A review of HSR experiences around the world

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ECONOMIC ANALYSIS OF HIGH SPEED RAIL IN EUROPE

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Chapter 1:

A review of HSR experiences around the world

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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 kilometres of new high speed lines in operation around the world and, in total (including upgraded conventional tracks), more than 20,000 kilometres of the worldwide rail network was devoted to provide high speed services to passengers willing to pay for a lower travel time and a quality improvement in rail transport.

Just in Japan, were the concept of *bullet train* was born in 1964, 100 million passenger-trips have been performed per year during the last 40 years. 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 more: it is expected to reach 25,000 kilometres of new lines by 2020 (UIC 2005a).

However, building, maintaining and operating HSR lines is expensive, 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 paper is to discuss some characteristics of the HSR services from an economic viewpoint, while simultaneously developing an empirical framework that 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 carried out under different economic and geographic conditions.

This is particularly relevant because the economic magnitude of HSR investments and the described prospects for network expansion are not in correspondence with the research

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

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 have been 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 assessment has been based on individual countries case studies, we will adopt an international comparative perspective. We have 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 the planned 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 has been 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 in the planning stage, some of them pending of further approval and/or funding. The projects in operation and construction have a total length of 16,400 kilometres, 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

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[2] The analysis carried out in this paper and, in particular, the list of HSR projects, is 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 (accessible 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.

what is (on average) the cost of building a kilometre of (new) high speed line, and 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 the 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 evolves the demand path for high speed services around the world and try to look for a pattern to predict for how long it will it go 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 that could be reached by trains 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]

- specially built high speed lines equipped for speeds generally equal to or greater than 250 km/h,
- specially upgraded conventional lines, equipped for speeds of the order of 200 km/h, and
- specially upgraded conventional lines, which have special features as a result of topographical, relief or town-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

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[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).

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]

Although HSR share 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 removes the need for drivers to see lineside signals.

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

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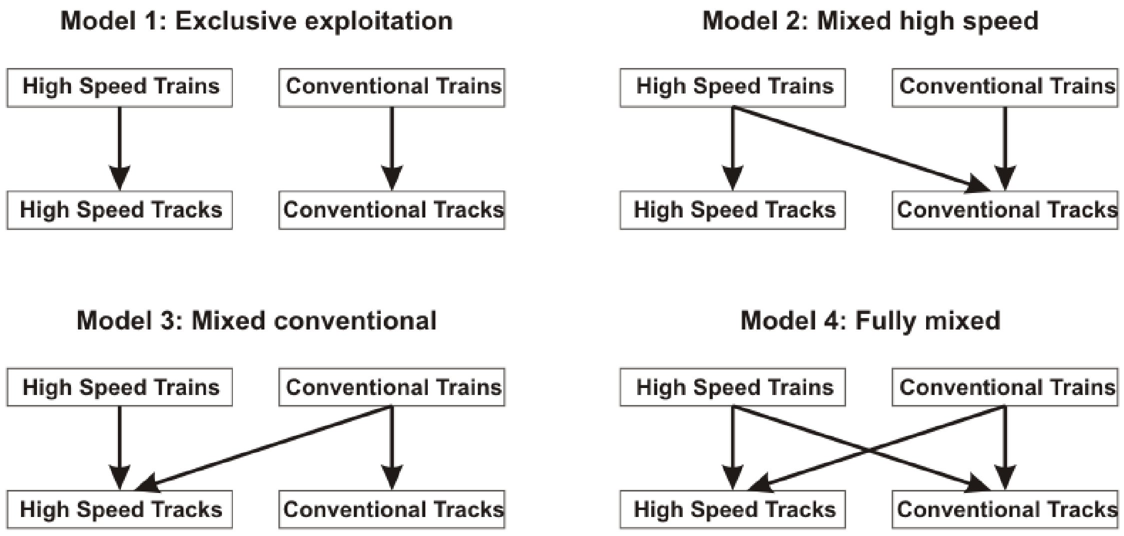
[6] The average commercial speed in several (supposedly) high speed services over the densest areas in North-Europe is often below the average speed of some conventional lines, running between distant stops through sparsely populated plain areas. New maximum speed tests have been recently (2007) announced 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 paper.

Figure 1.1. HSR models according to relationship with conventional services



All these differences suggest that – more than speed – it is the relationship of HSR with existing conventional services and the way in which it is organized the use of infrastructure what plays a more relevant role in the economic definition of high speed services. As summarized in Figure 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 adopted by the Japanese *Shinkansen* 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) 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,

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[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).

whose TGV (*Train à Grande Vitesse*) have 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 on the main advantages of this model.

3) The "*mixed conventional model"*, where some conventional trains run on high speed lines, has been 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 – which are also capable of using at higher than normal speed the specific HSR infrastructure (built in standard gauge).[9] The main advantage of this model is 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 determines in a different way the provision of HSR services depends on the traffic management restrictions, that can be better understood with the help of Figure 1.2.

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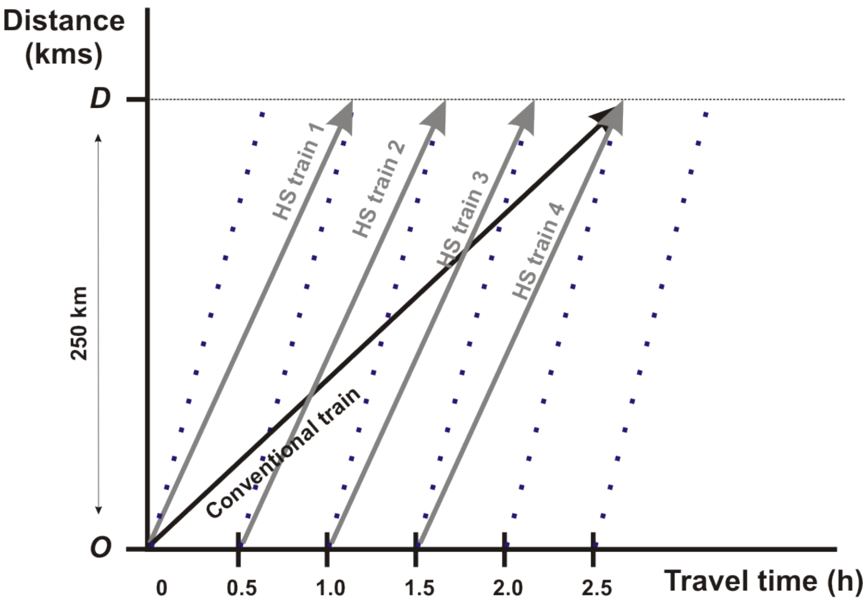
[9] The wheels in TALGO trains are mounted in pairs, being between rather than underneath the individual coaches. They are not joined by an axle and, thus, the trains can lightly switch between different gauge tracks.

Figure 1.2. Time slots in railways and the provision of HSR services



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 depends 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.

For this reason the network exploitation models in Figure 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 Figure 1.2, at least four high speed trains are precluded by the operation of a single conventional

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[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.

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 the daytime, while freight trains go at night. In some cases, night-time high speed trains are even diverted to lower speed lines in favour 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 an (very relevant) economic one. Three additional factors contribute to the definition of HSR in economic terms:

1) 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 be 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 represents a huge long-run investment for the companies (often, for more than 20 years), and critically determines the provision of high speed services.

2) 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 network 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.

3) 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 factor in the survival of their passenger rail services. In fact, HSR has been started to be publicized – particularly in France or Spain – as a different mode of transport, as a system with its own right that encompasses both a dedicated

infrastructure with a more and 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 technologies 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 paper.

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 but, 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 Figure 1.1).

These common design features do not imply that all HSR projects are similarly built. Just the opposite; the comparison of construction costs between different HSR projects is difficult since the technical solutions adopted in each case to implement these features do not only differ widely (depending on topography and geography), but also evolve 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 others (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% in the total investment amount.

- *"Infrastructure building costs"* include all those costs related to terrain preparation and platform building. Its amount varies widely across projects depending on the characteristics of the terrain, but usually represent 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) plus the sidings along the line, signalling systems, catenary and electrification mechanisms, communications and safety installations, etc. Individually considered, each of these elements usually represents between 5-10% of 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 with the pre-existing infrastructure. 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 as integrated with Paris-Lyon and the French high speed network.
- *Smaller extensions or complements of existing corridors*, such as Madrid-Toledo or Lyon-Valence, which are 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 that follows we have only

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[11] In most projects the superstructure costs often include building standard stations and auxiliary depots that, according to their architectonic characteristics cannot be considered as singular projects by themselves. 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 less. There also are other minor (supervision, quality control, etc.) in each project that may represent between 1-5% of the total investment.

considered 45 projects. We have 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 still are at planning stage, even when investment information was available have also been excluded. The reason for this latter exclusion is that, at this stage, deviation over planned costs is often substantial, as pointed out in the literature (see Flyvbjerg et al. 2004, for example).

Figure 1.3 summarizes the average cost per kilometre of building HSR infrastructure found in our database. The values are expressed in euro millions (2005) and include the infrastructure and superstructure costs, but not the planning and land costs. Overall, the construction cost per kilometre in the sample of 45 projects varies between 6 and 45 millions (with an average value of 17.5 millions). When the analysis is restricted to projects in operation (24 projects) the range varies between 9-39 million (with an average of 18.0 millions). 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]

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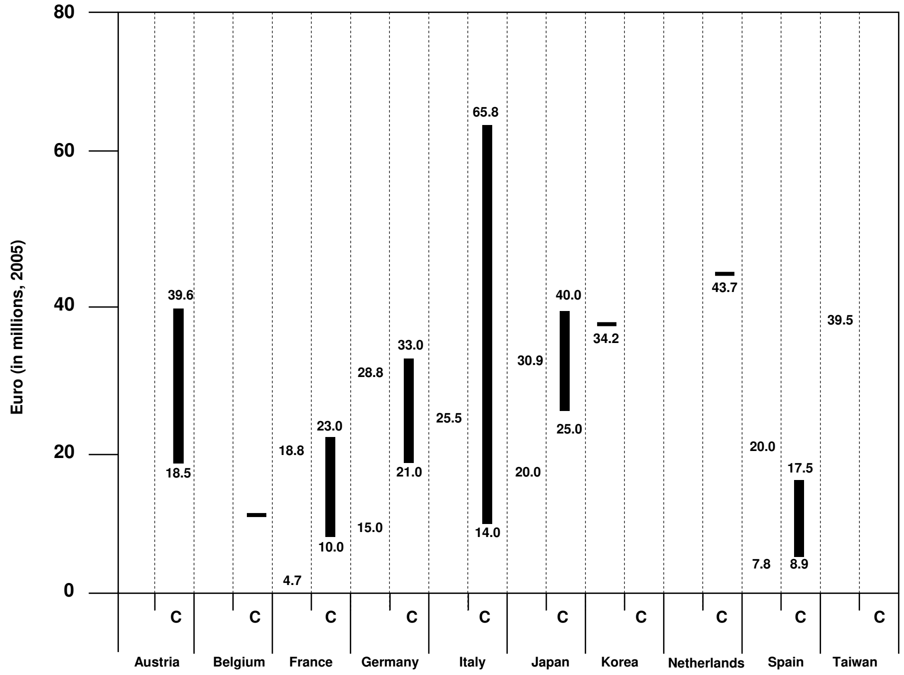
[12] This is qualitatively consistent with the comparison performed by SDG (2004), although the costs included in UIC (2005b) are different. Several individual projects reported in SDG (2004) – such as the HSL Zuid (Netherlands) and the Channel Tunnel rail link – have construction costs per km in the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

Figure 1.3. Average cost per kilometre 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*

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 centres, but also by construction procedures. In France, for example, the cost of construction is minimised by adopting steeper grades rather than building tunnels and viaducts. Because the TGV lines are dedicated to passengers (the exclusive exploitation model of Figure 1.1), grades of 3.5%, rather than the previous maximum of 1-1.5% for mixed traffic, are used. Although more expensive land is acquired in order to build straighter lines, 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 has been 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 in 2007), it can be observed 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 kilometre (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 kilometre 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 cost per kilometre 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 has been 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]

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

[14] This section deals only with the private costs faced by the infrastructure management agencies and the HSR operators. *Section 1.5* is devoted to the discussion of some of the external costs associated to 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 or while maintaining vertical integration see Gómez-Ibañez and de Rus (2006).

1.4.1. Infrastructure operating costs

This category includes the costs of the labour, energy and other material consumed by the 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 to technical and safety standards. In other cases, as in the maintenance of tracks, the cost is affected by the traffic intensity; similarly, the cost of maintaining electric traction installations and the catenary depends on the number of trains running on the infrastructure. According to the UIC statistics (UIC, 2006), the proportions of the cost of labour 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.

Table 1.1. Cost of HRS infraestructures maintenance by country

	Belgium		France		Italy		Spain	
Kms, of single track	142		2,638		492		949	
Maintenance of track	13,841	43.7%	19,14	67.3%	5,941	46.0%	13,531	40.4%
Electrification	2,576	8.1%	4,21	14.8%	2,455	19.0%	2,986	8.9%
Signaling	3,248	10.3%	5,07	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%	28,42	100%	12,919	100%	33,457	100%

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

Source: Elaborated from UIC (2005b).

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]

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 in almost the same in both networks.

From Table 1.1 the cost of maintaining a high speed rail line ranges from 28 to 33 thousand euros (2000) per kilometre 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 millions 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, labour 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 labour costs for ticket sales and for providing information at the railroad stations.[17] The remaining three components vary widely across projects depending on the specific technology used by the trains.

In the case of Europe, almost each 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), but in 1996 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*.

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[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.

[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.

Table 1.2. HRS technology in Europe: types of train

Country	Type of train	First year of service	Seats	Average distance (kms)	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.

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 just summarizes those related to capacity and speed, as well as 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 period of time trainsets stay at the depot. The remaining train operations include train servicing, driving, and safety and their costs consist almost exclusively of labour costs. Their amount varies across countries depending on the operational procedures used by the rail operator.[18]

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

Table 1.3. Comparison of operating and maintenance cost by HRS technology

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 UIC. Data in 2002 values.

(*) Under revision by the UIC.

The energy costs can be estimated from the average consumption of energy required per kilometre, 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 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 what are the most relevant stylized facts regarding the external costs of HSR.

The key question with environmental costs is related to the comparison with other modes. As long as price is 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 given trip depends on the amount of energy consumed and the air pollution from the electricity plant generated to produce it. Due to the potentially high diversity of primary energy sources used in each country, it appears to be relatively complex to make comparisons about air pollution emissions by HSR.

It is generally acknowledged; however, that in comparison with 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 litres of petrol 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 in the case of 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 favourable to HSR. Railways noise mostly depends on 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). There have been made measurements for noise levels of different high speed train technologies, and the values obtained ranged from 80 to 90 dB(A), which are disturbing enough, particularly in urban areas. Levinson *et al.* (1997) refer that it has been calculated that in order to maintain a

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[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 this source.

(tolerable) 55dB(A) background noise level at 280 km/h, one needs about a 150 metres corridor.

This final distance is important because it has been generally omitted in the traditional comparisons of land occupancy between HSR and, for example, a motorway, 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 build 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 passengers' fatalities per billion passenger-kilometres. 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 separately considered, since they are always included into the items related to terrain movement and preparation. Although 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, the final balance depending 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 complaint 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 would 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 accidents, noise, air pollution, climate change, urban effects and upstream/downstream effects, but not congestion or scarce capacity. High speed rail 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 over this corridor than conventional rail on the much longer Paris-Vienna corridor; over longer distances the advantage over air is reduced as much of the environmental cost of air is at take-off and landing (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 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.

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[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.

With respect to Europe, in 2005 it was reached a record of 76 billion of passenger-km. In the 1994-2004 period traffic evolution has 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 the other demand driving forces, namely prices, quality and income, this growth has been strongly dependent on the progress in building the 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 in 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.

This 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.

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[21] Compared to and 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)

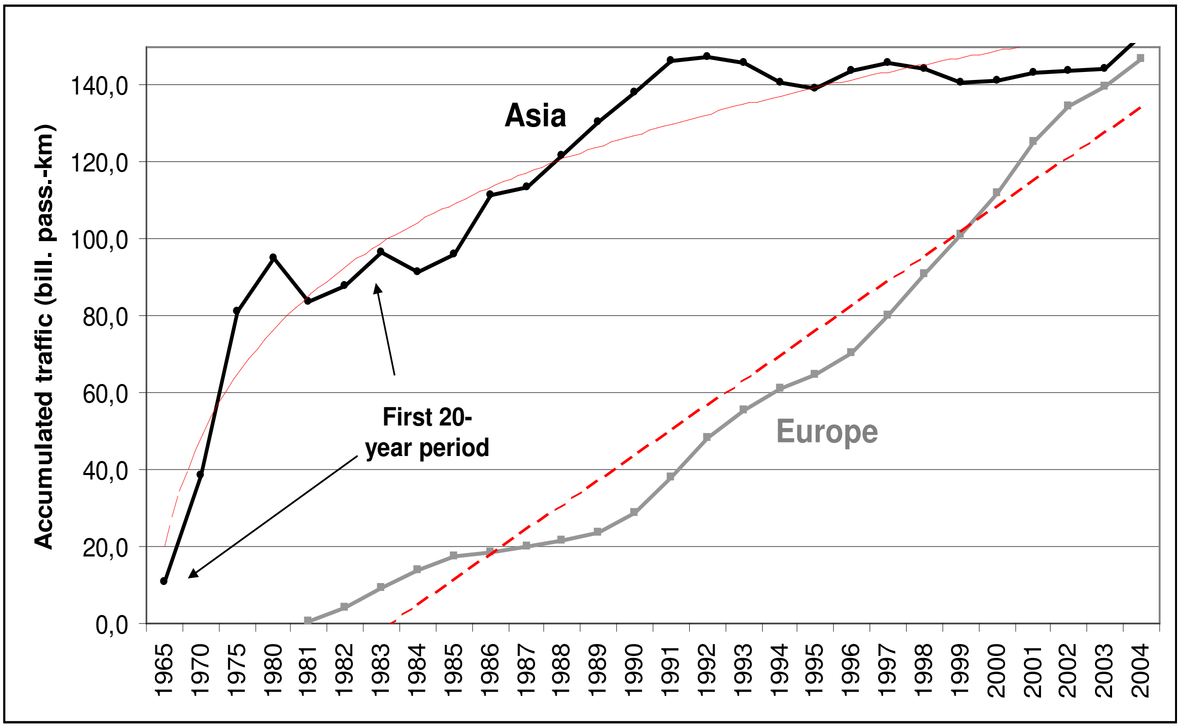
	France		Germany		Italy		Spain		Others		Europe	
	Pass-km (bn.)	**Growth rate (%)**	**Pass-km (bn.)**	**Growth rate (%)**	**Pass-km (bn.)**	**Growth rate (%)**	**Pass-km (bn.)**	**Growth rate (%)**	**Pass-km (bn.)**	**Growth rate (%)**	**Pass-km (bn.)**	**Growth rate (%)**
1994	21,9	–	8,2	–	0,8	–	0,9	–	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 from UIC (2005b) and companies' information.

The information contained 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 has been expanded during the 1994-2004 period. The data provides aggregate information of demand trends.

Comparing the evolution of aggregated traffic in Asia and Europe (Figure 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 has halved, and "only" 50 billion additional passenger-km have 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 Figure 1.4) at least until the high speed transport markets start to mature as in Japan.

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



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

1.7. Conclusions

This paper 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 them pending of further approval and/or funding.

From this information, the paper has started by discussing the economic definition of *high speed rail*, showing that it is not speed but the network exploitation model what really determines this concept. Our next step has consisted 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 kilometre (excluding planning and land costs) varies between 6 and 45 millions of euros (in 2005). When the analysis is restricted to projects in operation (24 projects) the cost varies between 9-39 million.

In order to obtain an empirically based approach to the true costs of high speed rail, a similar analysis has been 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 kilometre of single track. Excluding some extreme cases, the average cost of HSR infrastructure maintenance of a 500 km HSR line is equal to 30 millions euros per year.

With respect to social costs, since the available information from the projects in our database is limited, we have relied 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 depending heavily on load factors and the primary energy source. In the case of noise, the modal comparison is also favourable to HSR but highly dependent on the proportion of urban areas crossed by the HSR line.

HSR appears to be the safest mode in terms of passengers' fatalities per billion passenger-kilometres. 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, the final balance depending on the value of the geographical area affected.

Finally, we have briefly discussed current demand of HSR in aggregated terms and tried 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 paper has been 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 carried out under different economic and geographic conditions.