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# The BCA of HSR: Should the Government Invest in High Speed Rail Infrastructure?

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# The BCA of HSR: Should the Government Invest in High Speed Rail Infrastructure?

Ginés De Rus

## Abstract

This paper deals with public investment in High-Speed Rail (HSR) infrastructure and tries to understand the economic rationale for allocating public money to the construction of new HSR lines. The examination of data on costs and demand shows that the case for investing in HSR requires several conditions to be met: an ex ante high volume of traffic in the corridor where the new lines are built, significant time savings, high average willingness of potential users to pay, the release of capacity in the conventional rail network and airports. On the contrary, net environmental benefits seem to be insignificant in influencing the social desirability of HSR investment. This paper discusses, within a cost-benefit analysis framework, under which conditions the expected benefits could justify the investment in HSR projects.

**KEYWORDS:** infrastructure, public investment, high speed rail, benefit-cost analysis

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## Introduction

Investment in infrastructure requires a significant amount of public funds. In the case of intercity transport, most of the corridors are already in operation and investments in large projects, such as high-speed rail (HSR), can be viewed as a means to reduce the cost of traveling (time and cost savings, reliability, comfort and externalities) with respect to the situation prevailing without project (de Rus and Nash, 2007; de Rus, 2008). As the type of assets invested in HSR infrastructure is essentially irreversible and subject to cost and demand uncertainty, the optimal timing is a key economic issue, as the investment decision can be delayed in most cases (Dixit and Pindyck, 1994). These characteristics give a significant value to the option to invest, which is in the hands of governments.

The introduction of the HSR technology, consisting of infrastructure and rolling stock that allows the movement of passenger trains capable of speeds above 300 km per hour, has led to a revival of rail transport. Apart from the industry claims and the myth of high speed trains, this technology competes with road and air transport over distances of 400-600 km, and in which it is usually the main mode of transport. For short distance trips, the private vehicle has a comparative advantage; and for long distance travel, air becomes the hegemonic mode of transport.

The HSR technology is expanding all over the world thanks to the allocation of significant amounts of public money for the construction of new lines. Most probably inter-urban passenger transport networks will be deeply affected by public decisions on HSR infrastructure investments that will change the present equilibrium in intercity transport. National governments and supranational organizations, such as the European Commission, are helping to introduce the new technology through direct investment or by co-financing national projects under very favorable conditions.[1]

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[1] The proposals of the European Commission for the Trans European Transport Network envisage expenditure of 600b euros, of which 250b euros are for priority projects, and a large part of this expenditure is for HSR.

Other countries like the UK or U.S. have been reluctant in the recent past to finance the construction of HSR lines with public funds. Currently, the U.S. government's decision to include HSR passenger services as a centerpiece of national transport policy and China's announcement to spend $162 billion to expand its railway system have given a new endorsement to this rail technology that may compete with air and road transport in medium distance intercity corridors.

The introduction of HSR presents some interesting characteristics for the economic analysis of this public investment:

(i) It is a new infrastructure technology linked to modernity, supported by the general public, the media and politicians.
(ii) Its introduction is a government intervention involving a significant sum of taxpayers' money.
(iii) It affects the private sector of the economy (construction and rolling stock companies, airlines, bus operators, etc.).
(iv) It shows how a standard benefit-cost analysis framework can throw some light on the value for money of this investment.

The economic analysis of HSR investment has been covered from different perspectives, though research efforts on the economic evaluation of this infrastructure are limited compared with the amount of public money involved. A general assessment can be found in Nash (1991), Vickerman (1997), Martin (1997), de Rus and Nombela (2007). The cost-benefit analysis of existing or projected lines can be found in de Rus and Inglada (1993, 1997) for Madrid-Sevilla, de Rus and Román (2005) for Madrid-Barcelona, Levinson *et al*. (1997) for Los Angeles-San Francisco, and Steer Davies Gleave (2004) and Atkins (2004) for the UK. The regional effects of HSR investment can be found in Vickerman (1995, 2006), Blum et al. (1997), Plassard (1994), Haynes (1997), and Preston and Wall (2007), and in a broader context in Puga (2002). See Kageson (2009) for the environmental impact.

The benefit-cost analysis of infrastructure requires an explicit consideration of pricing. The average fare to be charged is an important component of the generalized cost of travel. Producer costs (infrastructure and operation) are basically included in the generalized cost of traveling by road or air. This is not always the case with HSR. Railways are far from full cost recovery when infrastructure costs are included. Therefore, the decision on which kind of pricing principle is going to be followed for the calculation of railway fares is really critical.

Given the high proportion of fixed costs associated with the HSR option, the decision of charging according to short-term marginal cost or, on the contrary, something closer to average cost, could radically change the volume of demand for railway in the forecasted modal split, and this unavoidable fact obviously has a profound effect on the expected net benefit of the whole investment. Although pricing is crucial for the understanding of this public intervention, it will not be covered in this paper (for a discussion of optimal pricing in railways see Nash, 2001, 2003; and Rothengatter, 2003). We will assume here that government charges prices equal to short-run marginal social costs.

This paper tries to shed some light on the economic dimension of the HSR investment decision, which not only affects the transport sector but has significant effects on the allocation of resources. In this paper we discuss under which circumstances it may be justified to invest taxpayers' money in the construction of HSR infrastructure. The costs and benefits of the construction and operation of HSR are described in Section 2. The benefit-cost analysis of investing in HSR infrastructure is presented in Section 3. Section 4 concludes.

## Costs and Benefits of HSR

Total *social costs* of building and operating an HSR line consist of producer, user and external costs. *Producer costs* involve two major types of costs: infrastructure and operating costs. *User costs* are mainly related to total time costs, including access, egress, waiting and travel time invested, reliability, probability of accident, and comfort.[2] *External* costs are associated with construction and operation of the line.

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[2] The introduction of HSR services reduces travel time and increases quality. We deal with the reduction of user costs as a benefit of the project.

The *construction costs* of a new HSR line are determined by the challenge to overcome the technical problems which cause it to fail to reach speeds above 300 km per hour, such as roadway level crossings, frequent stops or sharp curves, new signaling mechanisms and more powerful electrification systems. Building new HSR infrastructure involves three major types of costs: planning and land costs, infrastructure building costs and superstructure costs (UIC, 2005). Feasibility studies, technical design, land acquisition, legal and administrative fees, licenses, permits, etc. are included in *planning and land costs*, which can reach up to 10% of total infrastructure costs in new railway lines that require costly land expropriations. *Infrastructure building costs* involve terrain preparation and platform building. Depending on the characteristics of the terrain, there may be a need for viaducts, bridges and tunnels, with costs ranging from 15 to 50% of total investment. Finally, there may be a need for rail-specific elements such as tracks, sidings along the line, signaling systems, catenary, electrification, communications and safety equipment, etc., which are called *superstructure costs*.

Railway infrastructure also requires the construction of stations. Although sometimes it is considered that the *costs of building rail stations*, which are usually singular buildings with expensive architectonic design, are above the minimum required for technical operation, these costs are part of the system and the associated services provided affect the generalized cost of travel (e.g., quality of service in the stations reduces the disutility of waiting time).

From the actual construction costs (planning and land costs, and main stations excluded), of 45 HSR lines in service, or under construction, the average cost per km of a HSR line ranges from 10 to 40 million euros, with an average of 20 million. The upper values are associated with difficult terrain conditions and crossing of high density urban areas (Campos and de Rus, 2009).

The operation of HSR services involves two types of costs: infrastructure maintenance and operating costs, and those related to the provision of transport services using the infrastructure. *Infrastructure maintenance and operating costs* include the costs of labor, energy and other material consumed by the maintenance and operations of the tracks, terminals, stations, energy supplying and signaling systems, as well as traffic management and safety systems. Some of these costs are fixed, and depend on operations routinely performed in accordance with technical and safety standards. In other cases, as in the maintenance of tracks, the cost is affected by the traffic intensity. Similarly, the cost of maintaining electric traction installations depends on the number of trains running on operation. Infrastructure maintenance costs equal 100,000 euros per km, representing 40-67% of the total maintenance costs. Hence, the investment costs of a representative 500 km HSR line are 10 billion euros (planning, land costs and stations excluded), and 50 million euros per year for the maintenance costs of the line. To these fixed costs we have to add the operating costs of running the trains.

The *operating costs* of HSR services (train operations, maintenance of rolling stock and equipment, energy, and sales and administration) vary across rail operators depending on traffic volumes and the specific technology used by trains. In the case of Europe, almost each country has developed its own technological specificities: each train has different technical characteristics in terms of length, composition, seats, weight, power, traction, tilting features, etc. The estimated acquisition cost of rolling stock per seat goes from 33,000 to 65,000 euros. The train operating costs per seat goes from 41,000 to 72,000 euros and rolling stock maintenance from 3,000 to 8,000 euros. Adding operating and maintenance costs and taking into account that a train runs from 300,000 to 500,000 km per year, and that the number of seats per train goes from 330 to 630, the cost per seat-km can be as high as twice as it is in different countries (UIC, 2005; Campos and de Rus, 2009).

A common argument regarding the introduction of HSR services is that negative externalities will be reduced in the affected corridor, thanks to the deviation of traffic from less environmentally friendly modes of transport. Nevertheless, building and operating a HSR line lead to *environmental costs* in terms of land occupied, barrier effects, visual intrusion, noise, air pollution and contribution to global warming. The first four of these impacts are likely to be stronger where trains go through heavily populated areas.

Recent research has shown that, besides land occupation, barrier effects, visual intrusion and noise, the environmental effect of the HSR technology is particularly acute in the construction phase. Kageson (2009) concludes that "investment in high speed rail is under most circumstances likely to reduce greenhouse gases from traffic compared to a situation when the line was not built. The reduction, though, is small and it may take decades for it to compensate for the emissions caused by construction. However, where capacity restraints and large transport volumes justify investment in high speed rail this will not cause overall emissions to raise." It is worth pointing out the importance of fixed costs of this technology (infrastructure construction, maintenance and external costs associated with construction) to understand why the existing traffic volume is so critical for the social justification of an HSR project.

Regarding the energy consumption of high speed rail in comparison with other modes (CE Delft, 2003), while 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, for example, 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 yields management techniques to a greater extent than on trains which also handle significant numbers of short-distance passengers. HSR clearly results in 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 (de Rus and Nash, 2007).

The principal *benefits* from HSR come from: lower total travel time, higher comfort and reliability, generated demand, reduction in the probability of accident, and in some cases, the release of extra capacity which helps to alleviate congestion in other modes of transport. Last but not least, it has been argued that HSR investment reduces the net environmental impact of transport and has favorable location effects.

Let us start with total travel time. The user time invested in a round trip includes access and egress time, waiting time and in-vehicle time. The total user time savings will depend on the transport mode that is used where the passengers come from. Evidence from case studies on HSR development in seven countries shows that when the original mode is a conventional rail with operating speed of 130 km/h, representative of many railway lines in Europe, the introduction of HSR services yields 45-50 minutes savings for distances in the range of 350-400 km. When conventional trains run at 100 km/h, potential time savings are one hour or more, but when the operating speed is 160 km, time saving is around half an hour over a distance of 450 km (Steer Davies Gleave, 2004). Access, egress and waiting time are practically the same.

When a passenger shifts from road or air, the situation changes dramatically. For road transport and line lengths around 500 km, passengers benefit from travel time savings but they lose with respect to access, egress and waiting time. Benefits are higher than costs when travel distance is long enough, as HSR runs, on average, twice as fast as the average car. Nevertheless, as the travel distance gets shorter the advantage of the HSR diminishes as in-vehicle time loses weight with respect to access, egress and waiting time. Nevertheless, in choosing modes between car and HSR, a key factor could be whether the traveler will need a car at his destination. This, in turn, could depend on trip purpose and the availability of mass transit at the destination. Similarly, the number of people traveling together could matter as the marginal cost of a second person traveling in a car that is already making the trip is near zero. Moreover, it is usually assumed that trip quality is higher for HSR than for auto travel. In some ways, that may be true, but not in all ways. For example, one can stop when and where one likes and it is easier to carry luggage with oneself if traveling by auto.

Air transport is, in some way, the opposite case to road transport. Increasing the distance reduces the HSR market share. For a 2,000 km trip (and shorter distances) the competitive advantage of HSR vanishes. But, what about the medium distance (500 km) where the market share of HSR is so high? In a standard HSR line of 500-600 km, air transport has lower in-vehicle time. The advantage of HSR rests on access, egress and waiting time, plus differences in comfort.

Assuming that access and egress times are less for HSR than for air travel, the net user benefit of shifting a passenger from air to rail could even be positive in the case of longer total travel after the shift. This would be the case if the values of time of access egress and waiting time are high enough to compensate the longer in-vehicle time. Nevertheless, the condition of a lower access and egress time for HSR than for air travel not always holds. Clearly, it depends on the exact origin and destination of the trip. Particularly for non-business travel, but even for business travel to suburban locations, air travel might have an advantage in access and egress time as well as in line-haul time.

The relative advantage of HSR with respect to air transport is significantly affected by the existing differences in the values of time, and these values are not unconnected with the actual experience of waiting, queuing and passing through security control points in airports. Hence, one should not discard the implications of potential increased security measures for rail travel. If these measures are increased, demand for HSR relative to other modes could decrease for two reasons: trip time could increase and trip quality could decrease.

Benefits also come from generated traffic. The conventional approach for the measurement of the benefit of new traffic is to consider that the benefit of the inframarginal user is equal to the difference in the generalized cost of travel with and without HSR. The last user with the project is indifferent between both alternatives, so the user benefit is zero. Assuming a linear demand function, the total user benefit of generated demand is equal to one half of the difference in the generalized cost of travel. Nevertheless, 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, and commuter and business trips reflect expansion or relocation of jobs or homes or additional economic activity.

Besides, many indirect benefits are associated with investment in transport infrastructure in general, and not exclusively in high speed, so even if they increase the social return on the investment in transport, they do not necessarily place high speed in a better position over other options for transport investment. Moreover, in undistorted competitive markets theory tells us that the net benefit of marginal change in a secondary market is zero (for a more detailed discussion on intermodal effects see Section 3).

Regarding the spatial effects, high-speed lines tend to favor central locations, so that if the aim is to regenerate the central cities, high-speed train investment could be beneficial. However, if the depressed areas are on the periphery, the effect can be negative. The high speed train could also allow the expansion of markets and the exploitation of economies of scale, reducing the impact of imperfect competition and encouraging the location of jobs in major urban centers where there are external benefits of agglomeration (Venables, 2007), Graham, 2007). Any of these effects are most likely to be present in the case of service industries (Bonnafous, 1987). Location effects are dependent on many factors and it is difficult to determine *a priori* whether the center or the periphery will be benefit from the relocation of the economic activity (Puga, 2002).

Although the effects of building a high-speed rail infrastructure are many, the first direct effect is the reduction of travel time (while simultaneously increasing the quality of travel) and, when cross effects are significant, the reduction of congestion in roads and airports. In cases where the saturation of the conventional rail network requires capacity expansions, the construction of a new high-speed line has to be evaluated as an alternative to the improvement and extension of the conventional network, with the additional benefit of releasing capacity. Obviously the additional capacity has value when the demand exceeds the existing capacity on the route. Under these circumstances the additional capacity can be valuable not only because it can absorb the growth of traffic between cities served by the high-speed railway, but also because it releases capacity on existing lines to meet other traffic like suburban or freight. In the case of the airport, the additional capacity can be used to reduce congestion or scarcity. In any case, the introduction of HSR would produce this additional benefit.

The environmental impact of investment in HSR points in two directions: one of them is the reduction in air and road traffic. In such cases, its contribution to reducing the negative externalities of these modes could be positive, although we must not forget that it requires a significant deviation of passengers from these modes. Moreover, the use of capacity must be high enough to offset the pollution associated with the production of electric power consumed by high-speed trains (and in the construction period), as well as noise pollution. Rail infrastructure also has a negative environmental impact such as the barrier effect, as well as the land taken for the access roads needed for construction and the subsequent maintenance and operation. The net balance of these effects depends on the value of the affected areas, the number people affected, the benefits from diverted traffic and so on.

To the extent that infrastructure charges on these modes do 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. The marginal external costs (including accidents and environmental cost but excluding congestion) per passenger-km for two European corridors, have been estimated in INFRAS/IWW (2000). The results show that HSR between Paris and Brussels have less than a quarter of the external cost of car or air. In long distances, the advantage over air is reduced, as much of the environmental cost of the air transport alternative occurs at take-off and landing.

The existence of network externalities is another alleged direct benefit of HSR (see Adler *et al*., 2007). Undoubtedly, a dense HSR network offers more possibilities to rail travelers than a less developed one. Nevertheless, we are skeptical of the economic significance of this effect. We do not argue against the idea that networks are more valuable than disjointed links. The point is that when there are network effects, they should be treated as benefits at a route level. Although rail passengers gain when the wider origin-destination menu is in a denser network, the utility of a specific traveler who is traveling from *A* to *B* does not increase with the number of passengers unless the frequency increases, and this effect (a sort of Mohring effect) is captured at a line level.

Airlines operate in open competition so the adjustment to the external shock in demand produced by the introduction of HSR services, is a reduction in the number of operations. This affects frequencies, first because the reduction in demand is substantially higher; second, because airlines are not subject to public service obligations and so the adjustment is legally feasible; and third, because of the nature of flight operations (slots required for take-off and landing), frequencies are necessarily affected when services are cut. The reduction in the number of flights per hour increases total travel time when passengers arrive randomly, or decreases utility when they choose their flight in advance within a less attractive timetable. The same argument applies to buses. Even if intercity services are provided through franchising, the long-term adjustment would inevitably mean a less attractive timetable.

## BCA of HSR

The history of the railways shows that public regulation based on restraints on competition and heavy subsidies were ineffective to prevent the road and air transport from replacing the railways as the dominant mode of transportation (Gómez-Ibañez, 2006). This is changing rapidly in the medium-distance passenger markets. Massive public investment in new dedicated infrastructure of high capital costs is bringing back to the railways a leading role in corridors where the auto and the airplane had left the rail with a marginal market share. Today, in corridors with a length around 500 km and HSR services, it is not unusual to find a rail share in the range of 70-90%.

It seems clear that the success of HSR is related both to its attractiveness (time savings, reliability and comfort) and its public support (prices barely cover 40% of total costs in some lines). The network expansion of HSR is taking place outside the market discipline. HSR technology is not a market response to the problem of airport delays and road congestion, but the result of government´s decisions to deal with the problem of congestion and environmental externalities.[3] In the railway industry and political headquarters, it is common place to link the success

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[3] An alternative explanation of the government´s decision to invest in HSR can be found in the `interest group competition´ model (Becker, 1983, 2001) or in the `white elephant´ model of political behavior (Robinson and Torvik, 2005), or in the existence of two levels of government (de Rus and Socorro, 2010).

of the HSR public investment with the high market share the rail has achieved with speedier and more reliable services. For an economist this is not the point, but rather whether the society is willing to pay for this investment.

Suppose that a new HSR project is being considered. The first step in the economic evaluation of this project is to identify how the investment, a `do something´ alternative, compares with the situation *without* the project. A rigorous economic appraisal would compare several relevant `do something´ alternatives with the base case. These alternatives include upgrading the conventional infrastructure, management measures, road and airport pricing or even the construction of new road and airport capacity. We assume here that relevant alternatives have been properly considered.

The public investment in HSR infrastructure can be contemplated as a way of changing the generalized cost of rail travel in corridors where conventional rail, air transport and road are substitutes.[4] Instead of modeling the construction of HSR lines as a new transport mode, we consider this specific investment as *an improvement* of one of the existing modes of transport, the railway. Therefore, it is possible to ignore total willingness to pay and concentrate on the incremental changes in surpluses or, alternatively, on the changes in resource costs and willingness to pay.

We follow here a resource-cost approach, concentrating on the change in net benefits and costs, and ignoring transfers.

The social profitability of the investment in HSR requires the fulfillment of the following condition:

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[4] In the case of complements (Banister and Givoni, 2006) the economic appraisal of HSR projects follows the same principles.

$$\int_0^T B(Q)e^{-(r-g)t}dt > I + \int_0^T C_f e^{-rt}dt + \int_0^T C_q(Q)e^{-(r-g)t}dt\,, \tag{1}$$

where:
*B(Q)*: annual social benefits of the project.
$C_f$: annual fixed maintenance and operating cost.
$C_q(Q)$: annual maintenance and operating cost depending on *Q*.
*Q*: passenger-trips.
*I*: investment costs.
*T*: project life.
*t*; year.
*r*: social discount rate.
*g*: annual growth of benefits and costs.

*B(Q)* is the annual gross social benefit of introducing HSR in the corridor subject to evaluation, where a `conventional transport mode´ operates. The main components of *B(Q)* are: time and cost savings from deviated traffic, increase in quality, generated trips, the reduction of externalities and, in general, any relevant indirect effect in secondary markets including, particularly, the effects on other transport modes (the conventional transport mode). Other benefits related to the relocation of economic activity and regional inequalities are not included in *B(Q)*. The net present value of benefits included in equation (1) can be expressed as:

$$\begin{aligned}\int_0^T B(Q)e^{-(r-g)t}dt &= \int_0^T [v(\tau^0 - \tau^1)Q_0 + C_C](1+\alpha)e^{-(r-g)t}dt \\ &+ \sum_{i=1}^{N}\int_0^T \delta_i(q_i^1 - q_i^0)e^{-(r-g)t}dt,\end{aligned} \tag{2}$$

where:
$v$: average value of time (including differences in service quality).
$\tau^0$: average user time per trip *without* the project.
$\tau^1$: average user time per trip *with* the project.
$Q_0$: first year diverted demand to HSR.
$C_C$: annual variable cost of the conventional mode.
$\alpha$: proportion of generated passengers *with* the project with respect to $Q_0$.
$\delta_i$: distortion in market *i*.
$q_i^0$: equilibrium demand in market *i without* the project.
$q_i^1$: equilibrium demand in market *i with* the project.

Equation (2) assumes that alternative transport operators breakeven and that the average gross benefit of a generated passenger-trip is equal to the value of a diverted passenger-trip (Abelson and Hensher, 2001). Substituting (2) in (1), assuming indirect effects—last term of expression (2)—are equal to zero, it is possible to calculate the initial volume of demand required for a positive net present value (de Rus and Nombela, 2007).

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 and the specific conditions in the corridor, it is possible to simplify the problem working with some assumptions.

The main purpose of these assumptions is to concentrate on the HSR benefits derived from time savings and generated demand, leaving aside the benefits from the provision of additional rail capacity and from the net reduction of accidents, congestion and environmental impacts due to diversion from road and air modes, which are more sensitive to the local conditions of each corridor. The idea is to make the basic model workable with real data, concentrating efforts on the uncontroversial effects of HSR investment, in order 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; improved quality; and willingness to pay for generated trips. The condition to be satisfied for a positive NPV can then be expressed as follows:

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

where:
*B(Q)*: annual social benefits of the project.
*C<sub>q</sub>*(*Q*): annual maintenance and operating cost variable with *Q*.
*C<sub>f</sub>*: annual fixed maintenance and operating cost.
*I:* investment costs.
*T*: life of the project.
*r*: social discount rate.
*g*: annual growth of benefits and costs.

Assuming $r > g$, and solving expression (3) for the project to be socially desirable, the following condition is obtained:

$$\frac{B(Q) - C_q(Q)}{r-g}(1 - e^{-(r-g)T}) - \frac{C_f}{r}(1 - e^{-rT}) > I\,. \tag{4}$$

Dividing by *I* and rearranging terms:

$$\frac{B(Q) - C_q(Q)}{I} > \frac{r-g}{1 - e^{-(r-g)T}} + \frac{C_f}{I}\frac{r-g}{r}\frac{1 - e^{-rT}}{1 - e^{-(r-g)T}}\,. \tag{5}$$

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 ($(r-g)/r$) of fixed annual maintenance costs. In the case of a finite project life, the only change is a more demanding benchmark for profitability.[5]

The social profitability of HSR infrastructure crucially depends on the net benefit of the first year of the project. When externalities and indirect effects are not significant, first year annual benefits

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

$(B(Q)-C_q(Q))$ come mainly from time savings, improved quality, and benefits from generated traffic,[6] 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.

The case for investing in an HSR line requires a minimum level of demand in the first year of operation. This minimum demand threshold required for a positive NPV is higher the lower are the value of time, the average time saving per passenger, the proportion of generated traffic, the growth or benefits overtime, the project life and the cost savings in alternative modes; and the higher are the investment, maintenance and operating costs, and the social discount rate.

de Rus and Nombela (2007) and de Rus and Nash (2007) calculate the required volume of demand (existing and deviated passenger-trips) in the first year of the project ($Q_0$) under different assumptions regarding the main parameters in (1) and (2). The minimum value of $Q_0$ that would be necessary for a positive NPV is the following:

$$Q_0 = \frac{1}{v(\tau^0 - \tau^1)(1+\alpha)} \left[ \frac{r-g}{1-e^{-(r-g)T}} I + C_q + C_f \frac{r-g}{r} \frac{1-e^{-rT}}{1-e^{-(r-g)T}} - C_C(1+\alpha) \right] \quad (6)$$

The results show that, with typical construction and operating costs (see Section 2), time savings, values of time, annual growth of benefits and the social discount rate, the minimum demand threshold required for a new high speed line investment to be justified on social benefit terms is around 10 million passenger-trips in the first year of the project. This initial demand volume was obtained under the assumption that benefits come mainly from time savings from deviated traffic, the willingness to pay associated with generated demand and the avoidable costs of the reduction of services in alternative transport modes.

Moreover, 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 underestimate the required demand threshold. In addition, diverted traffic also comes from road and

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

air transport. Time savings are lower when passengers divert from air transport, although 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 medium distance HSR lines.

Other key parameters are the value of time and the social discount rate. We use average values of time ranging from 15 to 30 euros. For the sake of robustness, the maximum value chosen is above the state-of-the-art values (see for example, Nellthorp et al., 2001). This range includes different possibilities of trip purposes and initial transport mode combinations, and the possibility of an extra willingness to pay for quality not included in the reported values of time. The social discount rate is 5% in real terms, as recommended, for example, by the European Commission for the evaluation of infrastructure projects.[7]

Sensitivity tests were applied to see the effects on the first-year demand threshold leading to a NPV=0, obtained with the mean values. Investment costs per kilometer were allowed to take the values, 12, 20, 30 and 40 million euros. The average benefit per passenger: 20, 30 and 45 euros. The percentage of generated demand relative to diverted demand: 20, 30, 40 and 50. Annual growth rate of net benefits: 2, 3 and 4%. The social discount rate: 5 and 3% alternatively. The results of the sensitivity test show that we only find a case for HSR at a total demand below 6m passenger-trips in the first year but in unlikely circumstances where low construction costs and a low discount rate are combined with high values of time savings per passenger. With high construction costs but otherwise favorable circumstances, a total first-year demand of at least 10m passenger-trips is needed; in unfavorable circumstances, the requirement may be considerably more than that.

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 and willingness to pay from generated passenger-trips. When the provision of new rail capacity is needed and there is significant congestion in roads and airports,

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[7] See European Commission (2008).

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 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 wider economic benefits.

The fulfillment of condition (1) is not sufficient. Even with a positive NPV it might be better to postpone the construction of the new rail infrastructure (even assuming that there is no uncertainty and that no new information is revealed as a benefit of the delay). Let us assume that the annual growth rate of net benefits is higher than the social discount rate ($g>r$) and that the new infrastructure lasts long enough to be compatible with a positive NPV. Even in this case of exponential growth of net benefits, the question of optimal timing remains. It is worth waiting one year if the net benefits lost are lower than the opportunity costs of the investment.

## Intermodal Effects: A Closer Look

The high market share achieved by railways in medium distances with HSR services has been an argument in favor of investing in the HSR technology. If passengers freely decide to shift overwhelmingly from air to rail, it follows that they are better off with the change. The problem is that a passenger decides to move from air to rail because his generalized cost of travel is lower in the new alternative (certainly, this is not so for everybody as air transport maintains some traffic) but this is not a guarantee that society benefits with the change as it can easily be shown.

The direct benefits in the corridor where the HSR line is built come mainly from the deviation of traffic from the existing modes of transport, railway included. These benefits are accounted for in $C_c$ and $v(\tau_1-\tau_0)Q_0$ in equation (2), where time savings $(\tau_1-\tau_0)$ should be interpreted as the average of the highest benefit obtained by the first user after the change and zero, the value corresponding to the last user, who is indifferent between both alternatives.

The intermodal effects measured in the primary market consist of the cost savings in the conventional mode and the product of the value of time, the average time savings and the number of passengers shifting from the conventional mode to the new transport alternative. The interesting point here is that these average values hide useful information regarding user behavior and the understanding of intermodal competition. Time savings include access, egress, waiting and in-vehicle time, with different disutility for the user. When users shift from road to HSR they save a substantial amount of in-vehicle time but they invest additional access, waiting and egress time, partially offsetting the initial travel-time savings.

The opposite case occurs in the case of air transport, where time savings experienced from users shifting to HSR come from a reduction of access, waiting and egress time (although this is not always the case as already mentioned in Section 2) which hardly offset the substantial increase in vehicle time. Even with a negative balance in terms of time savings, the user benefit can be slightly positive when the different values of time are considered (we do not include the ticket price in this comparison).

The conclusion is that the case for HSR investment can rarely be justified by the benefits provided by the deviation of traffic from air transport. It seems apparent than higher benefits could be harvested deviating traffic from road transport, but this is more difficult in the range of distances considered. The benefits of deviating traffic from road and air exceed the direct benefits discussed above, as other indirect benefits could be obtained in the other transport modes where their traffic volumes diminish *with* the project. Let us examine the conditions required for obtaining additional benefits in the secondary markets.

It must be emphasized that time savings in the primary market is an intermodal effect: the direct benefit obtained by users of other mode of transport who become HSR users. In addition, the reduction of traffic in the substitutive mode may affect its generalized cost and so the cost of traveling of the users who remain in the conventional mode.

The existing transport modes are not the only markets affected by the introduction of the new mode of transport. Many other markets in the economy are affected as their products are complements or substitutes of the primary markets. The treatment of these so called `indirect effects´ are similar for any secondary market, be it the air transport market or the restaurants of the cities connected by the HSR services (Harberger, 1965; Mohring, 1976).

Which indirect effects or secondary benefits should be included? The answer is in the expression $\sum_{i=1}^{N}\int_0^T \delta_i (q_i^1 - q_i^0)e^{-(r-g)t}dt$, included in equation (2). There are $N$ markets in the economy, besides the HSR product, and the equilibrium quantity changes in some of these markets $(q_i^1 - q_i^0)$ *with* the project. The change can be positive or negative. Suppose these markets are competitive, and unaffected by taxes or subsidies or any other distortion, so $\delta_i = 0$. In these circumstances there are no additional benefits. Therefore, for indirect effects to be translated in additional benefits (or costs) some distortion in the secondary market is needed (unemployment, externalities, taxes, subsidies, market power or any other difference between the marginal social cost and the willingness to pay in the equilibrium).

A similar approach can be used for the analysis of intermodal effects as secondary benefits. Expression $\sum_{i=1}^{N}\int_0^T \delta_i (q_i^1 - q_i^0)e^{-(r-g)t}dt$ in equation (2) includes road and air transport markets. For the sake of the analysis of intermodal effects, let us separate from the set of $N$ markets affected by the HSR investment the air transport (or the road transport market), and generically called any of these transport options the alternative mode $A$. The general expression that accounts for the indirect effect can be slightly modified for the discussion of intermodal effects.

$$\int_0^T (p_A - c_A) q_A \varepsilon_{AH} \frac{\Delta p_H}{p_H} e^{-(r-g)t} dt, \qquad (7)$$

where:

$p_A$: full or generalized price of the alternative mode (air and road in this paper).

$c_A$: marginal cost of the alternative mode.

$q_A$: demand in the alternative mode.

$\varepsilon_{AH}$: cross elasticity of air (or road) with respect to the HSR generalized cost.

$p_H$ : full or generalized price of a rail trip.

According to expression (7), the secondary intermodal effects can be positive or negative depending on the sign of the distortion and the cross elasticity ($\Delta p_H/p_H$ is always negative *with* the project). The reduction of road congestion and airport delays has been identified as an additional benefit of the introduction of HSR. Expression (7) shows that the existence of this benefit requires the non-existence of optimal pricing. Where road congestion or airport congestion charges are optimally designed, there are no additional benefits in these markets.

Moreover, suppose there is no congestion pricing and so the price is lower than marginal cost. Even in this case, the existence of additional benefits depends on the cross elasticity of demand in the alternative mode with respect to the change in the generalized cost of traveling by train. This cross elasticity may be quite low for roads and air travel outside the mentioned medium-range distances or when the proportion of passenger-trips interconnecting flights is high.

Finally, it is worth stressing that the distortion in airports and roads due to capacity problems can be dealt with by other economic approaches (congestion pricing and investment) which should be considered in the *ex ante* evaluation of new HSR lines as part of the relevant `do something´ alternatives.

## Conclusions

The economic rationale of spending public money on new HSR lines depends more on their capacity to alleviate road and airport congestion, and to release capacity for conventional rail where saturation exists, than in the pure direct benefits of time and cost savings and the net willingness to pay a generated demand. Therefore, the justification of investment in HSR is highly dependent on local conditions concerning airport capacity, rail and road networks, and existing volumes of demand. The economic evaluation of a new technology has to compare these local conditions, reflected in the base case, with the `do something´ of introducing the new alternative.

The fundamental problem of high speed is not technological, but economic: the cost of HSR infrastructure is high, sunk and associated with strong indivisibilities (the size of the infrastructure is virtually the same for a line of a given length regardless of the volume of existing demand). In corridors with low traffic density, the cost per passenger is extremely high, which makes the financial stability unfeasible and the economic justification of the investment doubtful.

The case for HSR investment as a second-best alternative, based on indirect intermodal effects, requires significant effects of diverted traffic on the pre-existing traffic conditions in the corridor. This means the combination of significant distortion, high demand volume in the corridor and sufficiently high cross-elasticity of demand in the alternative mode with respect to the change in the generalized cost. Moreover, it must be stressed that intermodal competition is based on the generalized price of travel. Modal choice is affected by the competitive advantage of each mode of transport, but the comparative advantage can reflect two completely different facts: it may reflect a technological advantage but, on the contrary, it may also be explained by the charging policy. The impact on market share in medium-distance corridors may vary dramatically depending on whether the government charges variable costs or aims for full cost recovery.

HSR trains are electrically powered, and therefore produce air pollution and global warming impacts when coal, oil and gas are the main sources to generate the electricity. The negative environmental effects of the construction of a new HSR have to be compared with the reduction of the externalities in road and air transport when passengers shift to HSR. The final balance depends on several factors but basically, the net effect depends on the magnitude of the negative externalities in HSR compared with the substituted mode on the volume of traffic diverted and whether, and to what degree, the external cost is internalized.

We have explored under what conditions net welfare gains can be expected from new HSR projects. Using some simplifying but plausible assumptions, it is possible to obtain 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. With typical construction costs and time savings, and expected demand growth, a figure of around 10 million passenger-trips would be required for a 500 km HSR line in its first year of operation.

## References

Abelson, P. and P. Hensher. 2001. "Induced travel and user benefis: clarifying definitions and measurement for urban road infrastructure," in Hensher D. and K. Button (eds.): *Handbook of transport systems and traffic control, Handbooks in Transport 3*. Elsevier, Pergamon.

Adler, N., C. Nash and E. Pels. 2007. "Infrastructure Pricing: The Case of Airline and High Speed Rail Competition," Paper presented at the 11th World Conference on Transport Research, Berkeley.

Atkins. 2004. *High speed line study*. Department of Environment, Transport and the Regions. London.

Banister, D. and M. Givoni. 2006. "Airline and railway integration," *Transport Policy,*13(4): 386-397.

Becker, G. S. 1983. "A theory of competition among pressure groups for political influence," *The Quarterly Journal of Economics* 98 (3): 371-400.

Becker. G.S. 2001. "A comment on the conference on cost-benefit analysis," in Adler, M.D. and E.A. Posner (eds) *Cost-benefit analysis: Legal, economic and philosophical perspectives*, Chicago: The University of Chicago Press.

Blum, U., K. E. Haynes and C. Karlsson. 1997. "Introduction to the special issue The regional and urban effects of high-speed trains," *The Annals of Regional Science*, 31: 1-20.

Bonnafous A. 1987. "The Regional Impact of the TGV," *Transportation* 14: 127-137.

Campos, J. and G. de Rus. 2009. "Some stylized facts about high-speed rail: A review of HSR experiences around the world," *Transport Policy*, 16(1) :19-28.

CE Delft. 2003. "To shift or not to shift, that's the question. The environmental performance of the principal modes of freight and passenger transport in the policymaking context." Delft.

de Rus, G. 2008. "The Economic effects of high-speed rail investment," OECD-ITF Transport Research Centre. Discussion Paper,2008-16.

de Rus, G. and V. Inglada. 1993. "Análisis coste-beneficio del tren de alta velocidad en España," *Economía Aplicada*, 3: 27-48.

de Rus, G. and V. Inglada. 1997. "Cost-benefit analysis of the high-speed train in Spain," *The Annals of Regional Science*, 3: 175-188.

de Rus, G. and C.A. Nash. 2007. "In what circumstances is investment in high-speed rail worthwhile?" Working Paper 590, Institute for Transport Studies, University of Leeds.

de Rus, G. and G. Nombela. 2007. "Is investment in high speed rail socially profitable?" *Journal of Transport Economics and Policy*, 41 (1): 3-23.

de Rus, G. and C. Román. 2005. "Economic evaluation of the high speed rail Madrid-Barcelona," 8th NECTAR Conference. Las Palmas, Spain.

de Rus, G. and M.P. Socorro. 2010. "Infrastructure investment and incentives with supranational funding," *Transition Studies Review*, 11 (17): 551-567.

Dixit, A.K. and R.S. Pindyck. 1994. *Investment under uncertainty*, Princeton University Press.

European Commission. 2008. *Guide to cost-benefit analysis of investment projects*, Directorate General Regional Policy.

Gómez-Ibañez, J.A. 2006. "An overview of the options" in Gómez-Ibañez, J.A. and G. de Rus, G. (eds): *Competition in the railway industry: An international comparative analysis*. Edward Elgar.

Graham, J.D. 2007. "Agglomeration, productivity and transport investment," *Journal of Transport Economics and Policy*, 41 (3): 317-343.

Harberger, A.C. 1965. "Survey of literature on cost-benefit analysis for industrial project evaluation." Paper prepared for the Inter-Regional Symposium in Industrial Project Evaluation, reprinted in A.C. Harberger, *Project Evaluation (collected papers)* (Midway Reprint Series), Chicago: The University of Chicago Press.

Haynes, K.E. 1997. "Labor markets and regional transportation improvements: the case of high-speed trains: An introduction and review," *The Annals of Regional Science*, 31: 57-76.

INFRAS/IWW. 2000. *External costs of transport*. Report commissioned by UIC. Zurich-Karlsruhe-Paris.

Kageson, P. 2009. *Environmental aspects of inter-city passenger transport*. OECD-ITF Transport Research Centre. Discussion Paper, 2009-28.

Levinson, D., J.M. Mathieu, D. Gillen and A. Kanafani. 1997. "The full cost of high-speed rail: an engineering approach," *The Annals of Regional Science*, 31: 189-215.

Martin, F. 1997. "Justifying a high-speed rail project: social value vs. regional growth," *The Annals of Regional Science*, 31: 155-174.

Mohring, H. 1976. *Transportation Economics*. Ballinger Publishing Company.

Nash, C. A. 1991. *The case for high speed rail*. Institute for Transport Studies, The University of Leeds, Working Paper 323.

Nash, C. A. 2001. "Pricing European Transport Systems: Recent developments and evidence from case studies," *Journal of Transport Economics and Policy*, 35 (3): 363-380.

Nash, C. A. 2003. "Marginal cost and other pricing principles for user charging in transport: a comment," *Transport Policy*, 10 (2): 345-348.

Nellthorp J., T. Sansom, P. Bickel, C. Doll and G. Lindberg. 2001. *Valuation conventions for UNITE, UNITE (UNIfication of accounts and marginal costs for Transport Efficiency),* 5th Framework RTD Programme. ITS, University of Leeds, Leeds.

Plassard, F. 1994. "High speed transport and regional development" in *Regional policy, transport network*. European Conference of Ministers of Transport. Paris

Preston J.M. and G. Wall. 2007. *The Impact of High Speed Trains on Socio-Economic Activity*, proceedings of the 11th World Conference on Transport Research, Berkeley (California, USA).

Puga, D. 2002. "European regional policy in light of recent location theories," *Journal of Economic Geography* 2(4): 373-406.

Robinson, J. A. and R. Torvik. 2005. "White elephants," *Journal of Public Economics* 89 (2-3): 197-210.

Rothengatter, W. 2003. "How good is first best? Marginal cost and other pricing principles for user charging in transport," *Transport Policy*, 10 (2): 121-130.

Steer Davies Gleave. 2004. *High speed rail: International comparisons*. Commission for Integrated Transport. London.

UIC. 2005. *High Speed Rail's leading asset for customers and society*. UIC Publications. Paris.

Venables, A.J. 2007. "Evaluating urban transport improvements. Cost–benefit analysis in the presence of agglomeration and income taxation," *Journal of Transport Economics and Policy*, 41 (2): 173–188.

Vickerman, R. 1995. "The regional impacts of Trans-European networks," *The Annals of Regional Science*, 29: 237-254.

Vickerman, R. 1997. "High-speed rail in Europe: Experience and issues for future development," *The Annals of Regional Science*, 31: 21-38.

Vickerman, R. 2006. *Indirect and wider economic benefits of high speed rail*. Paper given at the 4th annual conference on railroad industry structure, competition and investment, Madrid, October.