore define a group g_1 of airlines which contains two services j_1 and j_2 provided by low-cost and traditional operators. Likewise, we define a second group g_2 of rail services which contains two services j_3 and j_4 of HSR and conventional rail. The bus operator is finally dropped since we only have aggregate information at the road level which does not allow us to disentangle private vehicles from bus transportation activities.

8 For more details on these issues, the reader should refer to Kumbhakar and Lovell (2000).

9 Several papers have attempted to overcome these limitations by using calibrations and simulation procedures (as in Ivaldi and Vibes 2005) or by using aggregated models completed by demand predictions based on gravity techniques (such as Martín and Nombela 2007) or surveys (as in De Rus and Román 2006).

10 *Full* intermodal competition (among all the modes depicted in graph 4.2) is still rare, as pointed out by López-Pita et al. (2006). In most domestic routes within Europe, HSR have completely replaced conventional trains, and low-cost competition only exists on selected international destinations (such as Paris-Amsterdam).

We have gathered information on prices (average fares in off-peak season for a one-way seat) and modal market shares in the Paris-Amsterdam route for 2005 for both airline and rail groups.[11] The data enable us to evaluate prices, as well as market shares s_j and group market shares $s_{j/g}$ in equations (4.17)-(4.20). We however have no information on marginal costs MC_j, the demand elasticity parameter α, or the parameter σ that illustrates the correlation of preferences inside a transport mode. We need to simulate values for both parameters α and σ. Once this is done, we are able to provide estimates of marginal costs MC_j, own price elasticities η_j, cross price elasticities $\eta_{j/g}$ and price-marginal costs margins $(p_j - MC_j)/p_j$ for each of the four services j defined above.

We consider that σ takes values between 0.1 and 1. We can check ex-post which values of σ are more relevant in our context. Likewise, we need values of α that stick as much as possible to the reality. We use two sources of information: First, Ivaldi and Vibes (2005) suggest that, on the Cologne-Berlin route, α may be close to 0.02 for business passengers and 0.032 for leisure travellers, respectively. Although these values may change from one route to another, we consider them appropriate for our study in the sense that we test a wider range of possibilities, and inappropriate values will be rejected by our model and our data, as will be shown in more detail below. We therefore consider values between 0.02 and 0.04. As a second source, we can also verify ex-post which of these values are relevant using estimates of demand elasticity η_j provided by previous studies on transportation demand.[12]

The first set of results is presented in table 4.4. Using the model developed in previous sections, we compute values of own-price demand elasticities, marginal costs, and price-cost margins for each service j, depending on the values of α and σ. A higher α implies a more elastic demand with respect to the own price. Likewise, a higher σ entails a more elastic demand. These results are coherent with the economic intuition: In particular, as σ increases, the degree of substitution between two transport services of the same group increases, and a price increase of one of these services increases the willingness of travellers to switch to the other service of the same group. Second, marginal costs increase and margins decrease with α and σ. Again, this result goes in line with the theory: Margins decrease if demand is more elastic or if competing transport alternatives become more homogenous. This provides a much general framework to analyse the impact of intermodal competition when HSR is involved.

It can be seen that no information is provided for HSR when $\alpha < 0.3$. The reason is that we obtain negative marginal costs for these values of α, suggesting that, on this particular route, values of $\alpha \geq 0.3$ are certainly more relevant to describe the intermodal competition between airlines and HSR. A value of α close to 0.4 is probably the most indicated. For this reason, we present a full range of σ between 0.1 and 1 in this case only. Note that, in this case, demand elasticities for airlines are quite high, and the correlation parameter σ should be equal to, or lower than 0.5 in order to obtain elasticity values that remain close to reality (see footnote 11). This in turn suggests that low-cost and traditional air services on one hand, and high speed and conventional rail services on the other hand are far from being considered as homogenous services by the travellers.

Several additional comments are worth emphasizing. Focusing now only on the airlines group, our results suggest that low-cost airlines enjoy in general price margins (marginal cost, respectively) that are at least 50% higher (lower, respectively) than the ones of traditional airlines. This is not a surprising result since the literature on

[11] The available data are as follows: low-cost airline (*Vueling*): price €50, $s_j = 0.3$, and $s_{j/g} = 0.47$. Traditional airlines (average values): price €90, $s_j = 0.34$, and $s_{j/g} = 0.53$. High speed rail (*Thalys*): price €44, $s_j = 0.3$, and $s_{j/g} = 0.97$. Conventional rail (average values for an international travel combining three national operators): price €85, $s_j = 0.01$, and $s_{j/g} = 0.03$. Note that the market shares suggest that all services are almost equally important in the market.

[12] See, for example, Goodwin (1992) or Oum, Waters, and Yong. (1992).

TABLE 4.4: Intermodal competition effects: own-price elasticities, marginal costs, and price margin simulations

		AIRLINES						RAILWAYS					
		Low-cost			Traditional			HSR			Conventional		
α	σ	η	MC	Margin	η	MC	Margin	η	MC	Margin	η	MC	Margin
0.02	0.6	–1.49	16.5	0.67	–2.45	53.4	0.41				–4.15	64.5	0.24
	0.7	–1.93	24.2	0.52	–3.16	61.5	0.32				–5.52	69.6	0.18
	0.8	–2.82	32.3	0.35	–4.57	70.3	0.22				–8.26	74.7	0.12
	0.9	–5.47	40.8	0.18	–8.80	79.7	0.11				–16.5	79.8	0.06
	1.0	—	50.0	0.00	—	90.0	0.00				—	85.0	0.00
0.03	0.6	–2.24	27.7	0.44	–3.68	65.6	0.27	–0.98	—	—	–6.23	71.3	0.16
	0.7	–2.90	32.8	0.34	–4.74	71.0	0.21	–1.02	1.00	0.97	–8.28	74.7	0.12
	0.8	–4.23	38.2	0.24	–6.86	76.9	0.14	–1.09	3.79	0.91	–12.39	78.1	0.08
	0.9	–8.20	43.9	0.12	–13.2	83.2	0.07	–1.30	10.3	0.76	–24.7	81.5	0.04
	1.0	—	50.0	0.00	—	90.0	0.00	—	44.0	0.00	—	85.0	0.00
0.04	0.1	–1.51	17.0	0.65	–2.56	54.8	0.39	–1.23	8.46	0.80	–3.73	62.2	0.26
	0.2	–1.66	19.9	0.60	–2.79	57.8	0.35	–1.24	8.69	0.80	–4.19	64.7	0.23
	0.3	–1.85	23.0	0.53	–3.10	60.9	0.32	–1.25	8.97	0.79	–4.77	67.2	0.21
	0.4	–2.10	26.3	0.47	–3.50	64.3	0.28	–1.26	9.35	0.78	–5.56	69.7	0.18
	0.5	–2.46	29.6	0.40	–4.06	67.8	0.24	–1.28	9.86	0.77	–6.66	72.2	0.15
	0.6	–2.99	33.3	0.33	–4.91	71.7	0.20	–1.31	10.6	0.76	–8.30	74.8	0.12
	0.7	–3.87	37.1	0.26	–6.32	75.8	0.16	–1.36	11.7	0.73	–11.0	77.3	0.09
	0.8	–5.64	41.1	0.18	–9.14	80.1	0.11	–1.46	13.8	0.68	–16.5	79.8	0.06
	0.9	–10.9	45.4	0.09	–17.6	84.9	0.05	–1.74	18.7	0.57	–32.9	82.4	0.03
	1.0	—	50.0	0.00	—	90.0	0.00	—	44.0	0.00	—	85.0	0.00

Note: The parameter α is related to demand elasticity, as in equation (4.3); σ illustrates the correlation of preferences inside a transport mode. η represents the estimated cross price elasticities. Marginal costs (*MC*) are given in Euros. Prices and market shares correspond to those in footnote 11.

airlines has shed light on this type of discrepancies between low-cost and traditional airlines. Second, and this is probably the most interesting result, a comparison of airlines and high speed rail suggests a clear advantage of the HSR in terms of demand elasticities and margins. Note indeed that the HSR demand elasticity is closer to one than the one of low-cost or traditional airlines, suggesting that passengers of this particular mode are less sensitive to price fluctuations than the ones travelling on airlines. Note moreover that HSR enjoys very high margins. Altogether, these two results may suggest that HSR has room for the reimbursement of the costs of infrastructure, although this result requires a wider analysis across different routes. Finally note that the results on conventional rail suggest rather low margins and high demand elasticities. These last results should, however, be considered with caution since the price for conventional services we use in the simulation is unrealistically high.[13]

[13] Recall that, after the introduction of *Thalys* TGV in the Paris-Amsterdam route, conventional train services on this route were dropped. For simulation purposes, we built a Paris-Amsterdam service by adding three different national services (Paris-Belgium border-Brussels-Dutch border-Amsterdam), which obviously results in a higher price.

TABLE 4.5: Simulation: cross-price elasticities ($\alpha = 0.04$)

σ	Low-cost airlines-HSR	
	$\eta_{LC/HSR}$	$\eta_{HSR/LC}$
	0.528	0.600
	Traditional airlines-HSR	
	$\eta_{T/HSR}$	$\eta_{HSR/T}$
	0.528	1.224
	Low-cost-Traditional airlines	
	$\eta_{LC/T}$	$\eta_{T/LC}$
0.1	1.436	0.704
0.2	1.701	0.835
0.3	2.041	1.002
0.4	2.496	1.226
0.5	3.132	1.540
0.6	4.086	2.010
0.7	5.676	2.793
0.8	8.856	4.360
0.9	18.39	9.060
1	—	—

Finally table 4.5 presents estimates of cross-price demand elasticities for low-cost and traditional airlines, as well as HSR, when $\alpha = 0.04$. Again, we are confident that σ should be close to 0.5 or lower. The results suggest that the most important price effects on demand are those of the traditional airlines on the demand of HSR ($\eta_{HSR/T} = 1.224$), and those of the traditional airlines on the demand of low-cost airlines ($\eta_{LC/T}$ between 2 and 3 most probably). On the other hand, a change of the price of HSR seems to have a limited effect on the demand of low-cost and traditional airlines. Hence it seems that the most important substitution effects are those realized by passengers usually travelling with traditional air companies. These travellers are more sensitive to a change in the price of the service of these companies. Passengers travelling by HSR and low-cost airlines are less sensitive to change in prices of their usual transport mode. These results are in line with our estimates of own-price demand elasticities presented in the previous table.

Altogether these results suggest that our economic model is quite relevant to describe the strategic interaction between transport operators of the same or different modes. Note that we have not integrated the cost side of our analysis in our simulation exercise. To test for the competition effect between several operators of the same mode on cost reduction, we would need to observe at least two different routes (or the same route in two different points in time) with two different competitive structures. This was not possible in this study and should be accounted for in future research.

4.6 CONCLUSIONS

Over the past decades, passenger transport markets have undergone important changes concerning the modal distribution of the demand. The dominant position that railways enjoyed during the first half of the twentieth century has been quickly eroded by the plane, for long distance trips, and by the private vehicle, for shorter commuter distances. This has resulted in the loss of competitiveness of the traditional railway in comparison to other transport services, mainly originated by travel times far superior to those of alternative modes. In this context, high speed rail services (HSR) have been developed since the 1980s in Japan and Europe as a new transport mode, as a new opportunity for many railroad operators, as a new technology capable of providing answers to the transport system in terms of economic viability and sustainability. In fact, HSR has already become in many corridors the most convenient modal choice for a large segment of travellers, who face in these services a lower generalized cost.

The effects of HSR on other transport modes is one of the key factors to account for when evaluating this apparent success. The interaction between high speed rail and other modes may take place in the form of competition and complementarity. Both types are relevant although the second one has attracted more attention so far. Intermodal competition usually results in substitution of operations between modes, driven by their commercial viability, relative market strength and different institutional and environmental constraints. Alternatively, modal substitution may also improve the internal efficiency of each particular system (substitution through competition) and may reduce, in the broadest sense, the systems' cumulative burdens/emissions on the environment (substitution through complementarity).

Taking into account these two definitions, in this chapter we have reviewed the existing empirical evidence that quantifies the intermodal effects of HSR. We have found, for example, that most studies place the competitive advantage of high speed trains in the range of 100-500 km, that rail market share is closely related to time and distance, and that the competitive pressure from HSR on alternative transport modes affects their efficiency and their operational strategies, as in the case of low-cost airlines. In most cases, these results were compiled from specific examples on separate corridors carried out by different studies, and an integrated theoretical approach is seldom provided.

To address this limitation, we built a general framework to study the intermodal effects of HSR. We developed a model of demand of transport services that accounts for the type of mode as well as the type of operator offering the service. Transport services are seen as differentiated products offered by operators competing in an oligopolistic market, a city-pair route, which is modelled as a market with differentiated services competing against each other in terms of generalized costs. Competitors are traditional and low-cost airline carriers, HSR operators, or private vehicles. Intermodal effects are specifically considered by assuming that the degree of intermodal competition affects each operators' incentive to reduce costs.

Provided that enough data on generalized costs for each route can be collected, our model allows the estimation of a system of demand, price and cost equations by simple econometric procedures. We can then explain each mode's market share as a function of the elements of generalized costs, the behavior of the transport operators and the overall characteristics of the route. This methodology has been put into practice through an example on the Paris-Amsterdam route, one of the few routes where full intermodal competition between HSR, conventional rail and airlines (including low-cost) do actually exist. Departing from structural data from prices and current market shares, we were able to simulate the behavior of rail companies and airlines, and their impact on each other through their respective own-price and cross-price elasticities.

One of the most interesting results from these exercise is that air services and HSR services are not necessarily perceived as homogenous services by the travellers, thus creating scope for differentiation among them. Furthermore, cross-price demand elasticities are usually lower than one. Looking at the interaction between HSR and low-cost airlines, for example, we see that a 1% increase in the price of HSR services (low-cost airlines, respectively) entails a less than 1% increase in the demand of low-cost airlines services (HSR, respectively), which restricts the possibilities of price competition.

Although we believe that our model is quite insightful to describe the strategic interaction between transport operators in terms of intermodal competition attending to the specific features of each mode, our empirical results should be further explored with more corridors and better datasets. Our chapter lays off the foundations of a measurement procedure, but more research on the intermodal impacts of HSR is still needed.

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5
Indirect and Wider Economic Impacts of High Speed Rail

5.1 INTRODUCTION

Indirect impacts, especially on the improved economic performance at a regional level, are often used to justify additional benefits from high speed rail (HSR) projects, sometimes even to make the difference between a project which is not justifiable on a strict user benefits basis and viability. Regional authorities are especially vocal in using this argument in favor of projects, as for example in the development of the *Schéma Directeur* TGV in France. Similar arguments were heard in Italy or in the recent discussion for a new north-south line in the UK. In Spain, indirect economic impacts and territorial balance were key political arguments also used by different National Governments to launch very ambitious HSR projects. For most cities, HSR investments are great opportunities to start major renewal projects, develop new tertiary centers around new stations or even remove the negative impacts of pre-existing railway lines. Even when regional authorities understand that being connected to a HSR is not an economic priority for them, short-term real-estate business opportunities linked to urban renewal projects provide convincing evidence. Since HSR is mainly financed by National and European funds, it is politically unavoidable that all regional authorities push in favor of HSR.

The usual economic assumption is that, in the short term, the time savings made by all travellers will result in a direct increase in productivity; and in the longer term the improvements in accessibility, which the creation of a HSR link makes, will enlarge market areas, increase the implicit competitiveness and productivity of firms in a newly connected region, and attract new economic activities, more tourists or new residents. These assumptions may lead to three possible outcomes: an overestimation of potential demand which inflates predicted user benefits; an overestimation of non-user or induced benefits; and an assumption that all potential non-user benefits accrue to one region, ignoring any redistribution which the changing pattern of accessibility brings about. The social and political impact of *being connected* to a HSR tends to lead to these overoptimistic assumptions.

More recent theories of the role of infrastructure and transport improvements in regional development have stressed the way that transport costs (and hence accessibility) interact with other determinants of economic development, particularly scale economies and the size of market areas, in an imperfectly competitive world. Improvements in transport may, thus, benefit firms in more developed core regions more than those in less developed peripheral regions. Thus transport improvements to (and within) core city regions not only provide a direct benefit in terms of the enhanced productivity of existing workers and an increase in employment, but through agglomeration effects they raise the productivity differential of the core city relative to the rest of the economy. This reflects the positive relationship between city size and productivity. Transport improvements may, thus, be as likely to lead to an increase in regional disparities as they do to increasing cohesion. This is not a universal or inevitable outcome; it will depend on the specific situation of the region, the initial levels of accessibility and the change in them and the existence of other policy measures which may accompany the transport improvement.

Most analyses tend to be about individual links of HSR developments, or at most of what are in most cases simple national networks. As the networks developed they begun, in both north-west Europe and southern Europe, to form international HSR networks linked to other transportation and communication networks. This poses new issues for analysis and appraisal. In this chapter we begin to address these issues by looking at the evidence of the impacts on development the emerging European HSR network has had.

We look in particular at evidence on the links between changes in accessibility and changes in regional economic activity for a selection of regions, which have benefited from the introduction of HSR services. In doing so, we identify some of the limitations of existing modelling approaches. A particular focus is on the relationship between HSR networks and regional and local transport networks and the role of accompanying policies towards economic development. We also identify the way that some intermediate regions may suffer from the introduction of HSR services, which form a corridor through the region with little or no benefit and often considerable costs.

The broad conclusion from the chapter is that HSR can be an element in improving the economic performance of regions, but there is no guarantee that all the impacts on any one region are positive in the long term, or that regions not connected to HSR will suffer any evident economic competitive disadvantage. This leads to some suggestions for improvements to the techniques of appraisal for HSR projects.

5.2 THE EMERGING EUROPEAN HSR NETWORK

High speed rail in Europe has had a 25 year period of development from the inauguration of the first French TGV service between Paris and Lyon in September 1981.[1] From slow beginnings national networks have emerged in France, Germany, Italy, and Spain. An international network bringing in Belgium, UK, and Netherlands to form the so-called PBKAL (Paris-Brussels-Cologne-Amsterdam-London) will be almost complete in 2007, and further international links are planned or under construction to links the French network to Germany (via TGV *Est*), Italy (via Lyon-Turin) and Spain (via Perpignan-Barcelona).

This network (and the rationale for it) has emerged a little haphazardly. The original lines in France, Germany, and Italy were seen largely as a means of overcoming bottlenecks on the original classic rail network. Such bottlenecks limited capacity, caused conflicts between types of traffic and imposed unpredictability. Increased speed was in many respects an accidental by-product of improved reliability. Constraints on improving existing, often highly curved and circuitous routes through mountains or along river valleys led to the often cheaper option of new construction.[2] New construction could take more direct routes—the rail distance between Paris and Lyon was reduced by about 120 km or 20 percent—and take advantage of more efficient new traction and rolling stock to employ steeper gradients and sharper curves (there are no tunnels on the more than 400 km of TGV between Paris and Lyon).

Taking more direct routes could mean that traditional centers along the route were no longer served. This applied to cities such as Dijon on the TGV-*Sud Est,* and later similar problems arose in connection with such towns as Orléans (on TGV-*Atlantique*), Amiens (on TGV-*Nord*) and Metz and Nancy (on TGV-*Est*). Attempts to use the new lines to generate new access points to

[1] This refers to what is now conventionally thought of as HSR, operating on dedicated newly constructed track with operating speeds of 250 km/h or above. The first Japanese *Shinkansen* was introduced in 1964 with speeds of around 200 km/h, speeds also achieved in both France and the UK by conventional trains on conventional track.

[2] It was estimated that the cost of the new Paris-Lyon TGV would be about 40% of the cost of upgrading the classic route, even where this was feasible.

the high level networks through a range of stations such as Montchanin-Le Creusot in Bourgogne, TGV Picardie (between Amiens and St Quentin) and TGV Lorraine have not thus far been a success either in generating traffic or in providing a focus for economic development. On the other hand TGV-*Est* is linking Reims more closely into the high-level network, and the redevelopment of Lyon-La Part Dieu and Lille-Euralille shows how accompanying regeneration policies can be effective. TGV Lorraine is also interesting in that although as far as 27 km from Metz and 37 km from Nancy, it is relatively close to the regional airport for these two cities. Furthermore the use of a technology, which enables high speed trains to travel at normal speeds on conventional rail, enables connection-free services to penetrate large parts of the rail network.

In Germany and Italy, where the lack of a dominant metropolitan focus has led to a more diffuse development of HSR to overcome bottlenecks without creating a national network, this focus on the major centers has been less strong until recently. Thus the first German NBS (*Neubaustrecke*) provided parallel routes over the links between Göttingen and Würzburg and Mannheim and Stuttgart avoiding particularly slow and circuitous routes. Similarly the first Italian links sought to improve journey times on the core Milano-Bologna-Firenze-Roma route where again the traditional route suffered from speed penalties due to the topography. Second and third generation developments have led to a greater concentration on key intercity routes rather than by-passing natural barriers, for example the Frankfurt-Cologne line and improvements to lines serving Berlin in Germany, and the eventual moves to completing a T-shaped network in Italy serving all the major cities. The emphasis in Germany has now shifted to more detailed improvements to the network in terms of smaller ABS (*Ausbaustrecke*), that is, allowing higher speed.

The success of the early HSR developments in generating traffic and in switching traffic from both air and road led to an increasing desire for regions not to be excluded from the emerging network. The early projects carried sufficiently large estimated rates of return on a financial basis to make them worthwhile; later projects would increasingly rely on the need to identify a wider social benefit to justify the use of public funds. Moreover as a network began to emerge, it became more difficult to identify a precise added value for each new link as the network effects became more complex.

Experience with the first HSR in France, TGV-*Sud Est*, showed that for distances of around 400-450 km and a two-hour typical journal time, HSR was not just competitive with air, it would completely dominate the market. Even at the 600-800 km range, HSR could be highly competitive given access times, frequencies and reliability.[3] HSR thus started to be seen not just as a competitor to air for inter-regional journeys, but as a complement for longer international and inter-continental journeys. Thus interconnection of the HSR network with airports became seen as a core design feature. The French network serves Paris Charles de Gaulle and Lyon St Exupéry (Satolas) directly and a number of smaller regional airports by close proximity. The Frankfurt-Cologne line serves both Frankfurt (Main) and Cologne-Bonn airports. The Brussels-Amsterdam line will serve Schiphol airport.

At a European level, the emergence of the concept of trans-European networks (TENs) during the 1990s led to the designation of a HSR network independent of that for classic rail. As Turró (2000) explains, this was simply an amalgamation of the four main national networks already referred to, but it went further in two main areas: the designation of Northern and Southern European HSR networks. The Northern network is the star-shaped link of the PBKAL; the Southern network provides links between the Spanish, French and Italian networks. These have been (or still are being) built on a link-by-link basis with little or no regard for the overall network effects, and the by-passing and redistributive impacts are significant.

[3] For more details, see chapter 2.

The major problems of the TENs are the duplication between networks, and the desire of cities and regions to ensure they are connected to each network—their perception is that it would be a serious disadvantage for them not to be connected when other cities were. In fact the amount of central EU funding for each TEN link is relatively small, and although dedication can give rise to eligibility for Structural and Cohesion Funds, national, regional and local governments (and the private sector) have to find the bulk of the finance; and this can prove to be a long-term burden on the public sector's commitments.

Because the various HSR projects were in a reasonably advanced state of planning, and because the promotion of a new mode of transport, which could provide a serious competitive challenge to the environmentally less attractive road and air modes (HSR competes with both), was an attractive proposition, HSR featured strongly in the initial list of priority projects determined at Essen in 1994. The extension of the priority list to around 30 projects following the Van Miert report of 2003 reveals that there are now six HSR TEN priority projects of which only three will have been completed by 2007 (see table 5.1). Of these the Lyon-Torino-Venezia project has been broadened to include multiple uses; and arguably, the West Coast Main Line in the UK is not a true HSR project, as it involves upgrading rather than new build and is for maximum speeds well below 300 km/h.

Table 5.1 clearly indicates that the priority TENs are built on national links to later provide international networks. In some cases this is because the international linkage underwrites the viability of the national project and vice versa. For example TGV *Nord* only makes full economic sense in the context of Paris-Brussels and Paris-London links. It would be difficult to justify each of these lines in its own right without the domestic Paris-Lille service and the ability to link Brussels-London services on the same infrastructure.[4] Some similar issues arise in the routing of TGV-*Est* and in the various elements of HSR South West. The problem is that the intentional impact of HSR has so far been much less dramatic in traffic generation terms than domestic HSR services. Eurostar services between Paris-Brussels and London have only reached about one-third of the original forecast passenger numbers after more than ten years of operation although the rail share of the air plus rail market has reached more than 70 percent.

That HSR has thus become a central plank in the development of the European transport infrastructure network is not in doubt. What remains in doubt is the rationale for this. Four broad objectives can be identified:

TABLE 5.1: HSR projects in Priority TENs

Projects or sections of projects	Date for start of operation
A. Essen List Projects	
PP2 High Speed Railway Paris-Brussels-Cologne-Amsterdam London	2007
PP3 Southern TGV	
– Madrid-Barcelona	2005
– Barcelona-Figueres-Perpignan	2008
– Madrid-Vitoria-Hendaya	2010
PP4 TGV Est	
– Paris-Baudrecourt	2007
– Metz-Luxembourg	2007
– Saarbrücken-Mannheim	2007
PP6 Lyon-Torino-Trieste-Torino-Venezia	2010
PP14 West Coast Main Line (UK)	2007
B. New 2003 Projects	
High Speed Railway, South-West	
– Lisbon/Porto-Madrid	2011
– Perpignan-Montpellier	2015
– Montpellier-Nîmes	2010
– Irún-Dax (cross border)	2010
– Dax-Bordeaux	2020
– Bordeaux-Tours	2015

Source: European Commission (2003).

[4] Paris-London via Lille is a longer route than the direct route from Paris via Amiens to the Channel Tunnel. The latter is listed as a future project in the French *Schéma Directeur*, but it is likely to be some time before it becomes viable. The failure to serve Amiens remains a persistent point of contention.

— A pure transport objective in which HSR is promoted as a less environmentally damaging alternative to road and air;[5]
— A competitiveness objective in which HSR has both direct impacts on productivity and indirect impacts through agglomeration and scale;
— A cohesion objective in which transport infrastructure investment impacts on accessibility and contributes to the process of convergence;
— An industrial and technological objective to reinforce European companies in the rail sector.

The development of the EU rail network to 2020 is shown in map 5.A.1, and the estimates of the level of investment to 2015 and further to 2030 in maps 5.A.2 and 5.A.3. From a European Union perspective, the real difficulty is how to determine the European added value from these networks, both from the key cross-border elements and from the key linkages between cities within member states (Vickerman 2006). It is to these issues we turn in the following part of this chapter.

5.3 DEFINING THE WIDER EFFECTS OF HSR

Although the primary motivation for the early HSR lines was, as we discussed above, one of enhancing capacity, it was also clear that the step change in speeds involved from the maximum of around 200 km/h, which had been achieved on some classic lines (and even more so from the ruling maximum on most of the network of 160 km/h) to 250 km/h and later to 300 km/h plus, was bound to have a major impact on both rail's competitiveness and on traffic generation. Greater speed implied lower generalized costs of travel; and lower costs implied a reduced impedance of distance, which would raise accessibility and the economic potential of the major centers served.

5.3.1 ACCESSIBILITY

The measurement of potential accessibility typically involves two elements: an activity function which assesses the activities that are to be reached, and an impedance function which represents the cost of reaching them. This can be summarized in an equation of the form

$$A_i = \sum_j W_j^a \exp(-\beta c_{ij}) \ ,$$

which measures aggregate accessibility at i based on the availability of activity a, at a series of locations j, the cost of reaching each j being given by c_{ij}. The β is a measure of the relative impedance. The application of such a measure to the European networks identifies a clear concentric pattern for road and rail, less so for air (and potentially for high speed rail). Map 5.A.4 shows the estimated accessibility by rail at the level of NUTS3 regions in 2001. Of course, taking each individual mode separately may give a misleading impression of actual accessibility of a region; for example accessibility is affected by major barriers such as sea or mountain ranges which may make land transport difficult but is compensated by the availability of air transport. To overcome this most measures of the impact of the development of the TENs tends to use a measure of aggregate multi-modal accessibility where the relative usage of each mode is used to weight the individual modal accessibilities as shown in map 5.A.5.

But such measures of accessibility need not only further refinement to allow for access to the network, which can be very variable (map 5.A.6), but also more difficult factors to include on a Europe wide basis, such as variations in frequency of service which may have a big impact on perceived accessibility.

Early works on the impacts of HSR focused on this impact on accessibility. Using conventional gravity-based models, a series of studies demonstrated how higher speeds would lead to very pronounced changes in the time-space maps of Europe (e.g. Spiekermann and Wegener 1994; Gutiérrez, González, and Gómez 1996; Gutiérrez 2001). Changes in accessibility, defined simply in terms of time, are only a part of the impact.

[5] Although it is maintained by some that the search for speed was gained at the expense of environmental sustainability (e.g. Whitelegg 1993).

First there is the problem that although absolute accessibility may improve, there are improvements in accessibility to all nodes in the network such that relative accessibility may not change significantly. Vickerman, Spiekermann, and Wegener (1999) demonstrate, using the same basic data as Spiekermann and Wegener (1994) but including access times to the new HSR networks and allowing for the changes to all nodes, that the new networks may reinforce the absolute dominance of the major metropolitan centers. On the other hand, Ulied (1997) demonstrates that major HSR impacts (in terms of the relative increase in markets available for daily business round-trips) will be in small and medium-sized cities in the center of Europe, where accessibility improvements are relatively larger than in large metropolitan areas, especially those located faraway from the geographic center of Europe. Small and medium-sized cities in the center will benefit from the interconnection of conventional rail and HSR to large metropolitan, ports and airports.

5.3.2. CONNECTIVITY

In the late eighties, Turró and Ulied developed an alternative measure of accessibility called «connectivity» (ICON). The measure aggregates the generalized cost of access to the different transportation networks from a given place, and the utility these connections may provide, in terms of effective services to most interesting destinations. The underlying assumption is that in territories with relatively dense transportation networks, and with economic activities well integrated into global markets, accessibility gains between origins, and destinations becomes less relevant than accessibility to networks. Not surprisingly, ICON results, when mapped clearly, indicate those areas with higher increases in relative accessibility as it is perceived by local and regional authorities. But changes in relative accessibility do not imply unambiguous changes in competitiveness and economic performance, a point to which we return in the following section.

5.3.3. THE IMPACTS OF ACCESSIBILITY CHANGE

Initial research into the impacts of the French TGV lines focused on the relative impacts on Paris and provincial cities. It suggests that although such services led to a substantial growth of traffic, the impact on the local economies of the cities served was much less certain. Generally such services cannot be shown to have had a major impact on the net redistribution of the economic activity between Paris and provincial cities, or on the overall rate of growth of these cities.

The evidence includes studies of the TGV *Sud Est*, Paris-Lyon, opened in 1981 (Plassard and Cointet-Pinell 1986), the TGV *Atlantique*, including a study of Nantes, opened in 1989 (Klein and Claisse 1997; Dornbusch 1997), and early studies of the TGV *Nord*, including studies of Lille and Valenciennes, opened in 1993 (SES 1998; Burmeister and Colletis-Wahl 1996). All of these studies demonstrate a considerable growth in traffic between Paris and each provincial city since the opening of TGV. The impact on business traffic is more mixed. In the case of TGV *Sud Est,* there was a substantial growth; in the case of TGV *Atlantique* as a whole, there was a marginal reduction in business traffic, but the period immediately after its opening coincided with a serious recession.

The Paris-Lyon study showed a major impact on the pattern of mobility, but with changes in both directions. Essentially many businesses in both locations modified their pattern of working leading to increases in travel in both directions. There was no overall net impact on the economies of the major cities, but there was a general tendency towards the concentration of economic activity towards these major cities from the regional hinterland, especially in Bourgogne and Rhônes-Alpes regions. This centralizing effect of high speed rail is now a well-established impact.

In the case of TGV *Atlantique*, the development of business traffic showed interesting contrasts. Tours, at 240km (1h 10m) from Paris, showed a significant reduction in business traffic of 24%

in total and of 40% in rail trafficl between 1989 and 1993. Nantes, 380km (2h 05m) from Paris, showed a total increase in business traffic between the two cities of 66%. In 1989, 73% of the traffic originated in Nantes, but there was a much larger increase in Paris-originated traffic (+99%) compared with that originating in Nantes (+55%). For Toulouse, 700km from Paris (5h 06m), the increase in total business traffic with TGV was 21%, but this increase was totally deviated from air (+45%) whilst despite the gain in time by rail of just over one hour, traffic fell by 58%. In this case however, most of the increase in traffic was locally based (+35%) and Paris-originated traffic actually fell by 5%. However, much of the driving force behind these changes was seen to be the business cycle rather than changes in the supply price of transport. The key factor here appears to be the differential impacts on the city located around 2 hours from Paris; those closer and further away did not benefit as much. This is consistent with other evidence that high speed rail has its major impact in the 2-3 hour journey-time band.

In Nantes there was considerable anticipation of the coming of the TGV in the light of some of the experiences of Lyon. This was mainly felt in property development, and relatively little impact on inward movement of enterprises was identified. As in the case of Paris-Lyon, there was evidence of a degree of internal reorganization within firms to take advantage of changing transport costs for business travel. Note that the stronger impact on Paris-originated journeys is consistent with the relative lack of development realized in Nantes. Given the general economic situation at the time of the introduction of the TGV, the impact on tourist traffic was stronger than that on business traffic, and this was reflected in a large increase of tourist facilities (an increase of 43% in hotel rooms in central Nantes, for example, between 1988 and 1993, although some retrenchment was noted after 1993, and occupation did not match expectations).

For TGV *Nord* the distances are too short to probably make any major impact (Lille is just 1 hour from Paris). Nevertheless total traffic grew substantially over the first three years of operation: 5% in the first year, 6% in the second year, and 11% in the third year. Except in year two, the growth was stronger for traffic originating in Nord Pas de Calais region. What is of interest is that rail showed much stronger growth in the latter market than for traffic originating in the Paris region.

The Lille study suggested that about one-third of all business travel was changed as a result of the introduction of TGV (both outward from regional based enterprises and inward by clients of such enterprises). However, 90% of enterprises identified no impact of TGV on their overall activities. As in the earlier studies, there was evidence of some internal reorganization, described in this study as a form of «spatial dualization». Some considerable differences were noted between Lille and Valenciennes: just as in the Paris-Lyon study, there was some evidence of centralization of activity towards Lille, the major regional center, at the expense of the weaker one, Valenciennes.

The French studies demonstrate the critical importance of time thresholds in the impact which TGV services will have on the relationships between major centers. Thus the headline time of two hours between Paris and Lyon was very significant. This is particularly true in the diversion of trips from air to rail, but it has also affected the potential for the creation of new journeys reflecting new activity possibilities. A further issue is that although much of the success of the TGV in generating new traffic has been caused by providing services for locations close to the new infrastructure, the economic spillover for these centers has not been as great as for the locations on the main lines.

Not many studies have been made in Spain to assess the regional development impact of HSR. In the study conducted by the University of Ciudad Real, results showed some local impacts in Ciudad Real, and marginal impacts in other cities. In the Madrid-Seville, Madrid-Barcelona-Perpignan, and other lines, a double affect is expected: On the one hand a relative substitution of air traffic between major cities, and on the other, an increase in the level of metropolitan integration of small and medium size cities along the corridor. In most cases, there are urban development projects around new HSR stations.

5.4. ECONOMIC IMPACTS OF HSR

Recent theoretical work in new economic geography provides us with a basis for a deeper understanding of the relationship between accessibility change and economic impacts. It focuses on the interrelationship between transport costs, market size, backward and forward linkages, and scale economies (Fujita, Krugman, and Venables 1999). The essence of the approach is to recognize that in imperfectly competitive markets for transport-using activities, there will be no unambiguous predictable response to changes in transport costs. This is equally true for the movement of goods and people, particularly for the latter where the movement is for business or commuting purposes. Thus changes in user benefits will not provide a complete measure of the change in total economic benefit, as they will not include these wider economic benefits (Jara-Díaz 1986). Wider economic benefits do not, however, just constitute a simple add-on or multiplier effect to the user benefits (SACTRA 1999). Moreover the distribution of those benefits between the affected regions is an empirical question.

5.4.1. DEFINING WIDER ECONOMIC BENEFITS

Wider economic benefits can be viewed in two ways. On the one hand, they involve an increase in total welfare which is greater than the measured increase in consumers' surplus to users through time savings, reductions in accident rates, etc. And on the other, these benefits can be seen as the increase in GDP which occurs as a result of the changes in economic activity, deriving from the transport change. These represent different ways of measuring benefits and typically give different numerical results. For example, time savings accruing in the course of commuting or leisure travel are welfare gains to the user, but do not have a direct effect on GDP, unlike time savings in the course of work. However where such time savings lead to an overall gain in productivity, because people can access more productive jobs more easily, it will be recorded as a change in GDP. For the economy as a whole, the overall impact will be broadly similar, but the ratio of total benefits to user benefits will differ. There could also be important differences in the impact on individual regions such that the welfare gain accrues in one place but the GDP benefits accrue in another. If improved transport infrastructure leads to greater concentration of employment, it can have different relative impacts on central and more peripheral regions.

Wider benefits are those which typically cannot be recouped from users through charging, and they arise in a number of ways: through impacts on the labor market, through direct impacts on productivity and competition in product markets, and through changes in patterns of agglomeration. In each of these cases, the main reasons for wider benefits occurring are due to the absence of a perfect competition. As Jara-Díaz (1986) shows, where there is perfect competition in transport-using markets, user benefits will be an accurate and sufficient measure of the total benefits from transport improvements.

We stress the importance of the labor market, because it has frequently been ignored in studies of wider benefits. Labor market effects in imperfectly competitive labor markets arise in three possible ways: changing participation rates, increased working hours and moves to more productive jobs (Department for Transport 2005). Improved transport can enable access to jobs which would not otherwise have been possible. If it enables workers from employment-deficient regions to access jobs in labor-deficient regions, there will be gains to the workers, to employers, and to the public sector, which gains tax revenue and faces lower social security payments. Similarly if easier commuting encourages existing workers to work longer hours, there will be potential gains to all three groups, although it might seem more likely that, in practice, workers would take the gains in increased leisure rather than in increased work. Possibly of greatest importance, however, is the impact on productivity which arises thorough workers being able to move more easily from less productive to more productive jobs. HSR has the important effect of creating a potential step-change in the size of labor markets, not just for daily commuting, but also for reinforcing the possibility of long-distance, weekly commuting where the constraints of housing or personal circumstances prevent job-related migration.

5.4.2. IMPERFECT COMPETITION AND WIDER BENEFITS

Jara-Díaz (1986) recognized that if the degree of monopoly was different in the two regions connected by a new infrastructure, there could be differential effects. In an imperfectly competitive world, there will be agglomeration forces which enable firms, that have larger markets and enjoy scale economies, to take more advantage of any reduction in transport costs. Hence reductions in transport costs can lead to more agglomeration and to unequal impacts on regions connected by the same infrastructure (Venables and Gasiorek 1999). However the nature of this approach is that the impact of any particular reduction of transport costs cannot be determined a priori. It will depend on the initial level of transport costs, the degree of agglomeration already present, the size of each market, the extent of scale economies, and on the backward and forward linkages within that market (Fujita, Krugman, and Venables 1999; Fujita and Thisse 2002).

The key factor is the extent of the mark-up over marginal cost in the transport-using activities, whether these are industries or labor markets. In perfectly-competitive sectors, there is no mark-up and, hence, any changes in transport costs will have to be passed on directly to the final activity, so the extent of the impact on the wider economy is dependent on the elasticity of demand for that final activity. Since the amount of transport demand depends directly on the demand for the final activity, the direct user benefits capture all the economic benefits. As mark-ups increase, there is in effect a wedge driven between the market for the transport-using activity and the transport associated with it. Any reduction in transport costs from the HSR does not need to be passed directly on to the customers of the final activity, but firms can use the opportunity to increase or reduce the mark-up. Reducing the mark-up by passing on more than the reduction in transport costs could be a way of increasing a firm's market area and gaining market advantage over firms in a more competitive market. On the other hand, firms may use the fall in transport costs to increase the mark-up, for example to invest so as to reduce other costs and gain from potential scale economies. It is also possible that the net impact can be negative. If the mark-up is negative, for example, where there are industries with significant subsidies, such as in economically lagging regions, then the direct user benefits may overestimate the total economic benefit. Hence the ultimate impact from any infrastructure project is likely to be unpredictable, both in terms of magnitude and sign.

5.4.3. TOTAL ECONOMIC IMPACT

How then can the total economic impact be assessed? There are three main elements: (1) the impact on competition in the affected regions, (2) the impact on the ability to gain benefits from the change in market power through agglomeration, and (3) the impact on the linkages and, in particular, on backward linkages, such as the labor market. Once these have been assessed, we have to identify how to include them in a full cost-benefit framework.

The impact on competition is ambiguous. In perfectly-competitive markets, as we have seen, the impact of increased competition is essentially neutral and should be adequately captured by the direct user benefits. In imperfectly-competitive markets, the direct effect of any increased competition, resulting directly from lower transport costs, is also likely to be essentially neutral in its impact. It is traditionally argued that monopoly power is derived from the effective barriers to competition provided by higher transport costs, so that reductions in such barriers are pro-competitive, reducing monopoly mark-ups and, hence, there is a wider benefit resulting from the reduction of prices. On the other hand, such competitive pressures, if they do exist, may also drive firms out of the market, and the effect of lower transport costs is to reduce the number of firms able to compete in the market in the long run. It is likely that such effects cancel each other out in most cases, and thus, there is little in the way of wider economic benefits that can be added.

There may be some exceptions to this conclusion: where new links are created, they have such a significant impact on transport costs (which are already very high) that significant market restructuring takes place introducing competition to previously protected local monopolies. This is the *unlocking* argument advanced by SACTRA (1999) and reaffirmed in its latest guidance by the Department for Transport (2005). These are likely to be rare in most developed market economies.

Much more significant than the market competition effects are the agglomeration benefits, which may result from the change in transport costs. The argument here is that the rise in output, which follows from the lower transport costs, has cumulative effects through the way in which firms interact in a market. This involves both localization economies, in which firms within the same industry benefit from the proximity to each other through such factors as specialized labor pools or shared R&D, and urbanization economies, in which firms obtain a form of public goods benefit from the existence of an urban infrastructure, including knowledge, research, and culture as well as the physical infrastructure. The larger the market, the greater the likely net additional impact; the latter arises because there is an additional impact on productivity. There is a long debate over the extent to which urban size and productivity are related, and the direction of causality, but there is an increasing consensus that there is a strong positive relationship between them, which can have a significant additional impact on the benefits from transport improvements (Fujita and Thisse 2002; Venables 2004; Graham 2005). It argues that although the lower transport costs may cause firms to increase the size of their market, such increased size provides an incentive for the firm to enjoy scale economies and to benefit from proximity to other more efficient firms. Typical productivity elasticities are in the range of 0.01 to 0.1. Ciccone (2002), using data for EU regions, finds an elasticity with respect to employment density of 0.05. Graham (2005) finds for UK industries a weighted average elasticity of 0.04 for manufacturing, but significant variations between industries with some as high as 0.2, and an average of 0.12 for service industries. Graham also identifies some important variations between regions reflecting different degrees of localization of industry groups.

A further element of this output benefit under imperfect competition is that, here, since the productivity increases, the direct user benefits will be greater than it would be under the perfect competition assumption. The largest direct user benefits from most projects are time savings, valued relative to the wage level (assuming that wages reflect productivity). The increase in productivity implies that a higher value of time savings should be applied since the increased productivity enables firms to increase output (or produce the same output with fewer workers).

The basic advantage which some regions obtain in an imperfectly competitive world derives from a larger market size, which enables firms to increase both output (scale) and productivity. However it is useful to break up that larger market size effect into a pure market size effect and the backward and forward linkages, which are associated with agglomeration. One of the key backward linkages relates to the labor market. As transport costs are reduced, labor markets become larger, as commuting times are reduced, and firms have access to a larger labor supply. This enables firms to benefit both from wage levels which might be lower than they might be as result of more competition in the larger market, and from access to more skilled labor, which will be more productive for the reasons discussed above.

Normally one would expect that there would be a wage premium at the market center reflecting its greater accessibility, scale and productivity effects, as well as the wage necessary to attract labor to commute in from across the wider region. As transport improves, more workers find it attractive to work in the market center, both because such center is a larger catchment area, for which commuting is feasible, and because more people find it worthwhile to seek work in the center rather than elsewhere (or not at all); also if they are already working in the center, they will be prepared to work longer hours. Hence there is an output effect which arises because of the increased size of the labor market. Where there is also a productivity effect due to agglomeration effects at the market center, the output effect from the expansion of employment is added by the increased output of all existing workers.

Note that it is not the size of the infrastructure project which determines the scale of the wider economic benefits. Large projects are likely to have a wider impact in terms of greater, direct user benefits, but the wider benefits are not simply proportional to the direct user benefits. Some relatively minor projects, the *unlocking* projects, can have disproportionately large wider benefits, whereas some very large projects may have relatively little impact on the key scale, productivity, and linkage effects. This is why there is no a priori reason for applying a simple wider benefits multiplier. It also demonstrates that seeking a simple output elasticity, as in the macro analysis, can be misleading.

5.5. EVIDENCE ON THE WIDER ECONOMIC IMPACTS OF HSR

Most of the detailed studies of HSR impacts did not formalize the analysis to identify the components outlined in the previous section. The technical key to estimating such benefits came from the application of large scale computer-based models. There are two main types: advanced land use-transport interaction (LUTI) models and computable general equilibrium (CGE) models. A number of models of both have been applied to attempts to estimate the impact of the development of TEN networks, and also to specific case studies.[6]

Both LUTI and CGE models use a detailed description of the regional economies in the form of its input-output structure. Each sector can be described by its needs for inputs and their origin, and its markets and their location. Changes in transport costs, thus, feed into the cost function of each sector according to its transport intensity. LUTI models assume that markets clearly and implicitly assume that all economic agents are in perfectly competitive markets, so that prices reflect marginal costs. A change in transport costs will, thus, always be passed on in the prices of the activities using that transport.

CGE models use evidence on the actual mark-ups observed in a range of economic sectors and, thus, allow for the differential impacts, which a given change in transport costs can have on different regions depending on their sectoral and competitive structures. The basic structure of CGE models (see Bröcker 2004; Gunn 2004, for valuable introductions) involves a demand system, which expresses final consumers' preferences over a range of differentiated goods, a social accounting matrix which expresses the input-output structure of the economy, and a profit function for firms. Firms are assumed to be in imperfect competition producing differentiated goods. The outputs of the CGE model are the demands for goods and labor and the implicit flows between regions from which these demands generate, and a direct measure of changes in consumer welfare in terms of the equivalent variation in income (the income equivalent to the change in welfare resulting from a change in any input, such as the cost of transport).

One large-scale application of both of these approaches is in the SASI model (Wegener and Bökemann 1998) and the CGEurope model developed by Johannes Bröcker (Bröcker 2004), which have been used in a number of research projects looking at the impact of the Trans-European Networks (see, for example, Bröcker et al. 2004a, 2004b). They use a detailed representation of the European transport network mapped onto a detailed regional structure of Europe at the NUTS3 level. The model generates three important results. First, it demonstrates that despite significant changes in transport costs and accessibility, occasioned by the development of the TENs (accessibility in some regions changing by as much as 40 percent, see map 5.A.7), the impact on GDP using the SASI model is typically less than 4 percent (map 5.A.8), and on welfare using the CGEurope model even more modest (equivalent typically to less than 2 percent of regional GDP) (map 5.A.9). Secondly, it shows that the network as a whole has both positive and negative impacts, and although the largest positive im-

[6] For a more detailed analysis of the issues raised in the appraisal of major projects, see Vickerman (2007).

pacts relative to regional GDP are in the more peripheral, poorer regions, it is difficult to claim that despite significant investment expenditures, the TENs are a major force towards convergence and cohesion. Thirdly, specific investments can be seen to have differential impacts both on the specific regions they serve and in the added value they bring to the European economy as a whole. Thus even using a fairly aggregated modelling structure, much of the parameter dependence and variety of impact predicted by the theoretical model can be identified. This contrasts strongly with the purely accessibility-based estimates of HSR effects, which meant much larger benefits. Although the model does allow for the measurement of the impact of each link in the context of the development of a complete network, it does not, however, allow for the possible dynamic impacts which the development of this network could have (Laird, Nellthorp, and Mackie 2005).

A more specific application has been developed to evaluate the possible impact of a high speed rail link between the Randstad and the Northern Netherlands, including the possibility of using an ultra high speed *maglev* system (Oosterhaven and Elhorst 2003; Elhorst, Oosterhaven, and Romp 2004). The Dutch model focuses not just on the output and welfare implications, but also very specifically on the labor market since the improvement to transport will not just affect the location of employment, but also the residential location decision. This introduces further difficulties because it requires not just a balance of production and consumption in the goods markets with a potential response through migration to long-term imbalances, but a period-by-period balancing of labor markets demands and supplies, zone by zone. Furthermore, once the key benefiting users of the system are passengers rather than goods some of the simplifying assumptions used in the typical CGE structure become less plausible. For example, the use of *iceberg* transport costs, in which the cost of transport of a good is subsumed into the value of the goods moved such that they are worth less at the destination than at the origin by the amount of the cost of transport, is inappropriate for passengers. Similarly the assumption of constant costs of transport per unit of distance is even less appropriate for passenger transport.

Nevertheless the application of a CGE model to this project produces an interesting set of results. The wider benefits are shown to vary significantly as a result of the precise nature of the project and the region studied (especially core-periphery differences), and constitute a higher proportion of direct benefits than earlier studies suggested, of the order of 30-40 percent. These wider benefits are higher than theoretical simulation models suggested; SACTRA (1999) suggested that a figure of 10 to 20 percent was a likely range, following Venables and Gasiorek's (1999) conclusion that 30 percent was a likely to be exceeded in only a few cases. (It is worth noting, however, that in the earlier version Oosterhaven and Elhorst [2003] had produced a figure of 83 percent). What is clear from Elhorst, Oosterhaven, and Romp (2004) is that the degree of detail in the modelling of labor market responses may be crucial here. These employment effects arise by linking areas of labor surplus to those of labor shortages, rather than through the productivity effects arising as a result of agglomeration benefits, which has been argued before (Venables 2004).

5.6 NATIONAL AND LOCAL IMPACTS OF HSR

So far, we have dealt with the impacts at a very aggregate level, which tends to hide the detail of local impacts. The development of an integrated network at the national level previously has been largely confined to France, but the planned network for Spain will be even larger.

Map 5.A.10 demonstrates the considerable variation in accessibility to rail within Spain, and map 5.A.11 shows the very concentrated nature of rail supply. Map 5.A.12 shows the level of service of the initial HSR routes in service in 2006. However, even at this level, it is very difficult to separate out the specific impacts which further development will have. For that we shall need to look at individual lines and even individual sections of those lines.

5.6.1. SOME LOCAL IMPACTS 1: EVIDENCE FROM THE NORTH EUROPEAN HSR NETWORK

The North European High Speed Rail Network is the most developed network of high speed rail connections in Europe, linking Paris, Brussels, Cologne, Amsterdam and London, with direct onward linkages to Frankfurt, and via the Paris *Ceinture* to the rest of the French TGV network (map 5.A.13). The first elements of this network were completed in 1993, and the final stages should be in operation by the end of 2007. The network involves five EU member states. Besides providing high speed rail links between these major metropolitan regions in Europe, the network has opened up new opportunities for other possible nodes, particularly Lille, but at the same time, has removed or reduced access to international rail services from other towns and cities. Significantly for our purposes, a number of these are on or close to international borders, the effects of which could therefore be reinforced by the new links.

Excluding the French TGV links (Paris-Lille-Calais), which were built prior to 1993 and thus not included as TENs priorities, the total cost of the remaining links is estimated at €24.9 billion, of which just under €0.9 billion (to end in 2004) was from the TEN budget (European Commission, 2005). The projects are being delivered in a number of ways with both pure public sector projects managed by the relevant national railway infrastructure authority, and various models of public-private partnership. Services on the completed network will also be provided by a number of joint venture companies, providing overlapping services between the main destinations. Thus Thalys services between Paris-Brussels-Cologne-Amsterdam compete with SNCF TGV services, with Eurostar (joint UK, French, Belgian services) between Lille and Brussels, with DB ICE services between Brussels and Cologne, and with SNCB/NS services between Brussels and Amsterdam. Tickets are not interchangeable and not provided through booking (e.g., between London and Frankfurt).

This lack of easy booking and the lack of planning of reliable connections for through services limit the competitive edge of the network with airlines, which is one of the major objectives of this development. Thus, for example, on a direct competition between air and rail on the London-Paris segment, rail captured almost 80% share of the combined market. Although rail will find it difficult to make similar inroads on the longest possible journeys (e.g., London-Frankfurt), even with through booking and easier connections, there is a considerable market for modal shift, which will enable this network to fulfil one of its major objectives in terms of current EU transport policy. In late 2005, a joint venture between Eurostar and Thalys was established to further this aim, and in 2006, the Dutch High Speed Alliance (operator of the HSL Zuid) and various national rail companies joined such venture seeking to deliver more seamless high speed travel over a wide area of northern Europe.

As it is clear in map 5.A.13, the development of the network has required a number of compromises in terms of route choice. For example, the London-Paris route is significantly longer than the more direct route between the Channel Tunnel and Paris, made necessary by the economic considerations of combining the infrastructure with that between Paris and Brussels (this route is also longer than the more direct traditional route via Maubeuge and Mons). Here the commercial consideration of serving the Lille metropolitan area with a population of well over 1 million was critical. Less clear in the map, but also important, was the decision to place the route through the main railway station of Antwerp, involving a very expensive tunnelling operation, but ensuring that the rail penetrated the heart of the city. Similar decisions surrounded the location of stations in Lille and Rotterdam.

Perhaps some of the local impacts of new TGV routes are best seen in the context of the impacts on towns in the border regions, which may either have new links created or old links removed. On the Franco-Belgian border, Lille made the most of its position at the junction of the lines to these three main cities: London (under 2 hours), Paris (1 hour), and Brussels (40 minutes). On the other hand, the traditional (and more direct) Paris-Brussels route served the smaller town of Maubeuge and the Belgian city of Mons, both of which largely lost their international links. Maubeuge has irregular direct traditional rail services to Paris of 2 hours. Services to Brussels involve a change at Quévy, operate irregularly (essentially morning and evening services) and take between 1 hour 20 minutes and 2 hours. Belgian domestic services from Quévy operate every hour to Brussels. On the Belgian side of the border, in Mons, as in Maubeuge, through international services were largely lost, except for one return Thalys service a day to Paris. This is, however, some 40 minutes faster than the direct traditional services from Maubeuge, which is just over 20 km away across the border. Otherwise journeys to Paris involve a change in either Brussels or Lille, adding at least one hour to the journey time.

In contrast to the Franco-Belgian border, the border between France and Britain is one where the completion of the Channel Tunnel and associated high speed rail links introduced through international rail services, where none had existed previously (except for rail connections to traditional ferry services). Through services by Eurostar between Ashford in Kent, and Paris and Brussels take 2 hours and 1 hour 40 minutes, respectively. Such services open new journey possibilities to destinations beyond Paris and Brussels, with changes in Lille and Brussels, respectively. In the other direction, the coastal region of Nord-Pas de Calais gained direct services to London of just 1 hour 20 minutes (reducing to little over 1 hour on the completion of the high speed line all the way to London in 2007). There is an imbalance in these services, however. Calais has only three weekday services to London (and four in the opposite direction). The stops in Calais, where the station Calais-Fréthun is actually some way out of the town, tend to serve the Calais-Paris passenger more than the Calais-London passenger does. Ashford currently has 6 weekday services to Paris (7 on Mondays and Fridays), and 4 to Brussels with 6 in the reverse direction. Most Brussels services also stop in Lille. Oddly, Ashford-Calais has only three services and Calais-Ashford only two on a regular weekday, making simple, cross-border journeys by rail the least attractive option (the tariff also makes this journey very unattractive).

However, the completion of the UK Channel Tunnel Rail Link in 2007 and the opening of a new station at Ebbsfleet, close to the London Orbital M25 Motorway, will mean that many services currently stopping at Ashford will, instead, stop at Ebbsfleet (map 5.A.14). The Ashford-Paris service will be reduced by 50% to just three service per day, and the Ashford-Brussels service withdrawn completely. This issue of competition between stations along a line is an often overlooked problem as cities campaign for a station rather than looking at the level of service provided.

A third case is that of the Dutch-Belgian border. This case differs from the previous two in that it represents a still proposed development of the network rather than one which has already been brought into service. Nevertheless it can be seen from the planning of it that issues were raised both regarding the precise routing of the new Brussels-Amsterdam high speed line and regarding the services provided on that link and to towns not on the link. Thus the agreed route passes through the Central Station in Antwerp and then, via Rotterdam, to Schiphol Airport and Amsterdam, with stops just in these locations. This has the effect of by-passing the border town of Breda and also the Hague, which are currently served not by direct international services, but by international trains stopping at appropriate junction stations (Roosendaal and Den Haag HS) with connecting services to them. This has led to connections being provided to the new high speed line so as to enable the development of services specifically for these cities. Thus Breda will have two services an hour to Amsterdam via the high speed line, and there are proposed eight trains a day between the Hague, Rotterdam, Breda and Brussels with additional stops, which will complement the main inter-capitals service. Such a regional service may be the obvious solution for Ashford and Calais, but currently Channel Tunnel safety regulations and access charges make such a proposition uneconomic.

This section highlights the key local issues which arise in the context of HSR development and shows how HSR services need to be conceived as part of an integrated network with local rail (and other connecting) services, and not as a totally independent network if the real benefits are to be felt.

5.6.2. SOME LOCAL IMPACTS 2: TGV SOUTH-WEST, THE SPANISH-FRENCH CONNECTION

The national HSR networks of France and Spain provide a connection between the two countries, more specifically between Perpignan and Barcelona. The project is one of the priority TENs, or one of the 14 Essen projects, due for completion by 2010. It will remove a historic bottleneck due to the lack of interoperability caused by the difference of rail gauge of the French and Spanish rail networks (map 5.A.15).

Map 5.A.16 shows how the project will improve accessibility to HSR suggesting a considerable increase in accessibility. However one of the main potential impacts in the case of this project could be the environmental impact on protected areas (map 5.A.17).

5.7 CONCLUSIONS

The development of HSR as a new network of transport has accelerated in many European countries and become a key element in the priority TENs. The rationale for it has, however, been somewhat confusing, so it is not clear whether HSR is simply an updating of the rail system to deal with problems of capacity and, thus, help maintain rail's market share, whether it is a means of competing with the rapid growth of air travel for medium distance journeys in the 400 to 600 km range, or whether it is a more fundamental agent of economic change and territorial balance with impacts on both competitiveness and cohesion.

The analysis here suggests that whilst the wider economic effects of HSR can be significant, they are not always obvious or predictable and can vary significantly between different HSR projects. The analysis needs, however, to go further. Most of the analysis does not deal adequately with the dynamic effects, which the development of a completely new network could have on patterns of trip making and economic behavior. These may go beyond the simple network effects as evidenced by the rapid growth of that other new network of low-cost airlines. The next stage in the development of HSR is the joining up of the major international networks with the developing of national networks, and this could imply a step-change in effects even greater than that experienced by the first HSR links. Such a step-change does, however, carry implications for pricing and interconnection with other modes, including local and regional rail which need careful consideration. This implies a need to go back to thinking about appropriate definitions of accessibility change in the light of our better understanding of the links between accessibility change and the indirect benefits stemming from HSR developments.

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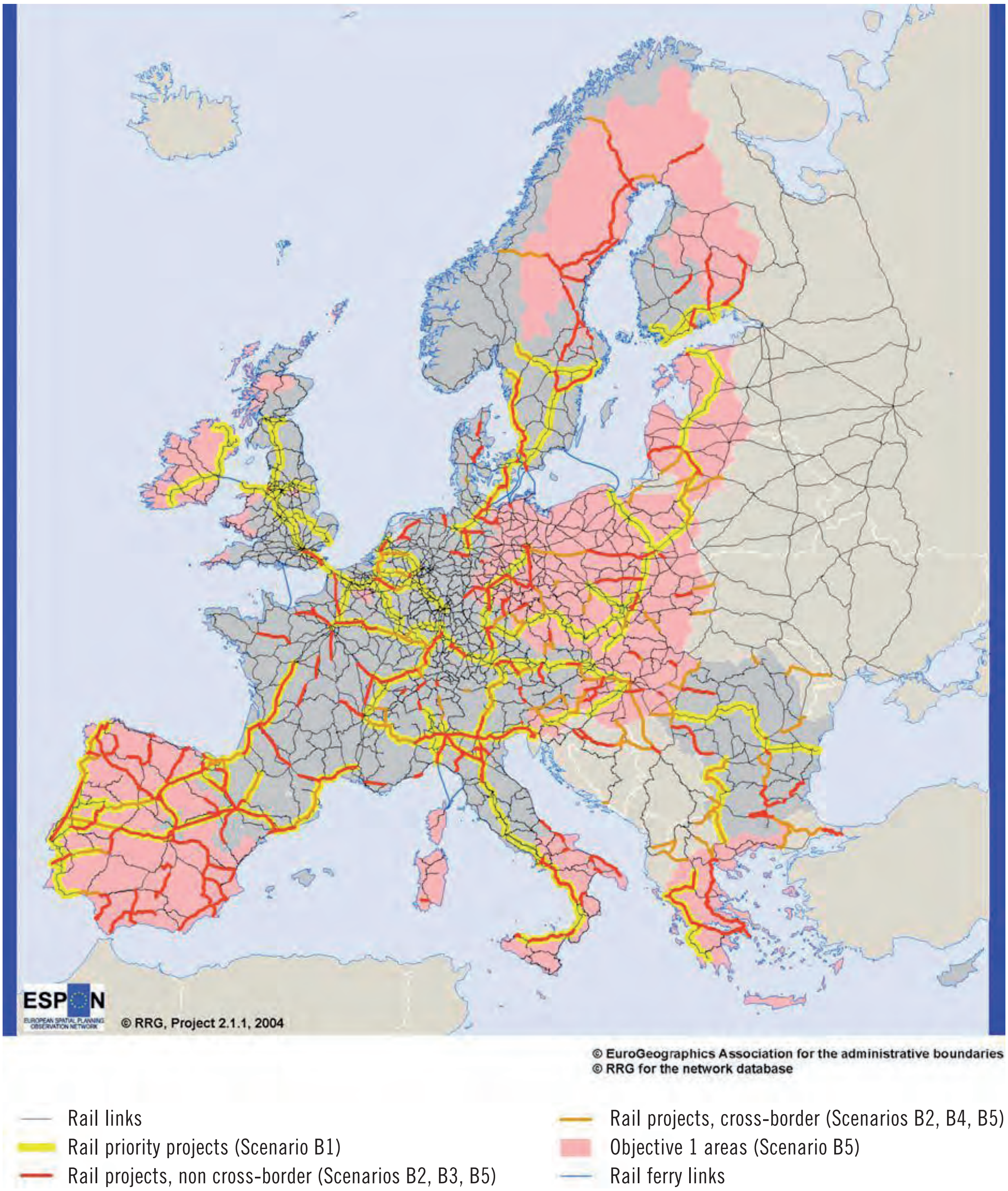
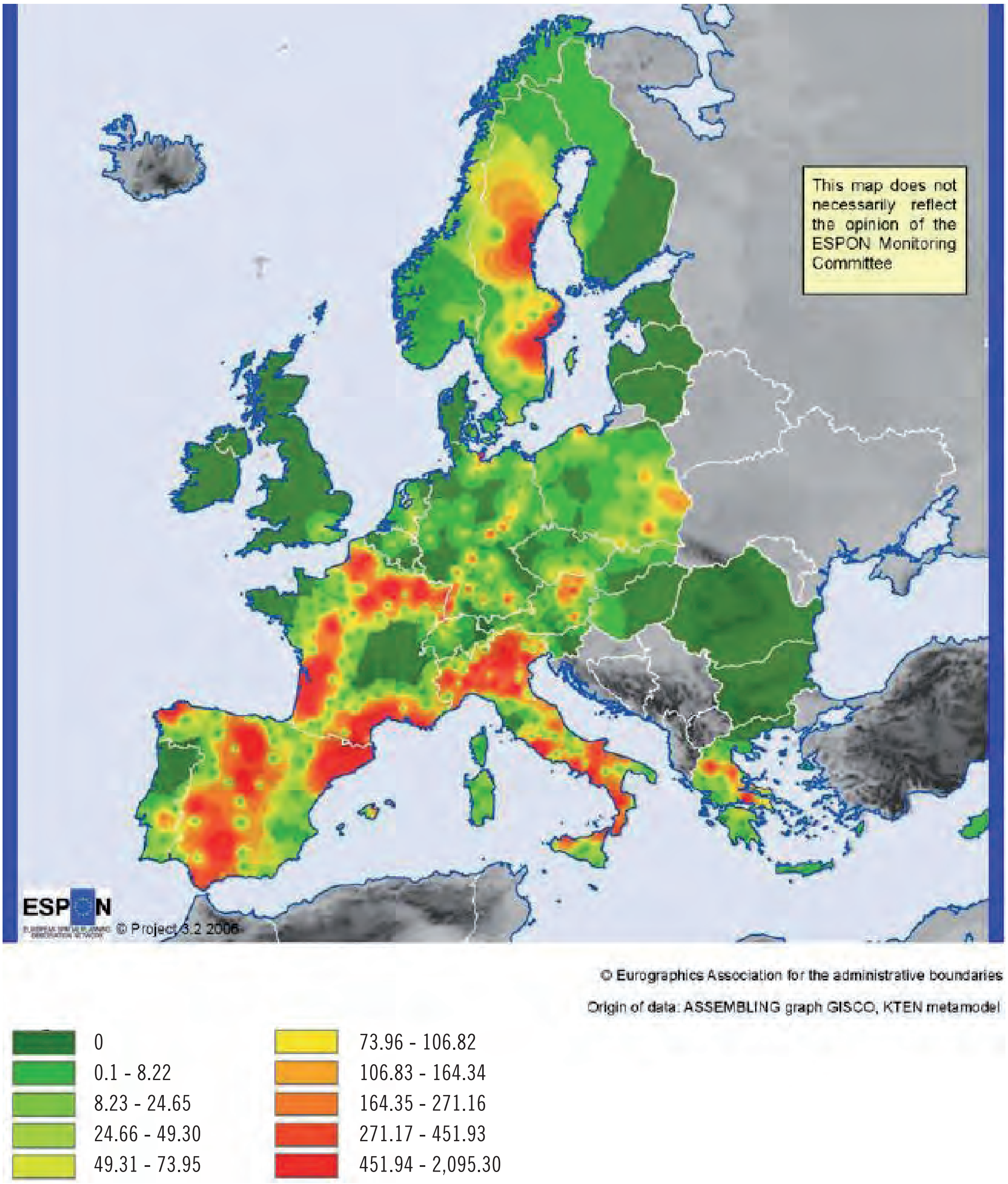
APPENDIX



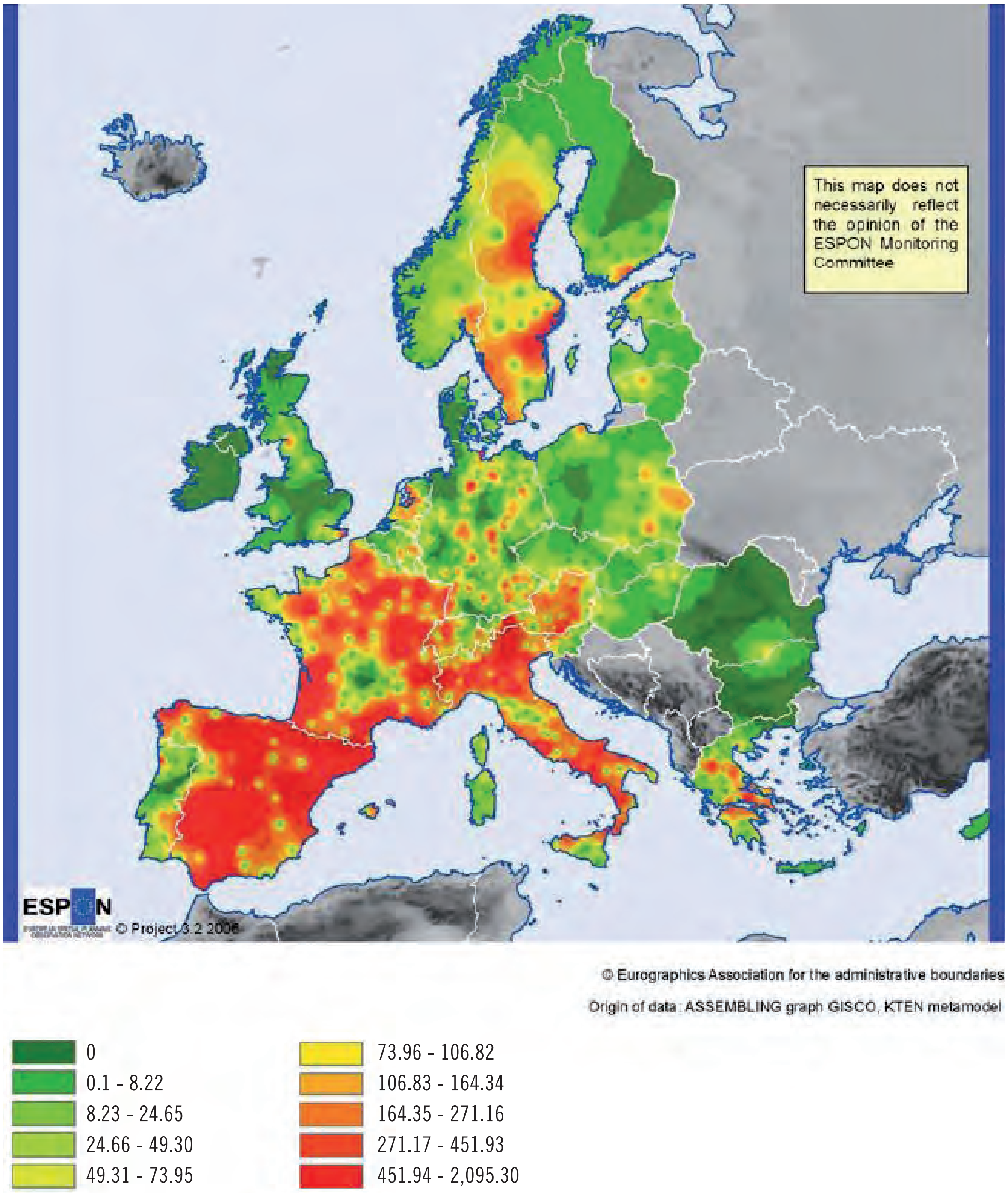
Map 5.A.1. Rail network development to 2021

Source: Bröcker et al. 2004a, 2004b



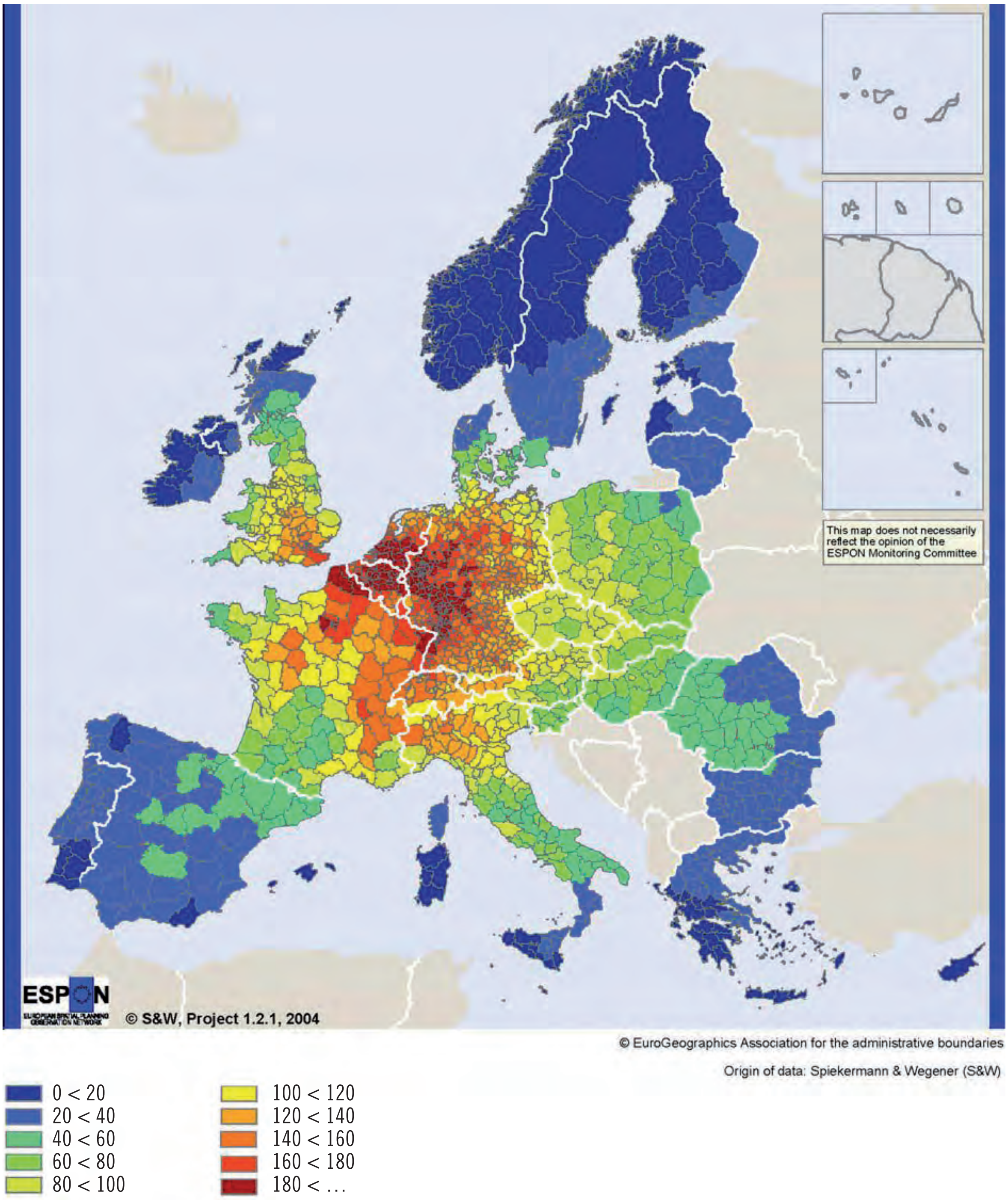
Map 5.A.2. Rail investment (million €) to 2015

Source: Mcrit estimates for ESPON Project 3.2



Map 5.A.3. Rail investment (million €) to 2030

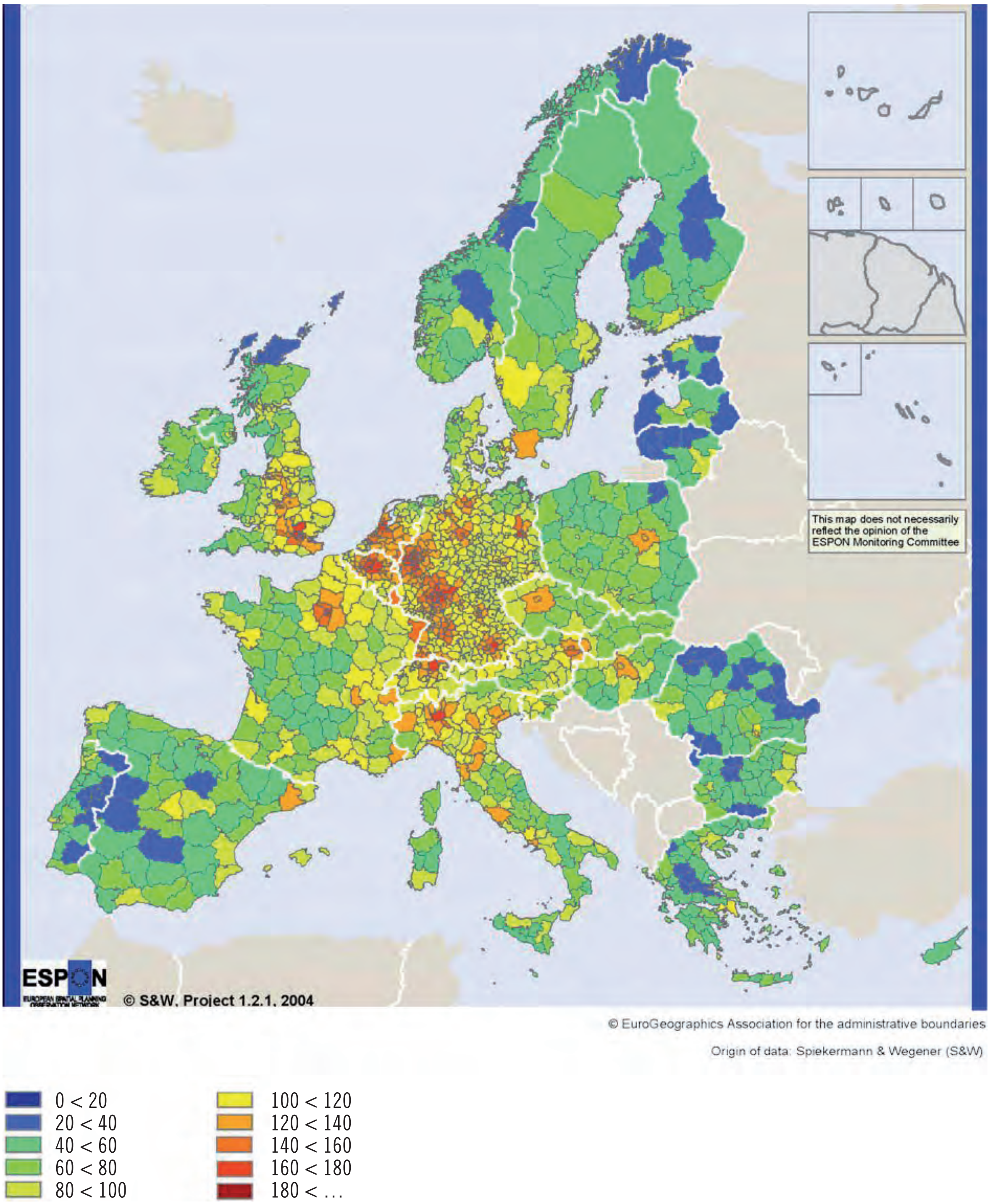
Source: Mcrit estimates for ESPON Project 3.2



Map 5.A.4. Potential accessibility by rail, 2001

Note: Accessibility (ESPON Space = 100)

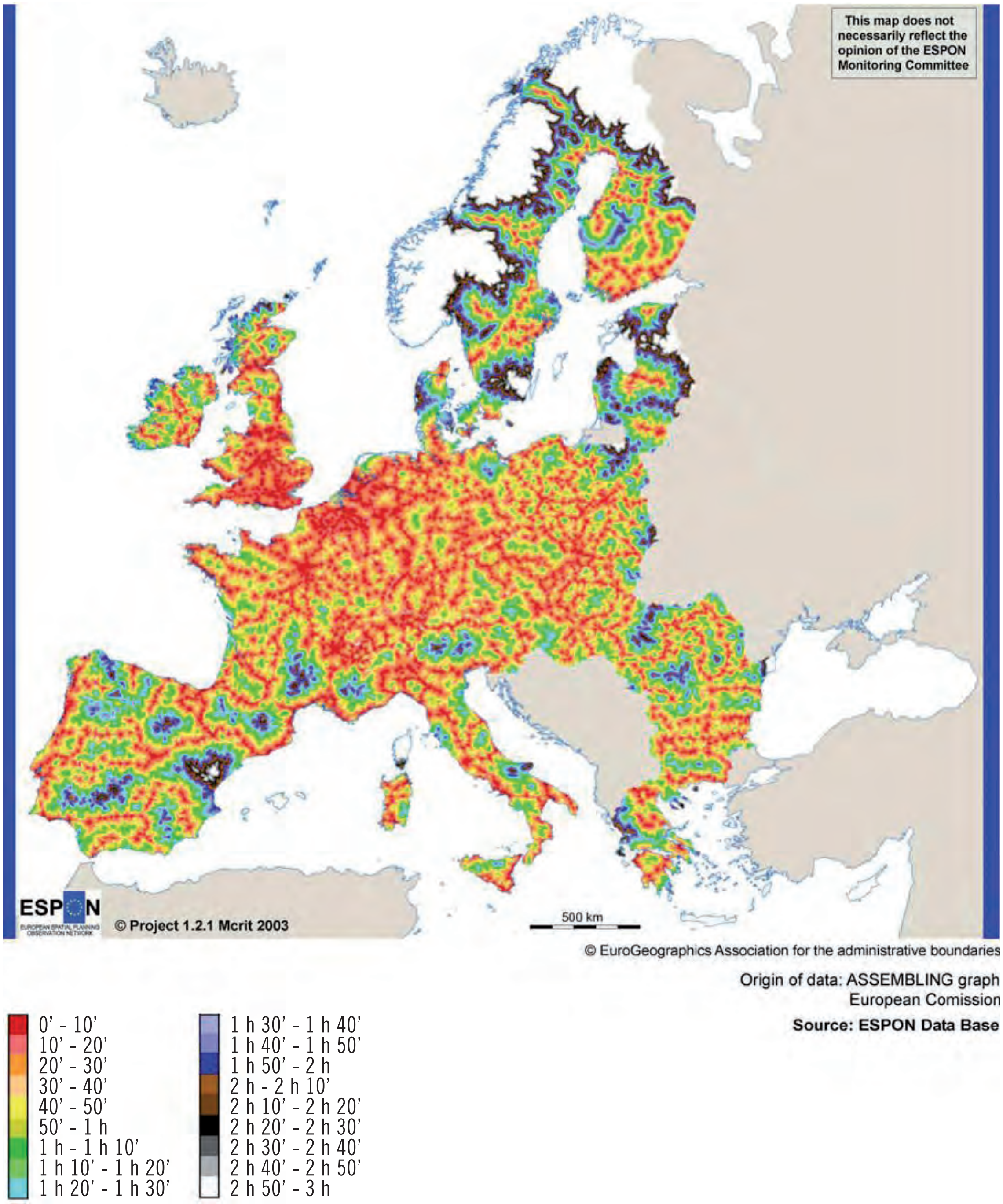
Source: Mathis et al. 2004



Map 5.A.5. Multimodal accessibility (road/rail/air), 2001

Note: Accessibility (ESPON Space = 100)

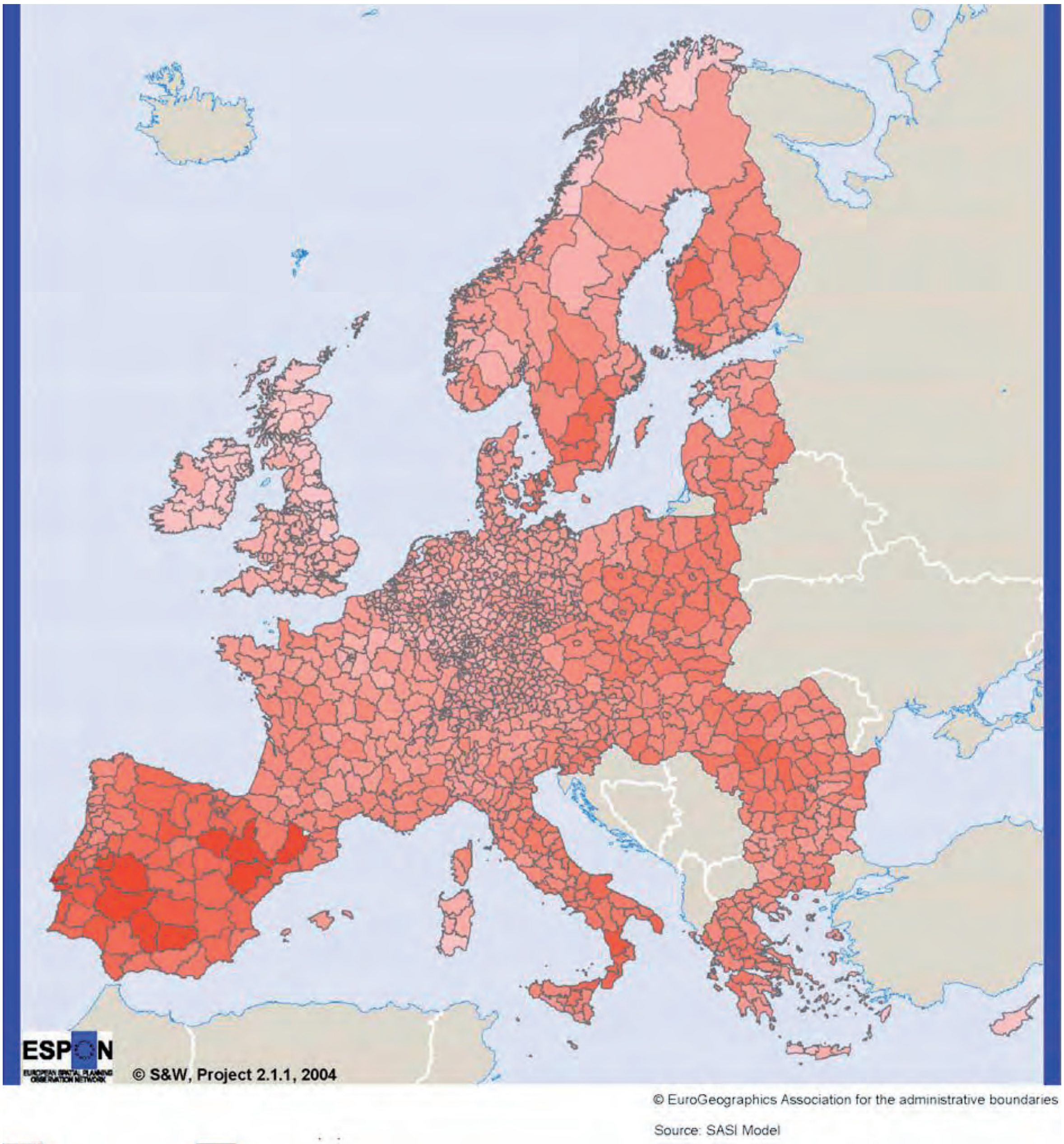
Source: Mathis et al. 2004



Map 5.A.6. Connectivity to rail stations

Note: Access time

Source: Mathis et al. 2004

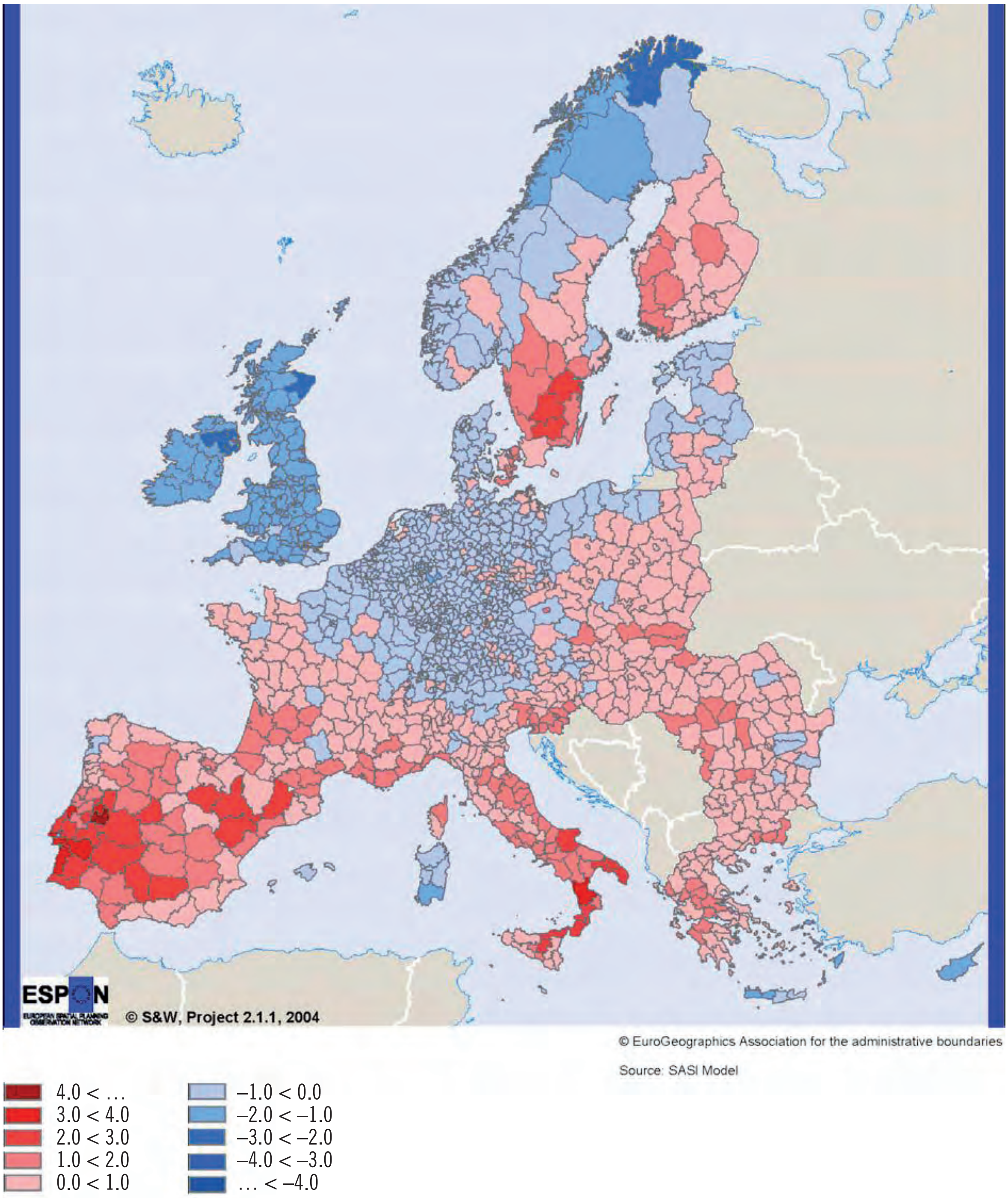


45 < …
40 < 45
35 < 40
30 < 35
25 < 30
20 < 25
15 < 20
10 < 15
5 < 10
0 < 5

Map 5.A.7. Change in accessibility 2001-2021: all TEN/TINA projects completed

Note: Different from reference scenario in 2021 (%)

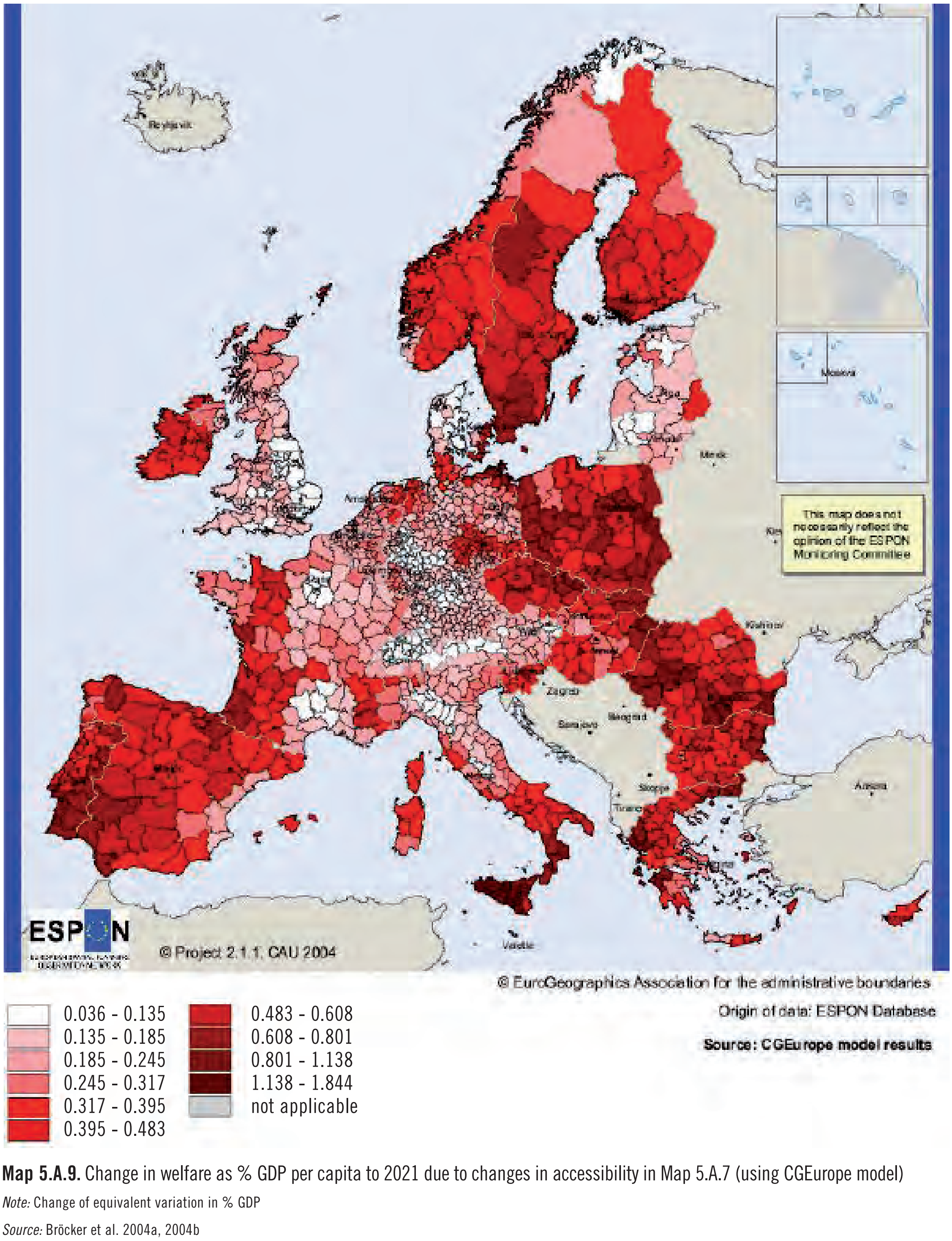
Source: Bröcker et al. 2004a, 2004b



Map 5.A.8. Change in GDP per capita to 2021 due to changes in accessibility in Map 5.A.7 (using SASI model)

Note: Different from reference scenario in 2021 (%)

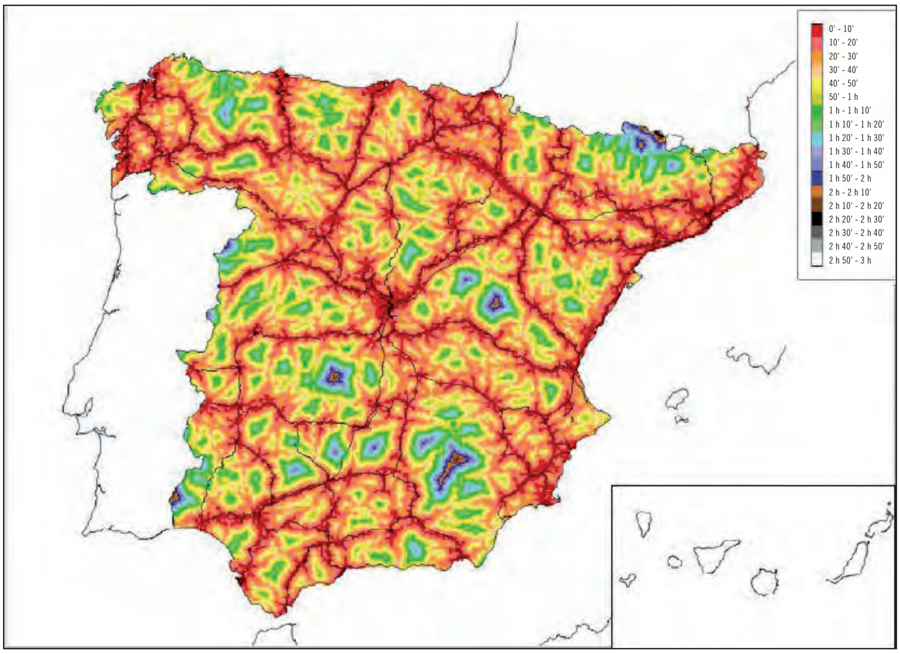
Source: Bröcker et al. 2004a, 2004b



Map 5.A.9. Change in welfare as % GDP per capita to 2021 due to changes in accessibility in Map 5.A.7 (using CGEurope model)

Note: Change of equivalent variation in % GDP

Source: Bröcker et al. 2004a, 2004b



Map 5.A.10. Accessibility to rail, Spain, 2005

Note: Minutes to the closest rail stations by road. MCRIT

Source: CEDEX-Ministerio de Fomento

Map 5.A.11. Rail services, Spain, 2006

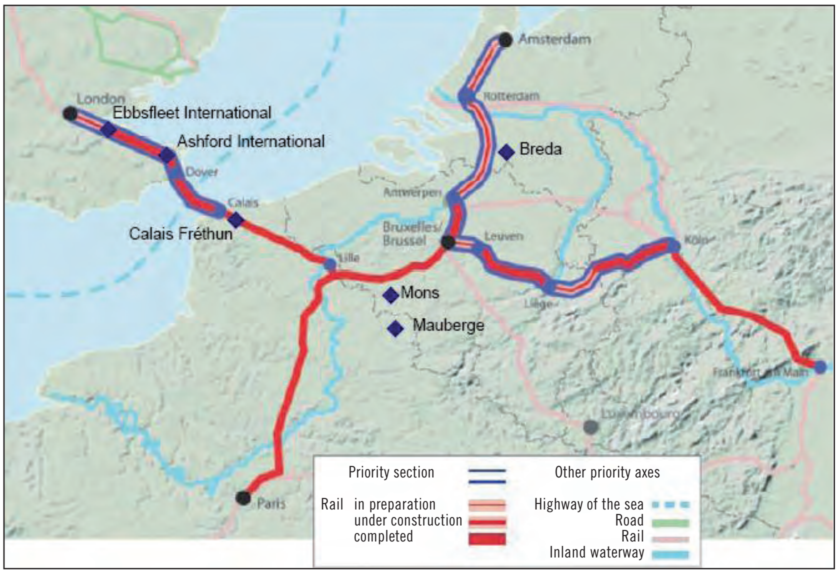
Note: Daily passenger train services, all except metropolitan services

Source: Renfe

Map 5.A.12. HSR Services, Spain, 2006

Note: Daily HSR passenger train services, all except metropolitan services

Source: Renfe

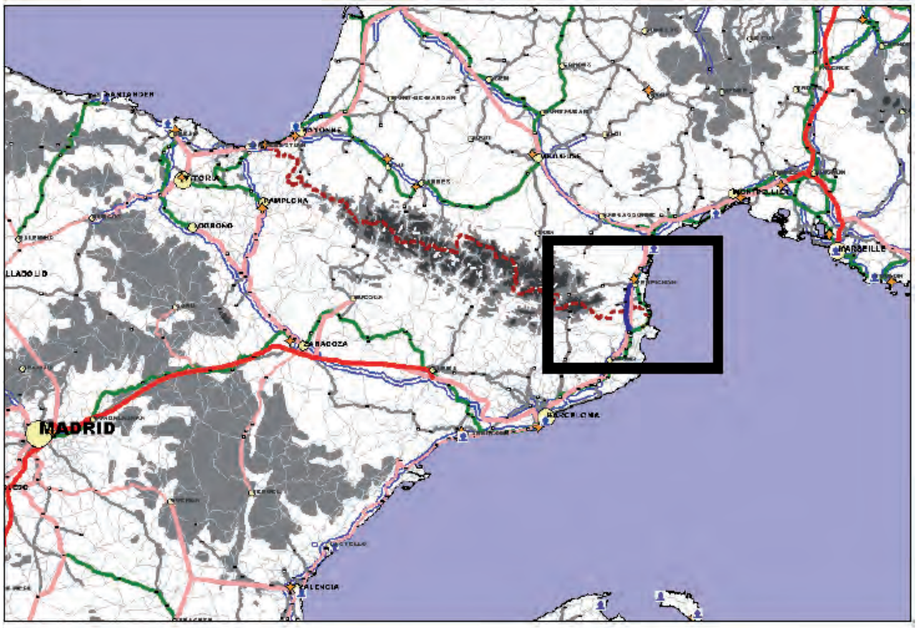


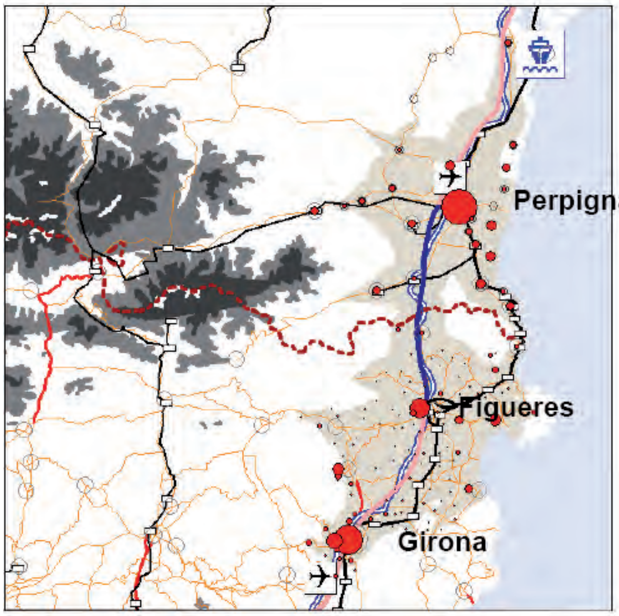
Map 5.A.13. North-West European HSR Network

Source: European Commission, 2005

Map 5.A.14. Channel Tunnel Rail Link and stations

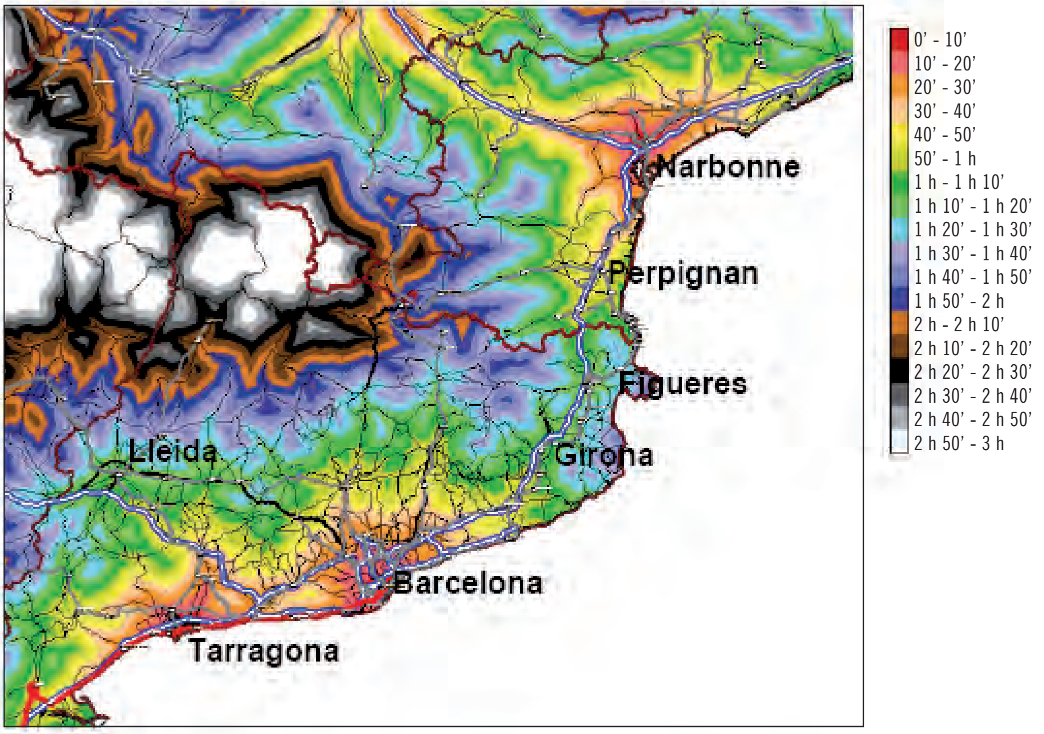
Source: www.lcrhq.co.uk/content/downloads/ctrlroutemaps.pdf



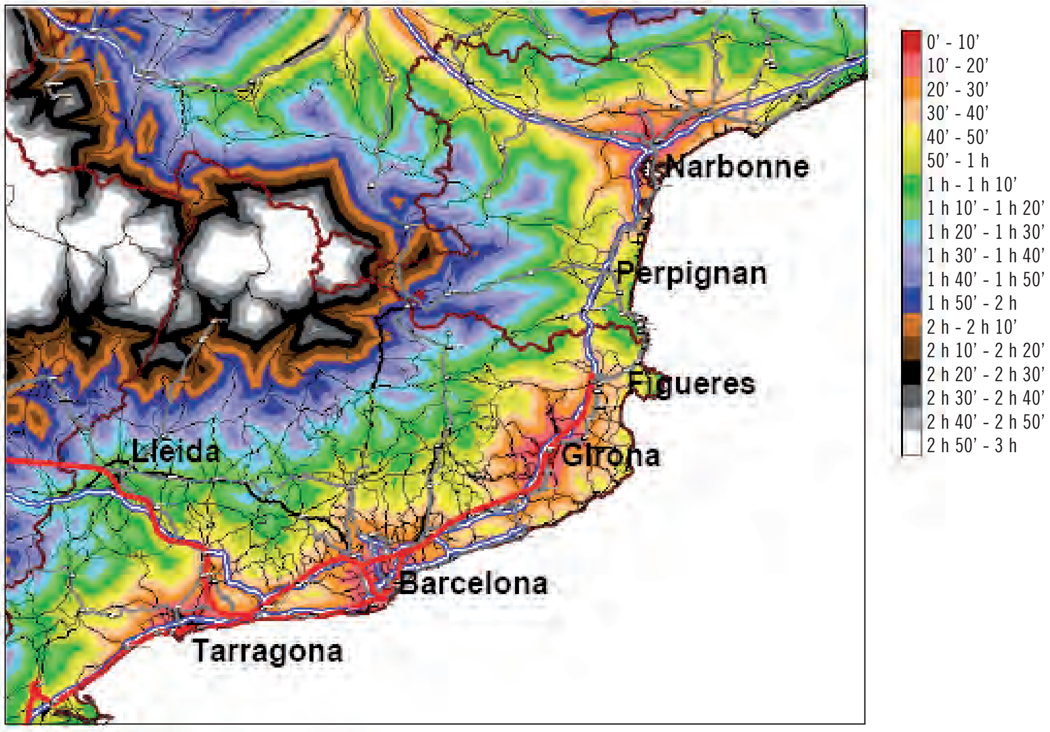


Map 5.A.15. TGV South and the France-Spain border region

Scenario 1 (without project). Surface at less than 30 minutes: 4,619 km²

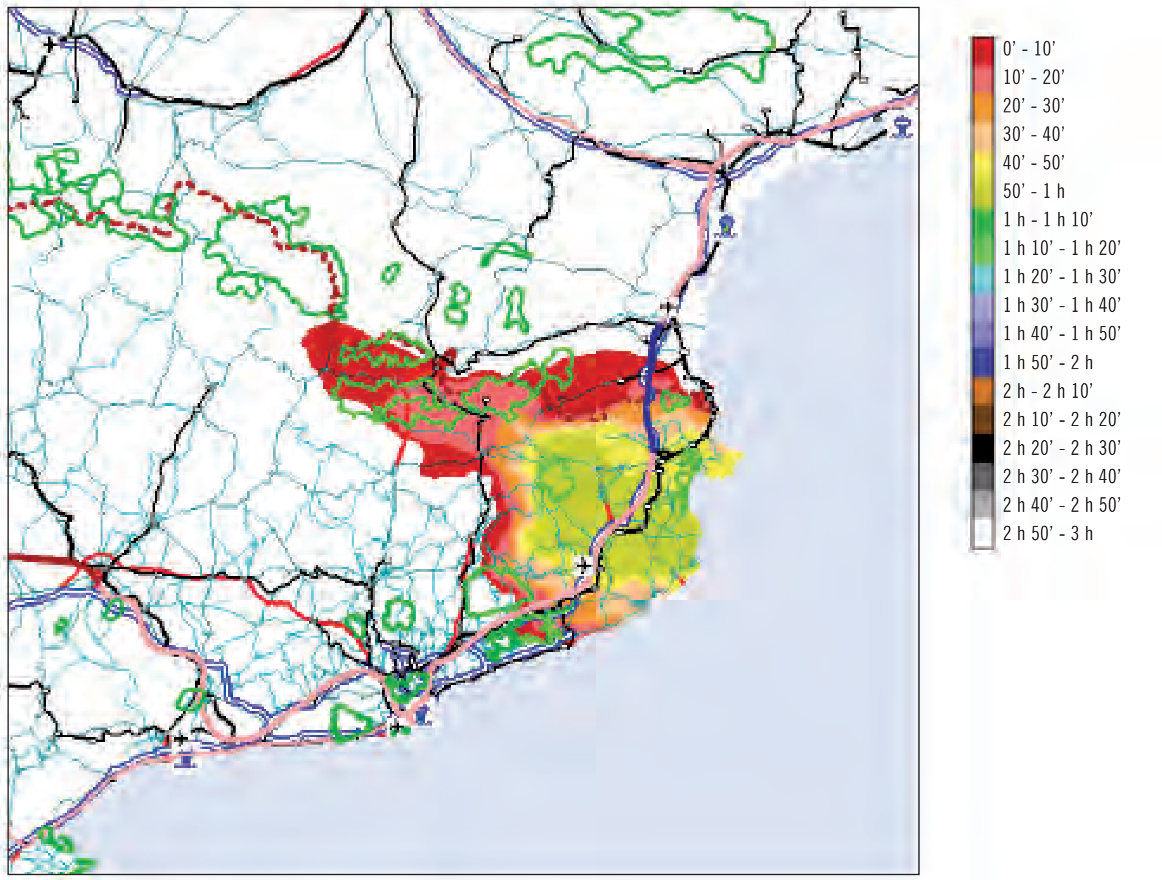


Scenario 2 (without project). Surface at less than 30 minutes: 6,439 km²



Map 5.A.16. Accessibility with and without HSR services

Scenario1 - Scenario 2: Savings of 458 hours/km² in the interior of protected areas



Map 5.A.17. Impacts of changes in accessibility on protected areas

Conclusions

Investment in high speed rail infrastructure has dramatically modified the position of the railway within the set of transport alternatives the passenger faces in his travel choices. Although the decline of the market share of railways has not changed, high speed trains have contributed to a substantial recovery of rail market share in medium distance corridors, where they compete with road and air transport.

High speed rail generates social benefits, which come from time savings, increase in reliability, comfort and safety, and the reduction of congestion and accidents in alternative modes. Releasing capacity in the conventional network, which can be used for freight transport, is an additional benefit of the investment in the construction of new lines.

The key question, central to this research project, is to determine whether the mentioned social benefits are greater than the costs the society incurs to carry on the construction and operation of high speed lines. In other words, the question is not whether we like high speed rail or not, but whether we are willing to pay its costs.

We analyzed under what circumstances the society may benefit from investing in high speed rail, and when it is worthwhile to delay the investment decision. The high speed rail network can be built gradually, adding new lines once the economic evaluation of projects offers some guarantees for the social profitability of public funds. The economic appraisal of new lines has to look carefully to the deviated and generated traffic, the time savings, any additional benefit, and the users' willingness to pay.

It is convenient to reinforce the role of the economic appraisal of the new high speed rail projects, co-financed with European Union funds, instead of using the rhetoric of regional development to support the expansion of the network. High speed rail infrastructure is not good or bad in global terms. There are socially profitable projects, and others which are not. Economists can help to identify those projects which are socially worthy, and whose benefits justify the sacrifice of leaving other social needs unattended. This research project hopes to contribute to this aim.

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