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In what circumstances is investment in HSR worthwhile?

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In what circumstances is investment in HSR worthwhile?

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1. Introduction

By High Speed Rail (HSR) we normally mean rail technologies capable of speeds of the order of 300km ph 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 600b euros, of which 250b 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 happened in the case of the Trans European Networks. Individual projects are suggested by, and appraised by, member state governments, even though they are applying to 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 programme to ensure that they are all worthwhile (TML, 2005).

The aim of this paper 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 an 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 four of the paper we formulate a model to incorporate the principal parameters influencing the outcome of an appraisal and in section five we use this model to draw conclusions on the circumstances in which high speed rail may be justified.

2. Overview of costs and benefits

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 unfavourable, 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' 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 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 has been 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.

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 kilometre is very high but creates very large capacity (assuming 12 trains per hour with 700 passengers per train gives 8400 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 centres 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 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 1 (CE Delft, 2003). Whilst HSR may involve twice the energy consumption per seat km of an average train this 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.

Table 1

Energy Consumption

(MJ/Seat Km)

Petrol car on motorway	0.47
Diesel car on motorway	0.34
Passenger aircraft on 500 km flight	1.8
Inter City Train	0.22
High Speed Train	0.53

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

Source CE Delft (2003)

What matters in assessing the overall environmental impact of the HSR is not only load factors 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 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.

2.3 Benefits

The principal benefits from HSR are:

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

Each of these elements will be discussed in turn.

Compared with a conventional train running at 160kmph, a high speed train will save some 35 minutes on a journey of 450km (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 2. The high value for business time is based on the fact that much business travel takes place during working hours and directly reduces labour 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
- 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 implies by current valuations even in these 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 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.

Table 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)

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 et al, 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 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, and show high speed rail between Paris and Brussels to 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 does 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.

Table 3

External Costs (euros/1,000 pkm)

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

Source: INFRAS/IWW (2000)

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

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 asome on rail but not air and in some on neither). 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) means 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 centres on whether these changes really are additional economic activity or whether it 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 relocated jobs to depressed areas, it may reduce involuntary unemployment. The experience of Lille, which has been regenerated by its location at the cross roads of high speed lines between Paris, Brussels and London is often cited as an example. High speed rail tends to favour 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 encourage the location of jobs in major urban centres 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).

Vickerman (2006) concludes that HSR may have additional benefits for these 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; they will typically 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 favour 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 favour investment in HSR.

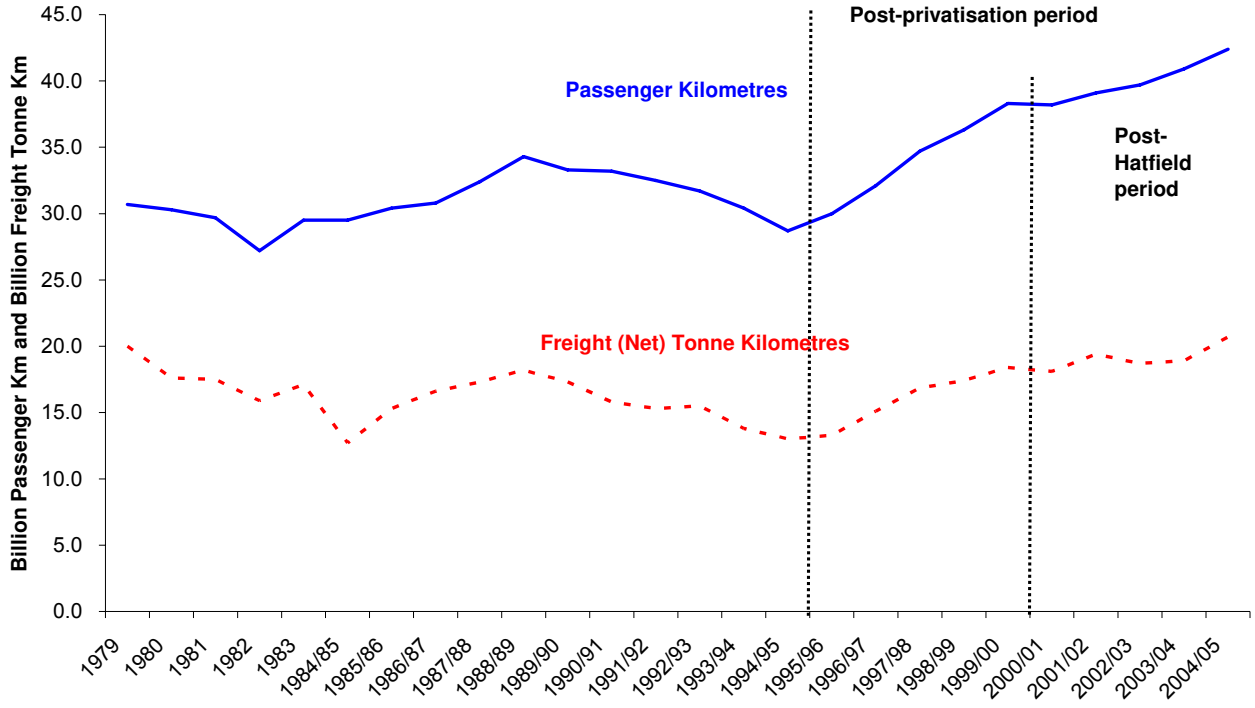
3. Empirical examples

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.

3.1. British HSR proposals

The Atkins study took place in a context of rapid growth in rail passenger and freight traffic in recent years (Fig 2), 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 existing routes, as well as providing 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 two 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 British 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 could serve Manchester.

Figure 2: Rail Passenger and Freight Volumes (1979 to 2004/05)



Sources: Transport Trends, 2002 Edition, Department For Transport and National Rail Trends, SRA

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

It was forecast that the new line if built to its extremities would attract nearly 50m 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 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% programme 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 4. Option 1 is the line from London to the West Midlands. which is the obvious first phase of any high speed rail programme in Great Britain, and is seen to be well justified in its own right. But option 2, the extension through to both Manchester on the West Coast route and right through to 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 favoured 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 5. Some 78% of benefits take the form of time savings and reduced overcrowding with 19% due to increased net revenue and only 3% 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 modelled. 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.

Table 4. Appraisal of Options 1 and 8 (£bn PV)

	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

Table 5: Cost Benefit Analysis Results, Option 1

	% of Total Benefits or Costs
Benefits – Revenue	
HSL 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%
HSL Operating	41%
Classic operating	-9%
Present Value Costs	**100%**

Source: Atkins (2003) unpublished full report

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.

3.2 Spanish Experience[1]

The construction of the first high-speed line in Spain was carried out between 1987 and 1993. The Madrid-Sevilla line started its operations in April 1992, with a demand highly influenced by the Universal Exhibition held at Sevilla in 1992 (EXPO) and the pricing policy applied by RENFE.[2]

The Madrid-Sevilla corridor includes several routes[3] (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-Sevilla 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-Sevilla 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 Sevilla, the introduction of the HST has induced a demand downshift of 50%, diminishing the load factor and flight frequency. The Sevilla airport suffered a reduction of 25% in its use, as Madrid-Sevilla represented 50% of airport traffic. Given the investments which were carried out in the airport of Sevilla in order to accommodate the peak of demand induced by the exhibition EXPO-92, and more recent investment at Barajas airport in Madrid, it is unlikely that this diversion will have significantly reduced congestion although it will certainly have reduced pollution from air transport.

For conventional railway transport, RENFE has also been affected by the introduction of the new product. The Madrid-Sevilla, 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

[1] See De Rus and Inglada (1993) (1997).

[2] Price reductions of 30% for the journey Madrid-Sevilla and 50% for Madrid-Ciudad Real were introduced in order to offset the effects of the demand decrease after the closure of EXPO (October 1992). These low prices have induced high-load factors for HSR, but are far from allowing the company to break even.

[3] Madrid-Sevilla, Cordoba, Ciudad Real, Puertollano, Malaga, Cadiz and Huelva; Cordoba-Sevilla, Ciudad Real and Puertollano; Sevilla-Ciudad Real and Puertollano; and Ciudad Real-Puertollano. Destinations not serviced by high-speed trains, namely Malaga, Cadiz and Huelva, are included because *Talgo* services use part of the HSR track.

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 HST has been 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.

In order to evaluate the economic effects of HST, 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-Sevilla corridor have been consulted, and real data of HSR for the period 1992–1994 and four months of 1995 have been 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) have been obtained for each market segment (commuters, long distance and Talgo) and each transport mode.

The evolution of demand for the 30 years 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 has been 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 labour. HSR infrastructure was built between 1987 and 1992, at a cost (including taxes) of 500 billion pesetas of 1996. 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 6. The NPV is -258 billion pesetas at 1987 prices, using a social discount rate of 6%. Table 5 shows the sensitivity of results to different assumptions: life of the project (40 years); shadow pricing of labour; increase of 25% in generalized costs of car, train and bus; 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 of 1987, which indicates that an economic evaluation of HSR, considering all social costs and benefits, reveals an 18% improvement on its performance. As Table 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 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.

Table 6. Benefits of high-speed train in Spain (millions of 1987 pesetas)

	Social benefit of HST*	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	-155.516	-135.265	-135.265
Time savings					
deviated traffic:					
– Conventional train	37.665	39.950	44.582	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	86.718	92.080	102.951	86.718	92.703
Costs savings					
– 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 HST	-258.329	-252.509	-259.533	-221.143	-228.819

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

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 Sevilla (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 5m 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.

4. Breakeven traffic volumes

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 $\overline{p}$ and each year receives Q users, assumed to be constant during the life of the project.[2]

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[3] incurs some annual costs of maintaining and operating the rail track, stations, signalling and other fixed plants, and the operating costs of labour 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 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[4]; 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:

$$I + \int_0^T (C_t + C_q(Q))e^{-rt}dt \qquad (1)$$

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.

[2] We drop this assumption later.

[3] The HSR can be vertically integrated or separated. All the 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 .

[4] 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.

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:[5]

$$\Delta W = \int_0^T \int_{g_1}^{g_0} Q(z) e^{-rt} dz dt + \int_0^T [\overline{p}(Q_1 - Q_0) - C_t - C_q(Q_1) + C_C(Q_0)] e^{-rt} dt - I + \sum_{i=1}^{N} \int_0^T S_i (q_{i1} - q_{i0}) e^{-rt} dt \quad (2)$$

where,

g_0: generalized cost *without* the HSR project.

g_1: generalized cost *with* the HSR project.

$\overline{p}$: 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.

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 (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.

[5] We are not maximizing welfare but obtaining a change in welfare when the government decides to build a new high speed railway line.

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 Diaz, 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 second line of expression (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 $(q_{i1} - q_{i0})$ 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 (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[6], which depends on the magnitude and sign of the distortions and the cross-effects in secondary markets due to the reduction in transport costs[7].

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 some 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.

[6] This is especially relevant for freight transport. The British Department of Transport suggest 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).

[7] These constitute net benefits which have not already been measured in the primary market.

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 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:

$$\int_0^T [B(Q) - C_q(Q)]e^{-(r-\theta)t}dt \; - \int_0^T C_t e^{-rt}dt \; > I \tag{3}$$

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), for the project to be socially desirable the following condition is obtained:

$$\frac{B(Q) - C_q(Q)}{r - \theta}(1 - e^{-(r-\theta)T}) - \frac{C_t}{r}(1 - e^{-rT}) > I \tag{4}$$

Dividing by I and rearranging terms:

$$\frac{B(Q) - C_q(Q)}{I} > \frac{r - \theta}{1 - e^{-(r-\theta)T}} + \frac{C_t}{I}\frac{r - \theta}{r}\frac{1 - e^{-rT}}{1 - e^{-(r-\theta)T}} \tag{5}$$

The economic interpretation of expression (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 ($r-\theta/r_I$) of fixed annual maintenance costs. In the case of a finite project life, the only change is a more demanding benchmark for profitability[8].

According to expression (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 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 $(B(Q)-C_q(Q))$ come mainly from time savings and benefits from generated traffic[9], net of variable costs. These net benefits depend on the volume of demand to be served, the time savings on the line 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 (5) but $\theta = 0$.

The growth rate (θ) in expression (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 labour costs. This would require choosing different growth rates for other cost categories which are not expected to vary proportionally with income.

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

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

Given the assumptions outlined above, $B(Q)-C_q(Q)$ in equation (5) can be expressed as the change in users´ surplus (diverted and generated), and the producer surplus:

$$\tfrac{1}{2}(g_0-g_1)(Q_0+Q_1)+p_1Q_1-p_0Q_0-C_q+C_C \tag{6}$$

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 in vt is the total value of time saved by the average passenger, therefore (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:

$$v\Delta tQ_0+\tfrac{1}{2}\left(p_0+vt_0-p_1-vt_1\right)\Delta Q+p_1\Delta Q+C_c-C_q \tag{7}$$

Rearranging and multiplying and dividing by Q_0:

$$v\Delta tQ_0+C_c+\tfrac{1}{2}\left(v\Delta tQ_0+\Delta pQ_0\right)\frac{\Delta Q}{Q_0}+p_1Q_0\frac{\Delta Q}{Q_0}-C_q \tag{8}$$

Since the conventional mode breaks even (as assumed) and costs are fully avoidable when traffic diverts to HSR, then $C_c=p_0q_0$ and $p_1Q_0=C_c+\left|\Delta p\right|Q_0$, therefore (8) is equivalent to:

$$v\Delta tQ_0+C_c+\left(\tfrac{1}{2}v\Delta tQ_0+C_c+\tfrac{1}{2}\Delta pQ_0+\left|\Delta p\right|Q_0\right)\frac{\Delta Q}{Q_0}-C_q \tag{9}$$

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

$$v\Delta tQ_0+C_c+\left(\tfrac{1}{2}v\Delta tQ_0+C_c+\tfrac{1}{2}\left|\Delta p\right|Q_0\right)\alpha-C_q \tag{10}$$

Considering that $v\Delta t$ is always greater than Δp (otherwise the number of passengers would not increase), (10) can be finally approximated by:

$$[v\Delta t Q_0 + C_C](1+\alpha) - C_q \tag{11}$$

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 (11) to be equivalent to (10) it is required that $v\Delta t = |\Delta p|$ and therefore, (11) overestimates the benefit from generated traffic by the difference $v\Delta t - |\Delta p|$ which if significant would bias the evaluation in favour of the project.

Substituting (11) back in (5) and rearranging, it is straightforward to figure out the minimum value of Q_0 which would be necessary for a positive NPV:

$$Q_0 > \frac{1}{v\Delta t(1+\alpha)}\left[\frac{r-\theta}{1-e^{-(r-\theta)T}} I + C_q + C_t \frac{r-\theta}{r}\frac{1-e^{-rT}}{1-e^{-(r-\theta)T}} - C_C(1+\alpha)\right] \tag{12}$$

4.3. Demand thresholds for social profitability

We have limited information concerning the actual values of key parameters in (12). To have a HSR line in operation requires incurring some fixed (and partially sunk) costs: the investment costs in infrastructure, which consists of the tracks and sidings along the line; the buildings and technical equipment for terminals and stations, the line signaling, traffic management and control system. These components need maintenance and operation (energy, materials and labor) and a reservation system; and though 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 paper.

Besides dedicated infrastructure, investment in high speed rolling stock is required, and maintenance and operating costs such as energy and labor expenses needed for having these trains in operation. These costs are demand-related, but it could be partially considered as fixed in the

short term. In this paper, 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 urban areas crossed, number of tunnels, bridges, and so forth.. We have worked with a range of typical cost values in standard circumstances (based on the HSR in operation in Europe), and using different values of time, from several European studies in the recent past. Then, a sensitivity test is applied using the most favorable assumptions regarding key parameters.

Data on infrastructure construction costs shows how the cost per km 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 despite of the difficulties associated to the limited evidence concerning cost data it is possible to work within certain realistic ranges for standard projects[10]. In table 7 the actual costs for a standard 500 km HSR are shown ((see Barrón de Angoiti, 2004).

The lower value of construction costs in Table 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 Mediterenee (France), or the ICE Frankfurt-Cologne (Germany), which is closer to the upper limit.

[10] There is also evidence of a systematic bias in the estimation of costs and demand in large infrastructure projects. Flyvbjerg, Skamris and Buhl (2003) found that 90% of projects have cost overruns. Overruns are general in space and constant for the past 70 years.

Table 7. Estimated costs of a 500 km HSR line in Europe (2004)

		Cost per unit (€ thousand)		*Units*	*Total cost (€ million)*
Capital costs					
	Infrastructure construction[(1)] (Km.)	12,000-40,000		500	6,000-20,000
Rolling stock[(2)] (Trains)	Rolling stock (trains)	40	15000	600.0	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
	Labour (Employees)		36	550	19.8

Source: UIC

(1) Terminal value = 50% of the investment in infrastructure.
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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 te other hand, if the conventional train's operating speed is 160 km/hr, time saving is 35 minutes over a distance of 450 km[11].

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 comes also 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 paper 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

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

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[12]. 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 (12) allows the estimation of demand thresholds changing the average time savings, the value of time and other relevant parameters. Figures 2, 3, 4 and 5 represent isoquants for particular values of Q that allow a NPV equal to zero. These values correspond to a 500Km line, an optimal distance for a HSR project. Any isoquant shows the level of demand required for a positive NPV for different $v\Delta t$ and investment costs (including rolling stock), under alternative 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 the minimum levels of demand required are, 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 figures 1 to 4 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 8 and 9 show a sensitivity test for first year demand thresholds leading to an NPV=0. Investment costs per kilometre are 12, 20, 30 and 40 millions of 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 6m 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 favourable circumstances, a total first year demand of at least 9m trips p.a. is needed; in unfavourable circumstances, the requirement may be considerably more than that.

[12] We do not see the advantage of conducting a risk analysis since the probability distributions of key variables are unknown...

[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)

As has been stressed throughout this paper, the estimated demand thresholds have been 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 would 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 would be equivalent to adding 10% to the level of demand, so the change they bring is not dramatic. In those cases where serious bottlenecks make it very difficult to introduce upgraded services on existing routes, the case for HSR investment is stronger. The case would also be stronger in circumstances where high speed rail provided major environmental benefits or indirect economic benefits.

Figure 2
First year demand required for NPV=0
($\alpha = 0.2$ $\theta = 3\%$)

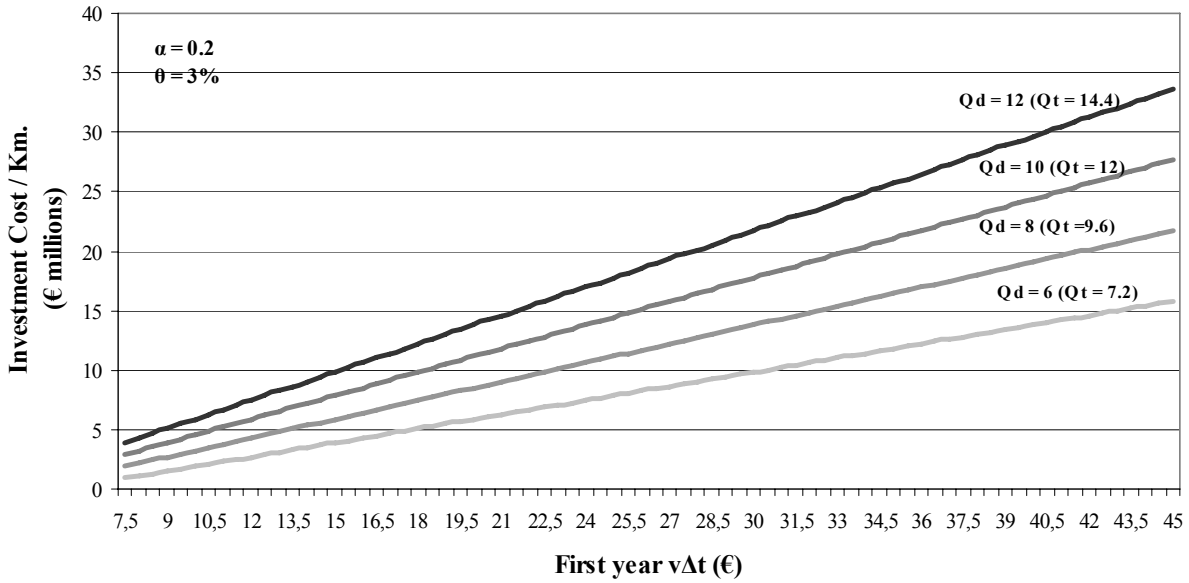
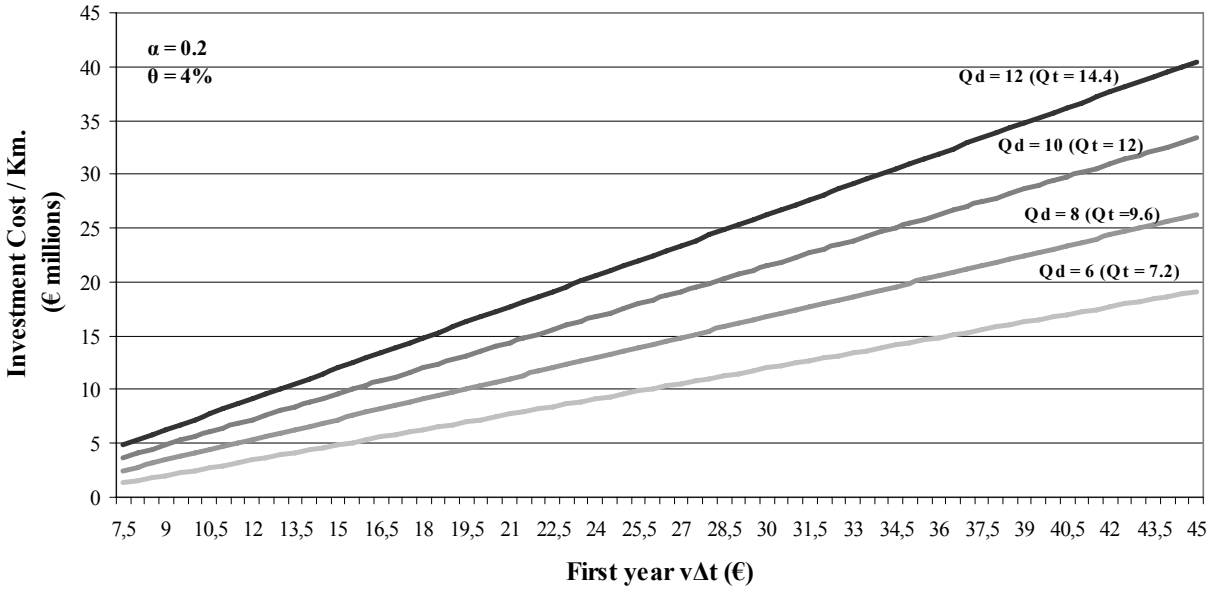


Figure 3
First year demand required for NPV=0
($\alpha = 0.2$ $\theta = 4\%$)



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

Figure 4
First year demand required for NPV=0
(α = 0.4 θ = 3%)

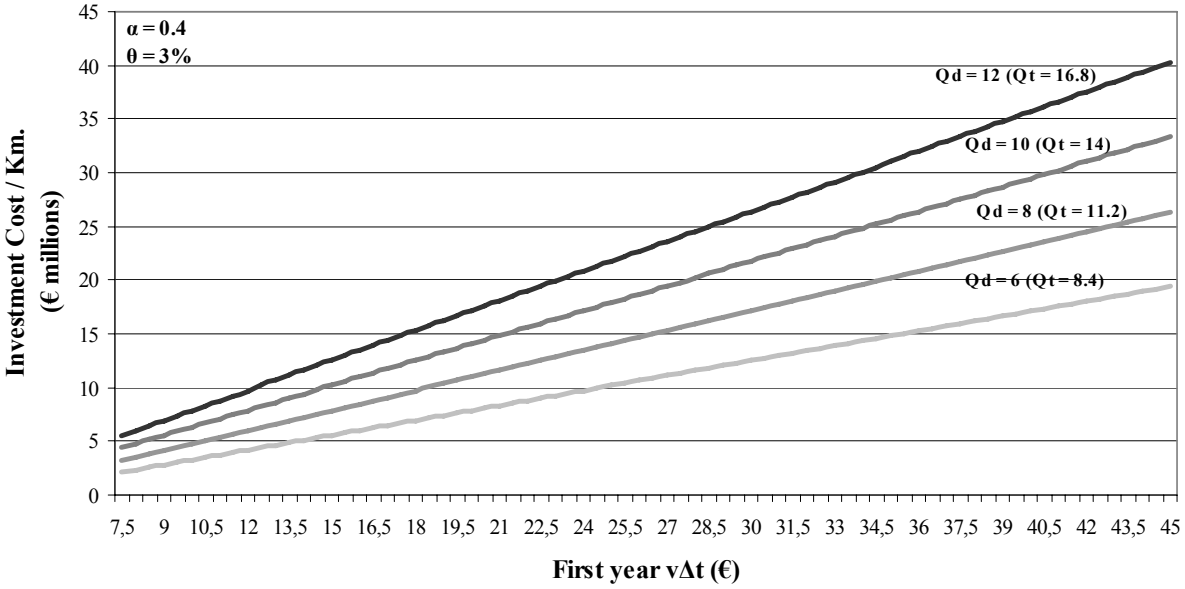
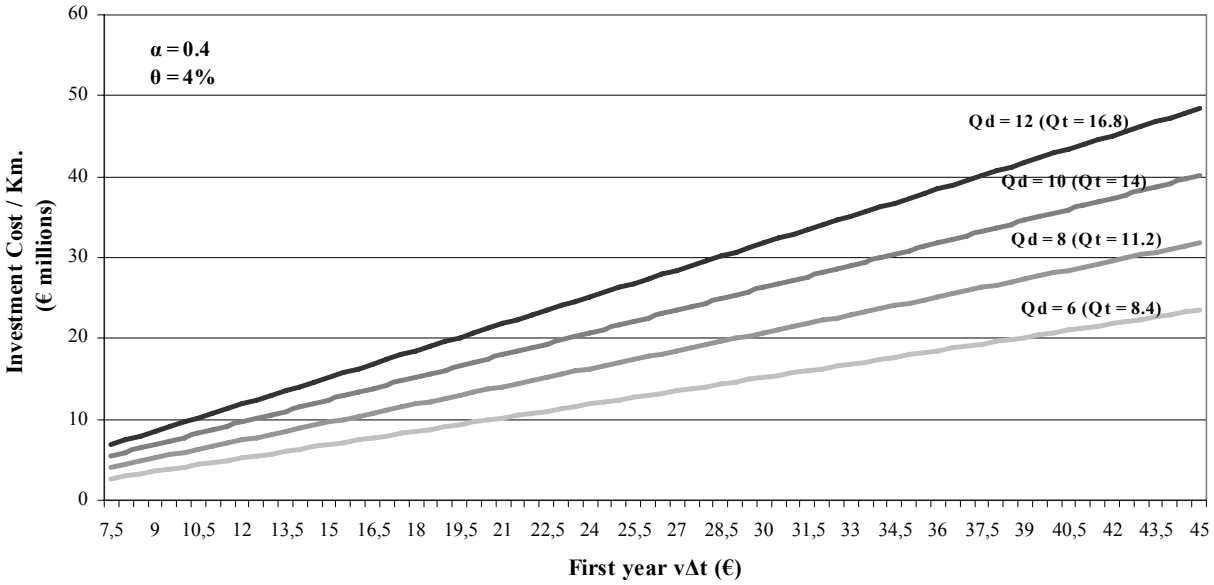


Figure 5
First year demand required for NPV=0
(α = 0.4 θ = 4%)



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 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	12	vΔt	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
			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
			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
			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
			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	22.8	19.4	16.3	22.6	19.2	16.1	22.4	19.0	15.9	22.2	18.8	15.7
			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
			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
			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 kilometre (construction + NPV of rolling stock, € millions)
r: interest rate
T: life of the project (years)
C_t: annual fixed maintenance and operating costs (€ millions)
C_q: annual maintenance and operating cost variable with Q (€ millions)
C_c: annual variable cost of the conventional mode (€ millions) $C_c=1/2(C_t+C_q)$

Table 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 kilometre (construction + NPV of rolling stock, € millions)
r: interest rate
T: life of the project (years)
C_t: annual fixed maintenance and operating costs (€millions)
C_q: annual maintenance and operating cost variable with Q (€ millions)
C_c: annual variable cost of the conventional mode (€ millions) $C_c=1/2(C_t+C_q)$

5. Conclusions.

The case for building new High Speed Rail (HSR) infrastructure depends its the 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– have 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 have explored under what conditions net welfare gains can be expected from new HSR projects. In this paper 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 6m passengers per annum on opening; with more typical construction costs and time savings a figure more like 9m 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 paper 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 this 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 volumes in Europe, investment in HSR infrastructure can rarely be justified on the basis of time savings and the net willingness to pay of generated traffic alone and on a single corridor. Some combination of using new high speed lines to bypass bottleneck sections, with trains continuing on upgraded conventional track or network benefits from serving a variety of flows with a single link will be needed, or strong congestion and environmental problems on competing 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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