Is Investment in High Speed Rail Socially Profitable?

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Abstract

The development of High Speed Rail (HSR) in Europe has been encouraged and financially supported by the European Commission. Several lines are in operation, and many others under construction or waiting for approval. HSR technology is presented as a solution to congested roads and airports. Besides, rail transport is generally regarded as more environmentally friendly than other modes. However, the case for a HSR investment is highly dependent on the volume of demand in the corridor, which generates the key benefits: time savings with respect to air transport, conventional rail and car, and the value of generated traffic. In this paper, we analyze under which conditions net welfare gains can be expected from new projects. Using real construction, maintenance and rolling stock costs of European HSR lines, and standard values of time, we try to figure out the required minimum level of demand from which investment in HSR could be considered profitable from a social perspective.

Keywords: railways, high speed train, infrastructure, transport, cost-benefit analysis.
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1. Introduction

One of the main transport policies pursued by the European Commission during the late 90s was the development of high-speed trains. The accession of new Member States has increased the average distance between European capitals, which calls for a wider high-speed rail network. The Trans-European Transport Network (TEN) is a key element of the European transport policy, and the construction of a High Speed Rail (HSR) network is still among the priorities of this policy (European Commission, 2001).

The discussion about the economic benefits of HSR investment and the opportunity of devoting public funds to its development is usually too general and imprecise, based on economic development arguments common to the literature on infrastructure and growth (Gramlich, 1994). Decisions to build HSR lines are taken, in general, without any clear overall plan (Vickerman, 1997). Besides, the TEN program suffers from problems of moral hazard, given the mixed financial responsibilities and the presence of non-economic objectives. In these circumstances, the economic viability of investments in rail infrastructure projects to change modal split is not guaranteed (Sichelschmidt, 1999).

The rationale for the investment decisions in the recent past goes far beyond the usual microeconomic approach used in project evaluation, into a less solid ground dominated by strategic and political arguments or regional development objectives. Recently the economic appraisal of HSR projects, including cost-benefit analysis, is required by the European Commission and routinely undertaken by the Member States, though political and strategic considerations are still paramount[1].

The economic justification for new investment in HSR is strongest where there exists a potential market for travel within 200-800 km but especially in the range 300-600 km. The benefits outside this range diminish: The social benefits below 200 km are quite low and cannot compete with air transport above 800 km.

The economic benefits of the construction of new HSR are very sensitive to the volume of demand. Cities with high population densities along the corridor mean more users sharing the fixed costs of capacity. Nevertheless, high density urban areas mean higher construction costs. The construction costs of 100 km of high speed railway line (speed above 250 km/hour) changes dramatically depending on geographic conditions and the crossing of urban areas. Values go from €1785 million to 2921 in Italy, to 625 to1334 in France, measured in 1997 PPP values. A conservative standard average value for 100 km in current euros could be 1200 million (Barrón de Angoiti, 2004).

A careful assessment of the value for money invested in HSR infrastructure is specially needed given the high cost of infrastructure construction and the high proportion of sunk costs in total costs. Nash

[1] See Phang (2003) and van Exel *et al* (2002) for the strategic consideration of large infrastructure projects.

(1991) suggests that there is too little evidence on the true costs and benefits of HSR proposals. Environmental and development benefits appear unconvincing. This conclusion is based on empirical evidence on demand response to speed changes (Fowkes, Nash and Whiteing, 1985; Owen and Philips, 1987; Bonnafous, 1987; Marks, Fowkes and Nash, 1986), development benefits (Bonnafous, 1987; Martin, 1997; Rietveld, 1989; Plassard, 1994) and environmental effects (Hughes, 1990).

The objective of this paper is twofold. First, we rely on a theoretical model to identify the key costs and benefits of a HSR project. Second, based on real values of construction, maintenance and rolling stock costs of European HSR lines, standard values of time, and several simplifying assumptions, we try to figure out the required minimum level of demand from which investment in HSR could be considered profitable from a social perspective.

The structure of the paper is the following. Section 2 presents the model used to analyze a HSR project, showing the key elements to be taken into consideration for its economic evaluation. Section 3 describes the values used in our calculations, and the results obtained. Section 4 compares the range of minimum demand required for the social profitability of HSR projects with the real case of the Madrid-Seville line. Finally, the main conclusions are presented in section 5.

2. The model

Let us consider the case of a project consisting in 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 mobile equipment during some initial period, which will be considered as the year of reference (t=0) and after when depreciation requires replacement. From t=0 until $t=T$, the railway operator charges a regulated fare $\bar{p}$ and each year receives Q users, assumed to be constant during the life of the project.[2]

Total infrastructure costs (expressed as opportunity costs) are equal to I, evaluated in constant terms of year t=0. During the life of the project, the operator incurs into 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 are fixed ($C_t(t)$) and thus invariable to the level of traffic Q, and other are demand related, depending on the number of users ($C_q(Q)$). All costs are computed with shadow prices if relevant.

Suppose initially a *base case* without the HSR consisting of passengers travelling from A to B in two transport modes: one that we shall call conventional[3] and the other, road transport by car.

[2] We drop this assumption later.

[3] We do not distinguish here between conventional railway, air transport or buses. For simplicity we call the public option the “conventional mode”. In section 4 we work with data from actual alternative modes.

Passengers pay a generalized cost g_0 composed by money and time when using the conventional mode or their private cars.

Defining social welfare as the unweighted sum of consumers and producers surpluses and assuming a continuous flow of benefits and costs, social welfare in the *base case* can be expressed as the sum of the surplus of passengers using the conventional mode, the producer surplus of the firm operating the conventional mode, and the surplus of the road users, during the life of the project properly discounted at the social discount rate:

$$W = \int_0^T \int_{g_0}^{\infty} Q(z) e^{-rt} dz dt + \int_0^T [\bar{p} Q(g_0) - C_C(Q(g_0))] e^{-rt} dt + \int_0^T \int_{g_0}^{\infty} q_R(z) e^{-rt} dz dt \qquad (1)$$

where:

$g_0 = \bar{p} + c_0$: generalized cost *without* the project.

$\bar{p}$: regulated fare[4].

c_0 : total value of time in the generalized cost of a trip.

Q(z): market transport demand of users in the conventional mode.

$C_C(Q)$: total cost in the conventional mode.

q_R : road users.

r: social discount rate.

Investment in HSR consist in building a new line between A and B which reduces the time component of the generalized cost for all passengers switching from the conventional mode and benefitting those who remain driving on the road[5] at a lower generalized cost, because congestion is eased. This investment generates some direct benefits, and we ignore, for the moment, indirect benefits in secondary markets.

Total costs of the proyect are:

$$I + \int_0^T (C_t + C_q(Q)) e^{-rt} dt \qquad (2)$$

where:

[4] We assume that the regulated fare includes taxes, and it does not change with the project. Therefore, taxes can be ignored for traffic diverted from other modes and should be included in the case of generated traffic as part of the willingness to pay for new trips, when the payment of this new trip has not been deviated from other tax generating activities with the same tax rate. We assume gross revenue of generated traffic as a benefit of the project.

[5] We ignore here the reduction of some externalities, as some not internalized components of accident costs and pollution. Other environmental impact as barrier effects and visual intrusion should also be counted on the cost side of HSR, particularly when HSR is not a substitute of a highway or an airport.

I: infrastructure construction costs.
C_t: annual fixed maintenance and operating cost.
$C_q(Q)$: annual maintenance and operating cost variable with Q.
r: social discount rate.

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

$$\Delta W = \int_0^T \int_{g_1}^{g_0} Q(z) e^{-rt} dz dt + \int_0^T [\bar{p}(Q_1 - Q_0) - C_t - C_q(Q_1) + C_C(Q_0)] e^{-rt} dt - I + \int_0^T \int_{g_1}^{g_0} (q_R(z)) e^{-rt} dz dt \quad (3)$$

where,

g_0: generalized cost *without* the HSR project.
g_1: generalized cost *with* the HSR project.
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.
q_R: road users who do not change mode *with* the project.
T: life of the project.
r: social discount rate.

2.1. Indirect effects

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 other markets where firms use transport as an input, or their products and services are related to the primary market through complementarity or substitutability links.

We assume the economy affected by the HSR project has two markets in equilibrium: one is competitive and the other is a monopoly. A value function ($V(p,c)$)for all the firms in both markets can be defined. Once the optimal quantity has been chosen, the benefit depends on p and c.

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

$$V(p,c) = nV_i(q(p,c)) + V_m(q_m(p_m,c)) \tag{4}$$

where:

V_i : value function of a representative competitive firm.
n: number of competitive firms.
V_m : value function of the monopoly.
p: price in the competitive market.
p_m: price in the monopolistic market.
c: marginal cost (transport cost included).

Differentiating the value functions totally, and taking into account that in the competitive market p y c are parameters (only c in the monopolistic market).

$$\frac{dV}{dc} = n\frac{\partial V_i}{\partial c} + \frac{\partial V_m}{\partial c} + \frac{\partial V_m}{\partial p_m}\frac{dp_m}{dc}. \tag{5}$$

When firms pursue profit maximization, and both q and q_m are at optimal levels, we can derive the value functions with respect to c, which shows the impact on secondary markets induced by the reduction of unit transport costs c caused by the HSR project:

$$\frac{dV}{dc} = n[-q + (p-c)\frac{\partial q}{\partial c}] - q_m + (p_m - c)\frac{\partial q_m}{\partial c} + \left(q_m + \frac{\partial q_m}{\partial p_m}p_m - c\frac{\partial q_m}{\partial p_m}\right)\frac{dp_m}{dc} \tag{6}$$

Expression (6) is the marginal change in total benefits (at the optimum in both markets) when c changes[7]. Expression (6) simplifies to:

$$\frac{dV}{dc} = -nq - q_m + (p_m - c)\frac{\partial q_m}{\partial c} \tag{7}$$

because at the optimum, in the competitive and in the monopolistic sectors, respectively, we have:

$$(p-c)\frac{\partial q}{\partial c} = 0 \tag{8}$$

$$\left(q_m + \frac{\partial q_m}{\partial p_m}p_m - c\frac{\partial q_m}{\partial p_m}\right)\frac{dp_m}{dc} = 0 \tag{9}$$

[7] The envelope theorem is very useful here but, for the sake of clarity on what should be measured in secondary markets, that “shortcut” is not taken.

It should be noticed that the first two terms on the right hand side of expression (7) have already been measured in the primary market, so the indirect benefits are reduced to $(p_m - c)\frac{\partial q_m}{\partial c}$. For a given reduction in transport cost, the magnitude of this indirect benefit of the project depends on the existing market power and the elasticity of demand in the monopolistic sector with respect to the reduction in transport costs.

Assuming the existence of taxes, subsidies and externalities in the competitive and monopolistic market, the indirect effects to be added to the direct benefits are:

$$n(t - e)\frac{\partial q}{\partial c} + (p_m + t - e - c)\frac{\partial q_m}{\partial c} \qquad (10)$$

where:

t : is a tax per unit sold (negative in the case of a subsidy).
e : is a negative externality, constant per unit sold.

It is worth noticing that the significance of the indirect effects in expression (10) depends on the existence of distortions in the economy. Taxes, subsidies, 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[8], which depends on the magnitude and sign of the distortions and the cross-effects in secondary markets due to the reduction in transport costs[9].

2.2. Simplifying the model

Let us make some useful simplifying assumptions. The first one is that indirect effects (positive and negative) cancel out in the aggregate and the reduction in road congestion is negligible. The second one is that changes in revenue equal cost changes in the alternative modes. The condition to be satisfied for a positive NPV can be expressed as follows:

$$\int_0^T [B(Q) - C_q(Q)]e^{-(r-d)t}dt \; - \int_0^T C_t e^{-rt}dt \; > I \qquad (11)$$

where:

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

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[8] 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). They do not account for negative externalities as congestion, or the existence of taxes and subsidies.

[9] Net benefits which have not already been measured in the primary market.

$C_q(Q)$: annual maintenance and operating cost variable with Q.
C_t: annual fixed maintenance and operating cost.
I: infrastructure construction costs.
T: life of the project.
r: social discount rate.
d : annual growth of net benefits.

Solving expression (11), the following condition is obtained for the project to be socially desirable:

$$\frac{B(Q)-C_q(Q)}{r-d}(1-e^{-(r-d)T})-\frac{C_t}{r}(1-e^{-rT})>I \qquad (12)$$

Rearranging terms and dividing by I:

$$\frac{B(Q)-C_q(Q)}{I}>\frac{r-d}{1-e^{-(r-d)T}}+\frac{C_t}{I}\frac{r-d}{r}\frac{1-e^{-rT}}{1-e^{-(r-d)T}} \qquad (13)$$

Assuming T tends to infinite and $r>d$, expression (13) simplifies to:

$$\frac{B(Q)-C_q(Q)}{I}>r-d+\frac{C_t}{I}\frac{r-d}{r} \qquad (14)$$

Expression (14) shows the condition to be satisfied in order to reach a positive net present value. The economic interpretation of (14) is similar to the more real case of a finite project life (compare to expression 13). The only change is a more demanding benchmark for profitability when the life period is 30 or 40 years instead of infinite[10].

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 of fixed annual maintenance costs.

According to expression (13), 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 construction, maintenance and operating costs.
- The lower r and the higher d .

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

- The higher is the share of fixed costs in total costs.
- 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 $(B(Q)-C_q(Q))$ are mainly time savings and benefits from generated traffic[11], net of variable costs. These net benefits depend on the volume of demand to be served, the time savings on the line and the VOT of the users.

The growth rate in expression (11) affects benefits and costs in the same way. This is an *ad hoc* assumption only justified on the lack of better evidence. In section 3, different values for d are tested. Another possibility is to introduce a separate variable to account for changes in the value of time overtime and labour costs. To do this requires choosing other growth rates for other cost categories which are not expected to vary proportionally with income.

Then, from (13) and given the value of r, d, I, T and C_t, the minimum value of $B(Q)-C_q(Q)$ required to satisfy condition (13) is immediately determined. Once the required value of $B(Q)-C_q(Q)$ is known, we can work out the required level of demand under certain assumptions.

3. Empirical evaluation of HSR projects

Following an approach based on changes in resource costs and willingness to pay, the cost and benefits of HSR projects can be classified as follows:

- Construction costs of the new line
- Investment in rolling stock
- Maintenance and operation of infrastructure and trains
- Time savings for HSR users
- Willingness to pay for quality of service improvements
- Time savings for road users due to the reduction of congestion
- Cost savings in alternative modes
- Accident cost savings
- Development benefits
- Environmental impact

Development benefits and environmental impacts are very difficult to assess without contemplating a particular project. The environmental impact of the HSR is not clear at all. High speed lines need land, crossing areas of environmental value. The rail track creates a barrier effect in the affected territory, produce noise and generate landscape intrusion effects.

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

The benefits of a HSR project are basically changes in users, operators and taxpayers surpluses, and these changes should be estimated with respect to a relevant *base case*. In many cases, the new HSR line is compared with a situation of long traveling times on an inefficient traditional network, but other less costly alternatives do exist, and these *do something* cases should be taken as the reference point.

One should underline here that not all the countries have chosen the hard line on investment in HSR disregarding the expected net social benefits. One case is Sweeden, where "... the X 2000 tilting train has provided the same basis for accelerating services on classic lines with speeds up to 200 km/h. Banverket, the Swedish rail infrastructure authority, has so far concluded that the additional benefits from implementing a new high speed network for the southern trunk routes in Sweden may not sufficiently outweigh the extra costs given the relatively marginal gains in time" (Vickerman, 1997).

To have a HSR line in operation requires incurring in some fixed (and partly sunk) costs: the investment costs in infrastructure and superstructure, which consists of the tracks and sidings along the line; the buildings and technical equipments for terminals and stations, the line signaling, traffic management and control system. This components need maintenance and operation (energy, materials and labor), a reservation system, and though these costs are in some way dependent of the volume of traffic, they cannot be completely avoided when demand is lower than expected.

Maintenance and operation costs of rolling stock are energy and labor expenses needed for having trains in operation. These costs are demand-related, but depending of the existence of a full HSR network or a single line, rolling stock costs could be 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 values for costs of 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. Although it is possible to work with ranges and probabilistic distribution for different cost categories and values of time, we have preferred to work with deterministic values based on a conservative approach consisting in the use of the most frequent 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.

In despite of the difficulties associated to the limited evidence concerning cost data (see Barrón de Angoiti, 2004), we believe it is possible to work within certain realistic ranges for standard projects. Table 1 shows the actual costs used in this paper, while table 2 summarizes some recent studies which have obtained values of travel time in Europe.

Table 1. Estimated costs of a 500 km HSR line in Europe (2004)

	Cost per unit (€ thousand)	*Units*	*Total cost (€ million)*
Infrastructure construction[(1)] (Km.)	12,000	500	6,000.0
Infrastructure maintenance (Km.)	65	500	32.5
Rolling stock[(2)] (Trains)	15,000	40	600.0
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.
(2) NPV of rolling stock investment = 20% of the investment in infrastructure.

Table 2 Passenger transport: Value of time per person/hour

Relevant VOT studies	HCG 1994	HCG 1998	SNRA 1997	EUNET 1998	UNITE Values
Transport Segment		Euro 1998			Euro 1998
Car / motorcycle		6.70	9.31		
Business	21.23	21.00	11.95		21.00
Commuting / private	5.53	6.37	3.91		6.00
Leisure / holiday	3.79	5.08	3.10		4.00
Coach (inter-urban)					
Business	21.23				21.00
Commuting / private	5.95		5.40		6.00
Leisure / holiday	3.08		4.37		4.00
Urban bus / tramway					
Business	21.23				21.00
Commuting / private	5.95		4.94		6.00
Leisure / holiday	3.08		3.22		3.20
Inter-urban rail		4.97	8.50		
Business		18.43	11.95		21.00
Commuting / private		6.48	6.21		6.40
Leisure / holiday		4.41	4.94		4.70
Air traffic				40.60	
Business			16.20		28.50
Commuting / private			10.11		10.00
Leisure / holiday			10.11		10.00

Source: UNITE

The assumptions used in our calculations are:

- There are various types of indirect effects, some of them increasing the benefits of the project, other reducing them, and the final effect is negligible.
- All the alternative modes operate in competitive markets or break even in the case of regulated markets.
- Market prices are equal to opportunity costs.
- Reduction of congestion and road accidents occurs but the overall effect on the project's NPV is no significant.
- There are no important user benefits beyond the time savings.

Based on these assumptions, the first year net benefits are equal to the change in all users (deviated and generated) surplus, and the producer surplus:

$$\tfrac{1}{2}(g_0 - g_1)(Q_0 + Q_1) + p_1 Q_1 - p_0 Q_0 - C_q + C_C \qquad (15)$$

where:

g_0: generalized cost *without* HSR.
g_0: generalized cost *with* HSR.
Q_0: demand *without* HSR.
Q_1: demand *with* the HSR project.
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 $g = p + c$. Expressing the change in c as the total value of time saved by a passenger, substituting and rearranging back in (15), we obtain expression (16) which approximates the value of (15):

$$[v\Delta t Q_0 + C_C](1 + a) - C_q \qquad (16)$$

where,

v: average value of time.
Δt : average time saving.
Q_0: demand *without* HSR.
C_C: annual variable cost of the conventional mode.
a : growth rate of generated traffic *with* the project.

Substituting (16) back in (13) and rearranging, it is straightforward to figure out the minimum value of Q_0 which would be necessary for a positive NPV. Assuming for simplicity that T tends to infinity:

$$Q_0 > \frac{1}{v\Delta t(1+a)}\left[(r-d)I + C_q + C_t\frac{r-d}{r}\right] - \frac{C_C}{v\Delta t} \tag{17}$$

What do we know regarding the actual values of the key parameters in (17), required for the profitability of the project? One of the key values is the expected time savings. Steer Davies Gleave (2004) provides some evidence, from its cases studies on HSR development, transport markets and appraisal processes in UK and six other countries : The *base case* is a conventional rail with 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. Nevertheless, if conventional trains' operating speed is 160 km, time saving is 35 minutes over a distance of 450 km[12].

These average values imply that all passengers travel the whole length of the line. Given the existence of other stations along the line and different trip length, these values overestimate the actual time savings. In this paper we consider time savings of 1 hour, 1.5 hour and 2 hours with the aim of obtaining more robust results.

Other key parameters are the value of time and the social discount rate. We use average values of time ranging from 15 to 30 euros. For the sake of robustness the maximum value chosen is above the state of the art values, as can be seen checking table 2. 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[13]. Avoidable costs in the conventional mode (C_C) are assumed to be a half of the high speed train (C_t+C_q). The social discount rate is 5%, recommended by the European Commission for the evaluation of infrastructure projects[14].

Table 3 and 4 summarize the results, corresponding to alternative scenarios based on different combinations of values of time, demand growth rates, and time savings.

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

[13] We do not see the advantage of conducting a risk analysis as far as the probabilistic distributions of key variables are unknown. The estimation of a distribution function of minimum demand levels required for NPV>0 would be misleading because the probability of obtaining results based on the simultaneous occurrence of extreme values for v, Δt, generated traffic, etc. would be too low, even assuming uniform distribution for key parameters.

[14] See European Commission (1997)

Table 3
Deviated demand required for NPV=0

Deviated Q (Millions)
Generated traffic = 0,1

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	22,1	14,7	11,0	20,5	13,7	10,2	19,0	12,7	9,5
	20 €	16,5	11,0	8,3	15,4	10,2	7,7	14,2	9,5	7,1
	30 €	11,03	7,36	5,52	10,25	6,83	5,12	9,50	6,33	4,75

Deviated Q (Millions)
Generated traffic = 0,25

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	18,9	12,6	9,5	17,5	11,7	8,8	16,2	10,8	8,1
	20 €	14,2	9,5	7,1	13,2	8,8	6,6	12,2	8,1	6,1
	30 €	9,46	6,31	4,73	8,77	5,85	4,39	8,11	5,41	4,06

Deviated Q (Millions)
Generated traffic= 0,4

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	16,5	11,0	8,2	15,2	10,1	7,6	14,0	9,4	7,0
	20 €	12,3	8,2	6,2	11,4	7,6	5,7	10,5	7,0	5,3
	30 €	8,23	5,48	4,11	7,61	5,07	3,81	7,02	4,68	3,51

Table 4
Total demand required for NPV=0

Q (Millions)
Generated traffic = 0,1

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	24,3	16,2	12,1	22,5	15,0	11,3	20,9	13,9	10,4
	20 €	18,2	12,1	9,1	16,9	11,3	8,5	15,7	10,4	7,8
	30 €	12,14	8,09	6,07	11,27	7,52	5,64	10,45	6,97	5,22

Q (Millions)
Generated traffic = 0,25

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	23,7	15,8	11,8	21,9	14,6	11,0	20,3	13,5	10,1
	20 €	17,7	11,8	8,9	16,4	11,0	8,2	15,2	10,1	7,6
	30 €	11,83	7,88	5,91	10,96	7,31	5,48	10,14	6,76	5,07

Q (Millions)
Generated traffic= 0,4

		δ =1,5%			δ = 2%			δ = 2,5%		
		Time savings			Time savings			Time savings		
		1	1,30'	2	1	1,30'	2	1	1,30'	2
VOT	15 €	23,0	15,4	11,5	21,3	14,2	10,7	19,7	13,1	9,8
	20 €	17,3	11,5	8,6	16,0	10,7	8,0	14,7	9,8	7,4
	30 €	11,52	7,68	5,76	10,65	7,10	5,33	9,83	6,55	4,91

4. Ex-post evaluation of the Madrid-Seville HSR line

The first HSR line in Spain was Madrid-Sevilla (AVE[15]). This line was opened in April 1992, the date of the Universal Exhibition held at Sevilla, with a low level of demand (less than 3 million passengers, commuters included) despite a favourable pricing policy applied by the operating company RENFE[16]. The line is currently used by high speed trains, running at more than 250 km/h, and by conventional rolling stock (Talgo) running at 200 km/h and providing services beyond Seville.[17]

A previous cost-benefit analysis of the Madrid-Sevilla HSR corridor (De Rus and Inglada, 1993, 1997) provides us with basic information that can be used for illustrative purposes about the social desirability of a HSR project, by applying expression (13).

The following is a summary of the background information regarding the first year economic benefits, the construction costs and the fixed annual maintenance cost of the infrastructure. All costs and benefits are given in euros, converted to 1993 values. Infrastructure costs are net of taxes and shadow pricing is applied to unskilled labour (conversion factor on actual monetary costs: 0.85). For the sake of comparison a 5% real discount rate is used instead of the officially recommended 6% in 1992.

First year benefits come from generated traffic (40%), time savings (24.7%), cost savings from other modes (32%), and reduction of accidents and congestion (3.3%). It seems clear that a high proportion of first year benefits depends crucially on the value of time. Values of time per hour used by the Spanish Department of Transport are €4.5 euros for cars; €9.8 for conventional rail; €2.4 for bus and €19 for air transport (1993 values).

Given the fact that 86% of the overall time savings come from rail passengers switching from conventional rail to HSR, the value of €9.8 (1993) for conventional rail (€13,5 in 2004 value) shows the importance of the VOT used to obtain the first year benefits. Air transport travel time is lower than high speed after including access and waiting time, though the generalized cost of air transport is lower given the lower price charged for HSR.

The cost savings in alternative modes which suffer traffic diversion rely on a favourable hypothesis for the project: total costs of providing the service are considered avoidable costs. Finally, accident and congestion costs are low because the HSR line was built at the same time of a new highway between Madrid and Sevilla.

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[15] AVE: Alta Velocidad Española (Spanish High Speed Train).

[16] In the first years, revenues were below total variable costs. Now, prices are slightly higher than average variable cost. Investment costs remain uncovered. Infrastructure maintenance is not included in AVE accounts, but the present profits of AVE as shown in the annual reports probably mean that revenue cover total variable costs.

[17] "Unlike the French case, the AVE cannot provide through service because it is built to standard European 1435 mm gauge, whilst the classic network in Spain is to a broader 1676 mm gauge. Trains with especially adjustable bogies maintain these services" (Vickerman, 1997).

The values used in our calculations are the following (in € millions):

First year benefits	108.98
Variable costs (depending on *Q*)	88.62
Infrastructure maintenance	21.60
Investment costs (conversion factor for shadow pricing: 0.85)	2,343.00

Substituting the data of the HSR line Madrid-Seville in (13) we obtain the first year net benefits (demand related) required to reach a positive social net present value during the life of the project, as well as the volume of demand needed to satisfy this condition. Table 4 shows the results for different growth rates of net benefit during the life of the project (40 years).

It is worth noticing here that the figure of demand corresponding to first year net benefits does not include fixed infrastructure maintenance costs. As the figures show, if we consider maintenance and operating costs variable with demand, first year net benefits are negative and the NPV of the project is negative whatever the length of the project is.

Table 4. First year net social benefits required for NPV=0
(Madrid-Seville High Speed Line)

Required B(Q)-C(Q)	d=2%	d=2.5%	d=3%	d=4%
In €(1993) Millions	117	107	98.6	82.4
% of Investment costs	4.98	4.58	4.21	3.52
First year required demand (Millions of passengers-generated traffic included)	15.9	14.7	13.4	11.3

Actual values: first year B(Q)-C(Q)= €M 20.4; Q= 2.8 million; % of investment costs= 0.87
d: annual growth of net benefits.

In any case, the volume of demand of the HSR line in its second year of operation was too low (3.6 million passengers including short distance commuters) to justify the investment. For demand growth rates ranging from 2 to 4 per cent, the initial number of passengers required in 1993 goes from 16 to 11 millions, considerably higher than the actual figure at that time[18].

[18] The volume of demand of the HSR line quoted in the text corresponds exclusively to high speed train operating in the corridor Madrid-Sevilla. Nevertheless, in the calculation of the benefits of the HSR line (de Rus and Inglada, 1997) Talgo trains using the line to go to Malaga o Huelva were included. Therefore, no relevant benefits derived from the investment in HSR infrastructure have been omitted.

Comparing the general results summarized in table 4 with those obtained for the Spanish first high speed line, it seems evident that the initial levels of demand obtained for the Madrid-Seville HSR are in a similar range.

It is quite evident that the minimum level of demand required for a reasonable return of public funds invested in HSR is much higher than the forecasted demand in many actual projects. Taking average values for infrastructure, maintenance and operating costs, standard values of time and other reasonable assumptions, the minimum level of deviated demand from other transport modes required in the first year of operation must be in the range of 8-10 million passengers/year, unless other benefits (such as a reduction of congestion or accidents) are significant enough to reduce the profitability threshold.

Moreover, even in the case of a positive net present value, based on a low demand at the beginning combined with a high rate of growth, another condition is required for the desirability of the investment in economic terms. The relevant question is whether social benefits from postponing the implementation of the project are large enough.

The condition to be satisfied to postpone the project is the following:

$$\frac{iI}{1+i}+\frac{(B-C)_{T+1}}{(1+i)^{T+1}}>\frac{(B-C)_1}{1+i} \tag{18}$$

Assuming insignificant net benefits in year $T+1$ the application of (18) is straightforward: it is worth to postpone one year the implementation of the project if the social discount rate is greater than the ratio between first year benefits and total investment, $(B-C)_1/I$. This was obviously the case in the Madrid-Seville high speed line, where first year net benefits were slightly negative.

5. Conclusions

Decisions to invest in high speed rail (HSR) infrastructure are not always based on sound economic analysis. A mix of arguments –strategic considerations, regional development, technology, congestion in competing modes, and so forth– usually makes the discussion on the economic rationality of investing in HSR vague and imprecise.

The investment in HSR in a particular corridor depends on local conditions affecting construction costs. Given the costs, the expected net social benefit of the investment in HSR relies heavily on the volume of demand and its composition. Congested corridors where new capacity is needed, deviated traffic from road transport and slow conventional trains gives much more value than air transport, and particularly when the reduction of congestion and accidents is significant. Even in this case, one could argue that there are more efficient ways to deal with externalities.

HSR projects require a high volume of demand with enough economic value to compensate the high cost involved in providing capacity. It is not only that the number of passengers must be large, but also a high willingness-to-pay for the new facility is required: many users who obtain high benefits when switching modes or travel more frequently.

We have explored under which 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. From actual construction, rolling stock, maintenance and operating costs of European HSR lines, standard values of time, and a usual rate of discount, we find that HSR investments with expected first year demand below 8-10 million of passengers are difficult to justify.

This threshold is based on the lack of additional benefits, such as a reduction of congestion and accidents, or indirect effects not accounted for in the reduction of the generalized costs of travel. In the case of particular projects in congested corridors, or where new capacity is needed as an alternative to highways, investment in HSR could be socially profitable. However, before building new HSR lines, these projects should ideally be contrasted with other alternative investments, which could yield better social outcomes.

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