Economic evaluation of the High Speed Rail*

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Abstract

Investment in high speed rail (HSR) infrastructure produces social benefits and costs. The potential benefits are basically time savings, higher reliability, comfort, safety and the release of capacity in the conventional rail network, roads and airport infrastructure. The costs are high, and sunk in a significant proportion; therefore, the social profitability of the project requires that HSR users' and other beneficiaries' willingness to pay is high enough to compensate the sunk and variable costs of maintaining and operating the line plus any other external cost during construction and project life.

In Sweden there are now plans to build a high speed rail between the country´s two largest cities, Stockholm and Gothenburg. The distance between the cities is around 500 km. This is a standard medium-length line where the HSR develops its full potential. In this paper we conduct a cost-benefit analysis of the HSR lines for Madrid-Barcelona, Madrid-Seville and Stockholm-Gothenburg. The first one has been running for a couple of years and the second one since 1992, so we can evaluate their performance and increase our understanding of the potential social profitability of similar lines, like the Stockholm-Gothenburg where the investment decision has not been taken so far.

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1. Introduction

All over the world, governments of different political orientation are investing in high speed rail (HSR) infrastructure. In some countries the enthusiasm is more intense than in others. There is no a single pattern. UK and the US are now closer to building HSR infrastructure but until now they have been reluctant to give the definitive approval, and the money allocated to HSR has not gone beyond financing the cost of the evaluation of its economic and financial viability. Other countries, like France and Spain, have been keener on HSR than other European countries like Norway or Sweden, for example, whose governments are still studying whether this type of investment is socially worthy. Spain is a unique case because with much less traffic density than other countries (and much less congestion) in the conventional rail network, it is going to very soon be one of the first countries in the world measured in HSR kilometers.

Other countries have chosen alternative ways of improving the intercity passenger rail services. UK and Sweden, for example, upgraded their conventional rail using their conventional network, increasing speeds on existing tracks up to 200 km per hour, using tilting trains where necessary because of the curvature of the track (Nash, 2010). Now, the so-called HS2, between London and Edinburgh, is under study to introduce a new HSR track.

HSR performs very well in terms of market share in corridors of 400-600 km but not as good with other key parameters that do not reach some minimum thresholds to offset the high investment costs associated to the construction of this rail infrastructure. Many lines are heavily subsidized, so high load factors and market shares are compatible with a poor social return. It is not surprising that HSR investment is more popular among politicians and the general public than among economists (Levinson *et al.*, 1997; de Rus and Nombela, 2007; de Rus and Nash, 2007; Nash, 2010).

Some critics with HSR investment point to the high investment costs associated with the construction of a new high speed line. However, the point is not whether the passenger prefers to travel with this technology instead of the conventional modes, nor the high cost of the HSR, but whether the society is willing to pay its opportunity cost. This is of course an empirical question and the answer is context specific. There is not anything intrinsically good or bad with this railway technology and the economists do have not any other *a priori* position with respect to the construction of new HSR lines, beyond the suggestion of the importance of comparing social benefits and costs of the project under consideration before taking any irreversible decision.

The comparison of the situation *with* the project with the counterfactual is quite a challenging task. In fact, it is the comparison between two dynamic worlds. One is the world *without* the project evolving with changes in income, prices and technology, and the other is the world with the project evolving in a presumably different way, every year during the lifespan of the project. The evaluation is based in the comparison of each year between these two different worlds.

Investment in HSR modifies the equilibrium in intercity passenger transport. Most of these corridors in developed countries are already in operation and HSR projects are no more than the introduction of faster trains, changing the generalized cost of travel with respect to the prevailing situation without project (de Rus and Nash, 2007; de Rus, 2009).

An interesting issue related to intermodal competition in intercity corridors is the asymmetry between the different operators. Although this is case specific, the separation between infrastructure and services that characterizes road, bus and air transport, puts the airlines at some disadvantage. Vertical unbundling may create some problems for the airlines that lose the control of the service as a package. In theory, vertical unbundling should not affect the final product supplied in the market but, in practice, this is far from being true as travel time has a strong component within airports, even where the airlines lose control of the process. On the contrary, high speed railways operate as if the infrastructure and services were integrated, controlling the access to the station and waiting time in the station. This fact has its consequences on modal split, as access-egress, waiting time, and the disutility of going through congested airports may determine, in the margin, user´s choice.

The construction of a new HSR line in a particular medium distance interurban corridor changes the modal split, and this change will occur regardless of the social value of the HSR project. The final impact will heavily depend on the pricing policy of the government with respect to the railways. The economic evaluation of HSR investment cannot be carried out without first determining which prices are going to be charged for HSR services. This is a key issue in general, but decisive in the case we are evaluating, where the market shares are very sensitive to pricing decisions taken in the public sector which affect the playing ground for intermodal competition. The public pricing decision regarding construction and maintenance costs of HSR infrastructure is crucial for the competitiveness of the railway operators, the intermodal equilibrium and eventually the result of the cost-benefit analysis of new lines. Therefore, this is an issue that the economic evaluation of new projects should not overlook. Investment and pricing decisions are interdependent.

There is considerable pressure on governments to built new high speed lines as if the investment were a kind of `now or never´ decision. This does not seem to be the case with this technology. The construction of HSR infrastructure is irreversible and there is uncertainty associated with costs and demand. In these conditions the question of the right moment to invest is critical as the investment can be postponed in most cases. Hence, the optimal timing of the investment should be addressed in the case of a positive Net Present Value (NPV). Even the idea of `all or nothing´ is false, as it could be profitable to build a line today and another in the future. Moreover, it is feasible to build a HSR rail track on parts of the overall line and use it for traditional trains at the same time as it is prepared for high speed services which would operate once demand motivates building new tracks on missing links. There exist several `do something´ alternatives.

The purpose of this paper is basically to answer the normative question of whether investing in the construction of HSR infrastructure in a standard medium-distance corridor like the Stockholm-Gothenburg in Sweden is socially desirable. The paper proceeds as follows. In Section 2, we describe the construction and maintenance costs of HSR, discussing the cost structure of a standard medium-distance HSR line and highlighting the fixedness of some costs and the dependence of the variable costs with the volume of passenger-trips. This is followed in Section 3 by a discussion of the economic benefits of HSR. We analyze the main direct and indirect benefits of a new HSR line, discussing which benefits we should concentrate our attention on, and which others are not expected to be relevant in answering the question of whether the investment is socially desirable.

In Section 4 we present the basic model for the economic evaluation of three HSR lines. The purpose of this section is to discuss the cost-benefit analysis framework with the aim of making our assumptions explicit, as well as to discuss the limitations of the practical approach that we follow in Sections 5 to 7. These sections contain an *ex-post* (or *in medias res* to be more precise) cost-benefit analysis of two similar lines in Spain: the Madrid-Seville, in operation since 1992, and the Madrid-Barcelona, fully in service since 2008 though operating between Madrid and Zaragoza since 2003. Sections 5 to 7 also contain an *ex ante* cost-benefit analysis of the Stockholm-Gothenburg project. Section 8 addresses the problem of intermodal competition, pricing and its consequences on project evaluation. Finally, conclusions are drawn in Section 9.

2. The cost of a High Speed Rail line

HSR lines have been conceived as a separate business by railway operators in many countries. The provision of HSR services in France or Spain, for example, is considered a different mode of transport, a new network with dedicated infrastructure and a more specialized and technologically advanced rolling stock. It brings with it an improvement over traditional rail transport (reliable timetables, sophisticated information and reservation systems, catering, on board and station information technologies services). In the case of Spain, the HSR lines are constructed with the European gauge, narrower than the 10.000 km of the conventional rail network.[1]

Both conventional and high speed railways are based on the same basic engineering principle: rails provide a very smooth and hard surface on which the wheels of the trains may roll with a minimum of friction and energy consumption. Nevertheless, there are technical differences. For example, from an operational point of view, their signaling systems are completely different: whereas traffic on conventional tracks is still controlled by external (electronic) signals together with automated signaling systems, the communication between a running HSR train and the different blocks of tracks is usually fully in-cab integrated, which removes the

[1] This section is based on Campos and de Rus (2009) and de Rus (2009, 2010).

need for drivers to see line-side signals. Moreover, the electrification differs since most new high speed lines require at least 25,000 volts to achieve enough power, whereas conventional lines may operate at lower voltages. Additional technical dissimilarities exist regarding the characteristics of the rolling stock and the operation of services.

The main difference with conventional railways is speed and this is not only a technical concept but also an economic one, since it is related to the infrastructure operation model chosen by the rail operator as we will see below. The technical definition of speed includes several related terms whose economic implications have to be separately considered. First of all to be considered is the maximum track speed, a technical parameter mainly related to infrastructure that, in the design stage, determines the radius of the curves and the gradient of the slopes. The ability of a train to trace closed curves without derailments or climb steep mountains or hills, is inversely related to its speed. For that reason, a HSR line faces tougher construction restrictions and may require a longer length the higher the maximum track speed of the project.

A second concept is the maximum operating speed, which is related to the technical characteristics of the trains and the way in which they are operated. This operating speed evolves with the technology and generally increases over time, constrained only by the maximum track speed. For example, most European HSR services operate with trains capable of maximum speeds in the range of 280-300 km per hour.

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

The most widely used concept is the commercial speed, which is simply calculated by dividing the total travel time over the line length. It can be noted that this is not only a technical concept (determined by the operating and track speeds), but an economic one as well: travel time is affected by technical considerations, but also by other (non-technical) elements, such as the commercial schedule, the number of intermediate stops, the quality assured to customers, etc.

Commercial speed is dependent on the relationship of HSR with conventional rail services. Also the way in which the services are organized with regard to the use of infrastructure plays a relevant role in the economic definition of high speed services. There are four different exploitation models: the *exclusive exploitation model* characterized by a complete separation between high speed and conventional services, each one operating with its own infrastructure. This is the model adopted by the Japanese HSR since 1964, mostly due to the fact that the existing conventional lines had reached their capacity limits and it was decided that the new high speed lines would be designed and built in standard gauge (1,435 mm). The second is the *mixed high speed model* where high speed trains run either on specifically built new lines, or on upgraded segments of conventional lines. This corresponds to the French model, whose high speed trains (TGV) have been operating since 1981, mostly on new tracks, but also on re-electrified tracks of conventional lines in areas where the duplication was impractical. This reduces building costs, which is one of the main advantages of this model.

The third, the *mixed conventional model*, has been adopted in Spain, where some conventional trains run on high speed lines, and where most of the Spanish conventional network was built in broad gauge (1,676 mm), whereas the rest of the European network used the standard gauge (1,435 mm). Talgo trains can run at higher speed on specific HSR infrastructure (built in standard gauge).[2] The main advantage of this model is the saving of rolling stock acquisition and maintenance costs, and the flexibility for providing 'intermediate high speed services' on certain routes. Finally, the *fully mixed model* allows for the maximum flexibility, since this is the case where both high speed and conventional services can run (at their corresponding speeds) on each type of infrastructure. This is the case of German intercity trains (ICE) and the Rome-Florence line in Italy, where high speed trains occasionally use upgraded conventional lines, and freight services use the spare

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

capacity of high speed lines during the night. The price for this wider use of the infrastructure is the significant increase in maintenance costs.

The choice of one exploitation model is a decision that affects the construction and maintenance costs of the HSR infrastructure and the costs of upgrading (and maintaining) the conventional network, and hence the definition of high speed becomes not only a technical question but also an economic one. The *exclusive exploitation* and the *mixed high speed* models, for example, allow a more intensive usage of HSR infrastructure, whereas the other models must take into account that (with the exception of multiple-track sections of the line) slower trains occupy a larger number of slots during more time and reduce the possibilities for providing HSR services. Since trains of significantly different speeds cause massive decreases of line capacity, fully mixed-traffic lines are usually reserved for high speed passenger trains during the daytime, while freight trains operate at night.

The cost of building and operating a HSR line consists of the construction and maintenance of the infrastructure, the acquisition, operation and maintenance of the rolling stock and the external costs. Sometimes, user costs are added to the total social costs of transport. These costs are mainly related to door-to-door travel costs, excluding money costs and including access, egress, waiting and in-vehicle time, reliability, probability of accident and comfort. As HSR investment usually means a reduction of the user costs, they are treated as benefits in Section 3.

The construction of HSR infrastructure requires a specific design aimed at the elimination of all those technical restrictions that may limit the commercial speed below 250-300 km/h. These basically include roadway-level crossings, frequent stops or sharp curves unfitted for higher speeds so that, in some cases, new signaling mechanisms and more powerful electrification systems may be needed, as well as junctions and exclusive track ways in order not to share the right-of-way with freight or slower passenger trains, when there is joint use of the infrastructure.

These common design features do not imply that all HSR projects are similarly built. Just the opposite; the comparison of construction costs between different HSR projects is difficult since the technical solutions adopted in each case to implement these features differ widely. The construction (and planning) period involves much more than track building. It requires the design and building of depots, maintenance and other sites, as well as hiring and training of personnel, testing of the material and many other preparation issues.

Infrastructure costs include investments in construction and maintenance of the tracks including the sidings along the line, terminals and stations at the ends of the line and along the line, respectively, energy supplying and line signaling systems, train controlling and traffic management systems and equipment, etc. Construction costs are incurred prior to starting commercial operations (except in the case of line extensions or upgrades of the existing network). Infrastructure maintenance and operating costs include the costs of labor, energy and other materials consumed by the maintenance and operation 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 during operation.

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 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) but there are projects like the HS2 in UK with an estimated cost per km of €70 million. Infrastructure maintenance costs are around €100,000 (2009) per km. Hence, the fixed costs of a representative 500 km HSR line are €10 billion (planning, land costs and stations excluded); and €50 million per year for the maintenance costs of the line.

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). To these fixed costs we have to add the acquisition costs of the rolling stock and the operating and maintenance costs of running the trains.

Rolling stock costs include three main subcategories: acquisition, operation and maintenance. With regard to the first one, the price of a HSR trainset is determined by its technical specifications, one of whose main factors is the capacity (number of seats). However, there are other factors that can affect the final price, such as the contractual relationship between the manufacturer and the rail operator, the delivery and payment conditions, the specific internal configuration demanded by the operator, etc. With respect to the operating costs, these mainly include the costs of labor and energy. These costs usually depend on the number of trains operated on a particular line, which in turn, are indirectly determined by the demand. Since the technical requirements (for example, crew members) of the trains may differ with their size, sometimes it is preferable to estimate these costs as dependent on the number of seats or seats-km. In the case of the cost of maintaining rolling stock (including again labor, materials and spare parts), costs are also indirectly affected by the demand (through the fleet size), but mainly by the train usage, which can be approximated by the total distance covered every year by each train.

There are other costs involved in a HSR project. For example, planning costs are associated with the technical and economic feasibility studies carried out before construction. These fixed costs, as well as those associated with the legal preparation of the land (expropriation or acquisition from current landowners), are not usually included in the published construction cost per km. There are other costs difficult to allocate to infrastructure or operation, as general administration, marketing, internal training, etc.

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 the 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 (2002). The operating and maintenance costs vary considerably. 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 (de Rus *et al*., 2009).

External costs

It has been argued that one of the reasons supporting the case for investing in HSR infrastructure is the positive net environmental effect associated with the operation of HSR services once the substitution effects are included. HSR trains attract passengers from road and air with higher environmental externalities and, when the deviation of traffic is substantial, as it happens to be in medium-distance corridors, the net effect on the environment of investing in HSR is likely to be positive. Although the above argument is empirical, it helps to identify the direct and indirect environmental effects of the HSR and whether, under reasonable assumptions, a reduction of the environmental damage can be expected with respect to the situation *without* project.

The environmental externalities of HSR point in two directions. One is positive, due to its substitution effect on air and road traffic. In such cases, its contribution to the reduction of these negative externalities is positive, although it requires a significant deviation of passengers from these modes as well as high load factors in the HSR to offset the pollution associated with the production of electric power consumed by high speed trains.

The other is negative: High speed lines need land, crossing areas of environmental value. The rail track creates a barrier effect in the affected territory, produces noise and generates visual intrusion on the landscape. The net environmental impact will depend on the reduction of environmental externalities in other modes of transport that lose traffic in favor of the new mode. Moreover, the emission of greenhouse gases during the construction period is massive and it may take decades of HSR operation to compensate for the emissions caused by construction (Kageson, 2009). 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. The net impact is very difficult to assess without contemplating the circumstances in a particular corridor.

There are some facts that can help to understand the reason why this external benefit of the HSR has been found insignificant in any independent economic evaluation of the construction of new lines:

- The environmental impact of a new HSR is not limited to the operation of trains during the life of the project (negative or positive) but also to the externalities during the construction period (negative). While the environmental costs of building the line are relatively easy to quantify, those associated to the operation are subject to a wide variability depending on the volume and composition of traffic, load factors, etc.

- There are several environmental effects of building a new line: land use, barrier effect, noise, pollution, etc. Some of these effects (barrier effect, negative landscape and biodiversity impacts) may be more important than the effect on global warming but as the social debate is concentrated on this particular effect at the moment, further research is required on these externalities given its irreversibility.

- The net effect on global warming depends on the change in the modal split within the corridor, the generation of traffic, the load factors in the different modes of transport, the technological change during the lifespan of the project and the indirect effects in other markets. The reported net environmental impact of HSR is very sensitive to the assumptions regarding these key factors.

- To the extent that infrastructure charges on road and air 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 noise, air pollution, global warming and other external costs and their comparison with taxes and charges

- Any measurement of the expected environmental impact of a new HSR line requires a counterfactual. The result of any cost-benefit analysis is strongly affected by the creation of the predictable world without the project. In our case, the construction of new road and airport capacity avoided, as well as the improvement in the technology of cars and aircraft during the life of the project, or the type of pricing to be applied in each mode of transport in the next decades, should be taken into account.

There are many negative environmental impacts when a HSR line is built (e.g., the barrier effect) to be weighed against the expected reduction of CO_2 emission when passengers shift from road and air to rail; and though some of them can be mitigated through tunneling, the contribution toward environmental improvements does not seem to be a strong point of HSR investment. Even in studies quite favorable to HSR, the conclusion with respect to the benefits on the environment is skeptical, "…since a scheme requiring such substantial new infrastructure would inevitably have significant negative landscape, biodiversity and heritage impacts, with relatively small benefits to air quality and noise levels" (Atkins, 2004).

The contribution of HSR investment to the mitigation of global warming is also very poor, or even negative, once the CO_2 emission during the construction period is accounted for. The construction of a new line produces a large amount of pollution emitted by the production and distribution of materials and construction processes. These would be, for example, the production and distribution of concrete, steel and ballast required for the different structure elements (sleepers, railway traction power structure, rails and rail vehicles) and the distribution and construction where trucks, bulldozers, tunnel-boring machines and other equipment operate, and also when these materials have to be removed and replaced to keep the track in operation.

The conclusions of the advantages of HSR in terms of global warming and other externalities do not allow supporting the investment in HSR on environmental grounds. Kageson (2009) calculates the effects on emissions of the introduction of HSR in a medium-distance corridor (500 km). A deviation of passenger-trips of 20 per cent from aviation, 20 per cent from cars, 5 per cent from long-distance coaches, and 30 per cent from conventional trains is assumed. Generated traffic accounts for the rest. In this 500 km corridor the HSR investment would result in a net reduction of CO_2 emissions of about 90,000 tons per year. Assuming a volume of demand of 10 million passenger-trips per year and a price of

$40 per ton of CO_2, the benefit of the reduction is equal to $3.6 million. As Kageson remarked, this amount is really low in the context of HSR costs. "The sensitivity analysis shows that alternative assumptions do not significantly change the outcome. One may also have to consider the impact on climate change from building the new line. Construction emissions for a line of this length may amount to several million tons of CO_2." (Kageson, 2009).

The following study was undertaken by Booz Allen Hamilton (2007) for the UK Department of Transport within the economic evaluation of the so-called HS2, and it includes the emission of greenhouse gases during the construction period. The report examines the effects on global warming of the construction of two lines: London-Birmingham and London-Scotland. The different length of the lines is a quite interesting fact for understanding the effects of HSR investment on the mitigation of emissions as in the first one (500 km) rail, it is more competitive than air but the room for additional benefits is lower, as conventional rail already had a significant market share, so the emission during construction was a heavy burden to offset during the change in the modal split. The second, longer line has potentially more to gain because the market share of air is higher, but the longer distance makes competition with air transport more difficult.

In this report, the net effect on CO_2 emission of the new line is estimated calculating the change in the emissions through the HSR line construction and operation in order to compare it to the situation without the project. To achieve a net reduction in carbon emissions, a reduction of the activity (traffic diversion) in the alternative modes is required so that the carbon saved on road and air exceeds the additional emission from the construction and operation of the HSR. The situation where the savings in the conventional modes compensates the emission produced by the HSR is called *emissions parity*.[3] Therefore an estimation of the change in the modal split in the corridor is needed to estimate whether the deviation of demand from competing modes is enough to achieve emissions parity.

[3] *Emissions parity* means that the amount of CO_2 is similar with project and without project. *Carbon neutral* means that the changes through modal split compensate the emission during construction and operation to a level at which there are zero net emissions with the project

Booz Allen Hamilton (2007) circumvents the forecast of the deviation of traffic from conventional modes to HSR estimating the required modal shifts to achieve emissions parity. When the modal split is greater than that corresponding to emissions parity level, the investment in HSR contributes to the mitigation of global warming. The carbon dioxide emissions, including those from rail and air are estimated over a 60-year period of analysis (2010-2070). Key assumptions underpinning the analysis include the future service pattern on the new and existing lines, and future growth in demand for rail and air. The effect of technological improvements in the fuel efficiency of vehicles and the expected reduction of carbon content of transport fuels are also included.

The results for the London-Manchester line show that even with a HSR market share of 100% (54% at present) it is not possible to achieve the emissions parity. "Therefore, based on the assumptions applied, there is no potential carbon benefit in building a new line on the London to Manchester route over the 60 year appraisal period. In essence, the additional carbon emitted by building and operating a new rail route is larger than the entire quantity of carbon emitted by the air services" (Booz Allen Hamilton, 2007).

In the case of the London to Glasgow/Edinburgh corridor, the construction of the HSR line can reach the emission parity if rail goes from its 14% present market share to more than 62%. This is not easy as the quality and speed of the conventional railways are already reasonable and the distance makes it more difficult for rail to compete with air services.

Finally, the contribution of the HSR investment to a reduction of emissions to mitigate global warming cannot be expected to be significant even if rail market share reaches the maximum level in the London to Glasgow/Edinburgh. "The transport emissions account for some 23% of the 554 million tonnes of CO_2 emitted by the UK (2005 figures). However, it should be made clear that the current emissions from rail and *domestic* aviation together account for only around 1% of total UK CO_2 emissions. While this does not take into account the alleged amplified climate change effect of releasing GHGs at altitude for aviation emissions, it does demonstrate the relative size of the opportunity for reducing emissions with a new domestic rail line, in the context of the national carbon footprint" (Booz Allen Hamilton, 2007).

The evidence for the US is similar to the one described above. Kosinski *et al*. (2010) show that building a high speed network can go beyond the emission parity making a contribution to the mitigation of carbon dioxide emissions. The HSR system evaluated in this study includes the city pairs linked as part of the network of the Federal Railroad Administration designated HSR corridors, and according to their estimation, 18.0% and 28.5% of 2008 air and auto travel, respectively, were found to be in the HSR range.

Although they show that under reasonable assumptions the investment on HSR can make a contribution to carbon dioxide reductions, the magnitude is again unsatisfactory from the perspective of investing in HSR for environmental reasons. Excluding the environmental impact during construction, Kosinski *et al*. (2010) conclude that HSR investment would likely lead to a modest reduction in CO_2 emissions of between 0.5% and 1.1% in the passenger transport sector.

The low potential to reduce CO_2 emissions in the transportation sector compared with the original projections without HSR is primarily due to the small share of overall travel that is between major metro regions connected within the proposed HSR network and expected to shift from air and road to HSR.

In the case of noise, the modal comparison is less brilliant although still very favorable to HSR. Railways noise mostly depends on the technology in use but, in general, high speed trains generate noise as wheel-rail noise and aerodynamic noise. It is a short-time event, proportional to speed, which burdens during the time when a train passes. This noise is usually measured in dB(A) scale (decibels). Measurements have been made for noise levels of different high speed train technologies, and the values obtained ranged from 80 to 90 dB(A), which are disturbing enough, particularly in urban areas. Levinson *et al.* (1997) found that in order to maintain a (tolerable) 55dB(A) background noise level at 280 km/h, it has been found that one needs about a 150-meter corridor between the tracks and any other structure.

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

The discussion on the environmental costs of the HSR has an interesting dimension in Sweden. In UK, for example, the NPV of the construction and operation of the HS2 is positive but the net balance of the environmental costs of the project is not considered as an additional benefit of the project (Atkins, 2004). In contrast, the Stockholm-Gothenburg-Malmo HSR lines are expected to be negative in some studies but the contribution to the mitigation of global warming through traffic deviation from more environmental damaging transport modes is high enough, according to some studies, to justify the investment (Äkerman, 2011; Janson *et al.*, 2010). Although other studies (Nilsson and Pyddoke, 2009; Kageson, 2009; Kageson and Westin, 2010) are less optimistic, the point is that the environmental effect is a key issue in the debate of the social worthiness of constructing HSR lines between Stockholm and Gothenburg and Malmo. In Section 7, where the economic evaluation of the HSR in Sweden is carried out, we have a more detailed discussion of this debate.

With respect to safety, any comparison of accident statistics for the different transport modes immediately confirms that HSR is – together with air transport – the safest mode in terms of fatalities per passenger-kilometers. This is so because high speed rail systems are designed to reduce the possibility of accidents. Routes are entirely grade-separated and have other built-in safety features. Part of safety costs is thus capitalized into higher construction and maintenance costs, rather than being realized in accidents. In the case of the barrier effects, alteration of landscapes and visual intrusion, some of these external costs are also internalized in land movements and construction, though the external part of this cost may be overwhelming.

3. The benefits of High Speed Rail

The provision of high speed rail services in medium-distance intercity corridors dramatically increases the market share of railways. Although society may not have improved, some individuals are better off with the project. Some users have voluntarily chosen to shift mode, having had the possibility of choosing between the former alternative and the new one. It is true that when conventional rail services are closed following the introduction of HSR services, some rail users do not have a similar alternative; but at least with respect to car, bus and air, the individual improvement is clear when the users shift from these modes to HSR.

The choice is based on the generalized cost of travel (money cost, door-to-door travel time multiplied by the value of time of passengers; values that vary with the level of comfort, and some other unobservable variables). The door-to-door travel time has several components and the value passengers place on each one is far from being the same. Passengers give more weight to access-egress and waiting time than to in-vehicle time and this has important consequences in terms of market shares. According to Wardman (2004) saving waiting time is valued on average 1.5 times than in-vehicle time, and 2 times in the case of access-egress. Price is also an important component of the generalized cost. The results of some customer surveys may lead us to think that time is what matters for a modal split, and that price is irrelevant, but another interpretation is that at the *present level* of HSR prices, time is the key factor. Intermodal competition may thus be strongly affected.

This individual decision between travel options is affected by the competitive advantage of each mode of transport. The advantage can be technological, affecting the trip length or the quality of travel, but it is also explained by the pricing policy of the government. The market shares in medium-distance corridors are sometimes determined in the margin by decisions taken outside of market discipline. For example, the rail market share will vary drastically depending on whether the infrastructure charges follow short-run marginal cost or aim for full cost recovery.

Leaving aside income transfers and focusing on the real resource changes, HSR generates social benefits, basically time savings, higher reliability, comfort and safety, and the reduction of congestion and accidents from alternative modes. When users shift to HSR from buses, cars or airlines, some avoidable costs add to total benefits. These cost savings may be significant when the equipment, energy and labor have alternative uses.

Table 1 shows the direct and indirect benefits associated with the investment in transport infrastructure. In the case of HSR, some of them are indisputable, as happens to be the case with time savings and new users' willingness to pay, but others are less clear, such as the spatial effects (tunnel effect of HSR in contrast with the corridor effect of conventional rail) or the agglomeration benefits, more connected with urban and commuting services than with the medium-distance intercity transport. Let us discuss the list of potential benefits in more detail.[4]

Table 1. Benefits of transport investment

Transport market (derived demand)	Primary markets (using transport)	Secondary markets
• Time savings • Higher reliability • Higher frequencies • Reduction in operating costs • Generated demand • Reduction of accidents • Environmental impacts	• Effects already measured in the transport market (except leisure and commuting time savings) • Wider economic benefits - Agglomeration - Higher competition • Spatial effects and regional development	• Complement and substitutes in markets with distortions (indirect effects- intermodal effects) - Taxes - Subsidies - Externalities - Unemployment - Market power

[4] The description of the benefits is based on de Rus (2008, 2010).

Direct benefits measured with the derived demand for transport

The direct benefits of HSR investment come from existing passenger-trips using conventional railway services in the corridor, the deviated demand from other transport modes and the induced passenger-trips after the reduction of the generalized cost of travel. The door-to door user time invested in a trip includes access and egress time, waiting time and in-vehicle time. The total user time savings will depend on the conditions in the initial transport mode. In the case of conventional railway, some case studies on HSR development in seven countries show that when the conventional rail has an 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 the 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 in conventional and HSR services.

The case of road transport is quite different with access-egress and waiting time, playing a decisive role in the generalized costs and eventually in modal choice. In the case of a HSR line with 500 km length, car passengers shifting to HSR 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. 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 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 car (de Rus, 2010).

In the case of air transport the picture is also different. In-vehicle time is longer by train but it is assumed that the user saves access, egress and waiting time, and enjoys additional service quality. The evidence (Wardman, 2004) is that the money value of time of access-egress and waiting time are of the order of 2 and 1.5 times higher, respectively, than in-vehicle time and hence, even in the case of longer door-to-door travel time after the shift, the value of time savings of a passenger shifting from air to rail could be positive, as far as the values of time of access-egress and waiting time are high enough to compensate the losses 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 more demanding security measures for rail travel. If these measures are taken, demand for HSR relative to other modes could decrease for two reasons: trip time could increase and trip quality could decrease.

It is worth stressing that under these circumstances the market rail share, crucial for the success of HSR investment, depends on some conditions to be fulfilled. The main condition to be fulfilled is that the generalized cost, net of transfers, be lower. This means that the resource cost is lower when the passenger shifts to HSR, but this may happen even in the case of negative net door-to-door travel time benefits if the avoidable resource cost in the initial mode of transport is high enough to offset those losses. It seems clear at this point that the magnitude of the total net benefits of passengers shifting modes are very sensitive to a set of variables which can take values within a wide range depending on the local conditions in the corridor. Yearly net benefits have to be significant to compensate HSR variable costs and then to produce a surplus per year high enough to compensate the initial investment costs.

Benefits also come from induced demand. The new passenger-trips of HSR may come from different sources: completely new generated trips; trip redistribution, i.e., trips that were made to a different destination without the project; diverted demand from other modes of transport; and finally, route or time reassignment. In the three first cases the number of passenger-trips increases for the project and so we have to account for the willingness to pay of both the deviated and the generated demand. The interesting point is that both types of demand can be measured with the same method (Abelson and Hensher, 2001). Users who switch to HSR from an alternative transport mode as well as new users or existing users traveling more, have benefits that go from the total marginal change to zero.

The conventional approach for the measurement of the benefits of new demand 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 (the `rule of a half´).

Nevertheless, this method may be misleading when the implementation of the transport project also affects some quality elements of the journey or there is a change in the frequency. In the first case, the application of the `rule of a half´ may underestimate the willingness to pay of the total benefits when using the resource cost approach, unless the additional willingness to pay for `quality´ is included (Abelson and Hensher, 2001). In the second case, when there is also a change of the time between services (headway), the change in consumer surplus has to be calculated taking into account all the transport modes, even when the schedule changes for only one of them (Jansson *et al*., 2010).

Indirect, spatial and wider economic impacts

It is not uncommon to find the emphasis on the indirect effects, wider economic impacts and regional development instead of the direct effect when a HSR project is presented by its promoters. It is true that transport investments produce other alleged benefits beyond the direct benefits already discussed, but it is unclear whether these additional benefits are new ones or double counting, as shown in the second column of Table 1. Moreover, some genuine indirect benefits exist but many of them could be associated with any other infrastructure project in general, and not exclusively with high speed, so even if the benefits 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.

The framework of conventional cost-benefit analysis does not include the evaluation of the impact of transport infrastructure projects on regional development. Puga (2002) argues that concentrating on the primary market and some closely related secondary market may be justified, provided that two conditions are met: first, that distortions and market failures are not significant and so there is no need to worry with the indirect effects of the project; and second, "the changes in levels of activity induced by the project fade away fairly rapidly as we move away from those activities more closely related to it. However, these conditions are often not met. There has been increasing realization throughout economics that wide ranges of economic activities may be affected by market failure and distortions. And the type of cumulative causation mechanisms modeled by the new economic geography can make the effects of a project be amplified rather than dampened as they spread through the economy" (Puga, 2002).

Should we worry about these wider economic benefits in the case of HSR investment? Puga (2002), Duranton and Puga (2001) and Vickerman (1995, 2006) suggest that additional benefits are not expected to be very important in the case of high speed railway infrastructure. The reason is that freight transport does not benefit from high speed and therefore the location of the industry is not going to be affected by this type of technology. Moreover, in the case of the service industry, HSR may lead to the concentration of economic activity in the core urban centers.

Recent research (Graham, 2007) suggests that agglomeration benefits in sectors such as financial services may be greater than in manufacturing. This is relevant to the urban commuting case but arguably is important for some HSR services (e.g., the North European network which links a set of major financial centers and may be used for a form of weekly commuting). It may be erroneous to conclude that scale economies and agglomeration economies (productivity impacts) are only found in manufacturing and freight transport.

Hernández (2010) examines the relationship between the construction of the Spanish HSR network and the creation of employment in the municipalities that benefit from the infrastructure. He develops an econometric model that explores the relationship between the density of employment and the existence of the HSR in different geographic areas. The motivation for exploring this relationship is to check whether the provision of infrastructure generates additional benefits to those considered in conventional cost-benefit analysis. The author uses GIS (Geographical Information System) with areas within concentric circles of 20 kilometers around the high speed rail stations to estimate the impacts of the infrastructure on the employment density. Given the existence of municipalities under and out of the influence of HSR, the strategy is to compare both groups with panel data to control the possible existence of unobservable variables. Moreover, to avoid the possible existence of endogeneity between the provision of the infrastructure and the increase of the employment density, the author includes a set of instrumental variables. A matching procedure is used to avoid the irrelevant comparison between groups under and out of the influence of HSR.

The results show that the magnitude of the impact of HSR rail is around 3.5-1.8% on the employment density of 10-20 km concentric areas around the station, taking into account the use of instrumental variables to solve potential problems of endogeneity. The author interprets the results with the aim of distinguishing between relocation effects and net effects, concluding that it is not possible to disentangle both effects and that the existing literature has not been able to differentiate it either.

Investment in HSR as well as other transport infrastructures has been defended as a way to reduce regional inequalities. If the definition of personal equity is difficult, its spatial dimension is even more elusive. European regional funds aim to reduce regional inequalities, but the problem is to define clear objectives so that it is possible to compare the results of different policies. The final regional effects of infrastructure investment are not clear and depend on of the type of the project and other conditions as wage rigidity and interregional migration. There are some ambiguities related to the role of opposite forces which affect the balance between agglomeration and dispersion. It is difficult *a priori* to predict the final effect.

Indirect effects are the impact of HSR on secondary markets, whose products are complements to, or substitutes for, the primary market. There are some indirect effects of HSR which, in some cases, may be important. These effects are called intermodal effects and take place in the substitutive (or complementary) mode of transport of the HSR. Are users of the alternative modes better off with HSR? What about the producers? It is important to distinguish here between transfers and real resource changes. We have already seen the direct benefits that society gains from the introduction of HSR, but users who remain attached to their former modes of transport may be affected positively or negatively depending on whether there are distortions on these modes of transport. The same is applicable to other economic agents.

The critical issue is whether price is higher or lower than marginal social cost in the alternative mode of transport. When price is below marginal cost in the original transport mode, society benefits from the diversion of demand to the new transport mode (assuming price equal to marginal cost in the new mode). This could happen because of the reduction of excessive congestion, or pollution. In the case of a positive externality the opposite might occur, and the indirect effect could be negative when the price is above the social marginal cost in the original transport mode, for example, if the reduction of demand in the original transport mode forces the operators to reduce the level of service, thereby increasing the generalized cost of travel.

The key point is whether the original transport mode was optimally priced. Although it has been argued that the reduction of road and airport congestion is a positive effect of HSR, this is only the case if there is a lack of optimal pricing. When road and airport congestion charges internalize the external marginal costs, there are no indirect benefits from the change in modal split. This can be viewed from another perspective. The justification of HSR investment based on indirect intermodal effects should be first compared with a “do something” approach, consisting of the introduction of optimal pricing.

It should also be mentioned that, for example, given the impossibility of road pricing, a second-best case for HSR investment based on indirect intermodal effects, requires significant effects of diverted demand on the pre-existing demand conditions in the corridor. This means the combination of significant distortions, 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.

The assumption that price is equal to the social marginal cost means that the loss of traffic by conventional modes of transport does not affect the utility of those who continue to use these modes of transport, nor the welfare of producers or workers in these modes. This would mean that operators are indifferent to losses in patronage, or workers are indifferent when losing their jobs, because in both cases they are receiving, in the margin, their opportunity costs. There are many reasons to abandon this assumption, one of which is the existence of unemployment, but we will concentrate here on how the reduction of demand in air and bus transport affects user's utility when the operators respond to a lower demand by reducing the service level.

Intercity bus services operate under concession contracts in many countries and so they cannot change their basic regulated timetables in the short run. Although they may cut the number of bus-trips when demand diminishes, the reduction in supply does not affect frequencies since the suppressed services leave at the same time as approved in the basic regulated timetable. However, it can be argued that although users are barely affected by the short-term adjustment of bus operators, financial difficulties will emerge later in contract renegotiations or when concessions expire. This means that users and/or taxpayers (or workers) will have to pay for the adjustment in the medium-term.

Airlines operate in open competition and therefore the short-term adjustment in response to the external shock in demand produced by the introduction of HSR services is the observed reduction in the number of operations. This affects frequencies, first because the reduction in demand is substantial; 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.

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).

There is evidence on the increase in land values (Cascetta *et al*., 2010; Preston and Wall, 2008) or on the increase in the GDP of places where HSR stations are located (Ahlfeldt and Feddersen, 2009). However, the problem is to disentangle genuine additional benefits from transfers resulting from the relocation of economic activity from other areas of the country, or from a simple reflection of the already-measured time savings into property values (Nash, 2010). Levinson (2010) identifies two major impacts in land values, one positive linked to accessibility benefits, and the other negative linked to noise along the line. The author argues that the effects on land use near the HSR stations are not significant when the traffic is not for commuting purposes. An example is Eurostar, a HSR line connecting London and Paris where "The development effects are not local (unlike public transit stations), which is not surprising since if they are serving long distance travel they are also serving less frequent travel, and as a consequence the advantages of being local to the station are weaker" (Levinson, 2010).

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 HSR, 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 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 the wider origin-destination menu, the utility of a specific traveler who is traveling from A to B in a denser network 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.

4. The Cost-Benefit Analysis (CBA) framework

The economic evaluation of HSR investment

We are examining the expected welfare effect of the projected construction of a HSR infrastructure in an intercity corridor, where people commute or travel for business or leisure or other purposes, and where bus companies, airlines and rail operators compete between them, and with cars, for passenger-trips. HSR services reduce rail travel time, changing the modal split in the corridor. In situations with capacity constraints in the conventional rail network and airports, additional benefits may be derived from the construction of new lines through the release of capacity for freight and other types of services in the case of rail, and for other destinations in the case of airports.

Other things happen as traffic is diverted from road and air to rail, and the demand shifts in many other secondary markets, with products which are complements or substitutes of transport services. Some cities may become more accessible and some additional economic benefits may have to be added to the conventional direct and indirect benefits, though it is essential (but difficult) to distinguish between genuine wider economic benefits from mere relocation of previously existing economic activity. Even in the case of additional benefits as it is the case of agglomeration economies, the possibility of other areas losing benefits for the same reason should not be discarded.

The story does not end here. The resources allocated to the HSR infrastructure and services are significant. Construction costs exceed those corresponding to any other transport alternative, and these costs include a significant environmental impact. The rest of the costs are distributed during the life of the project: rolling stock, energy, maintenance, labor and the environmental costs associated to the provision of services.

Moreover, investment costs are paid by the taxpayers in many cases, in a significant proportion, as HSR is constructed, and the services provided, by the public sector. Nevertheless, although the investment in dedicated high speed infrastructure is an expensive option for the improvement of rail transport, the point is not about the amount of HSR investment costs. The relevant issue is whether the society is willing to pay for this investment. The question is whether the social benefits of HSR investment are worth its costs. [5]

Contemplating a particular corridor we would need to know the change in welfare *with* the project with respect to the situation *without* the project and this is far from being an easy task. Let us 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 investment in HSR can be seen as a perturbation in the economy, changing individuals' utility. These changes, occurring to many individuals in many markets and during a long period of time have different signs. Some individuals are better off with the project and others are worse off. Leaving aside the problem of adding gains and losses accruing to different individuals, we have a first question to answer related to the identification of the causal effect of the introduction of HSR.

We are looking for the change in the utility of the individual when the project is introduced, and this requires comparing the level of utility that an individual would have had if the project had not been implemented. Therefore, we need to construct a counterfactual and probably this is one of the most complex issues in the economic evaluation of projects. We have to imagine the world

[5] For a general equilibrium cost-benefit rules see Johansson (1993).

without the project every year during the lifespan of the project and compare it to how we think the world will evolve with the project. Then we compare these two moving imagined pictures.

A practical approach for the economic evaluation of investing in HSR

There are two approaches to estimate the net present value of any project: aggregating the change in the surpluses, derived from the implementation of the project; or alternatively, ignoring transfers between different individuals, and accounting for the changes in resource costs and willingness to pay. When adding the surpluses of different agents, we obtain the net social surplus. In this process of aggregation, transfers net out, and therefore we find the real gains from the project net of costs. This is equivalent to calculating the time savings, increase in comfort, reduction of accidents, net willingness to pay of generated passenger-trips, etc., net of investment, maintenance and operating costs, and external costs.

Assuming a single conventional transport mode, the approach of adding the changes in surpluses to measure the net social benefit (*W*) of HSR can be expressed as follows:

$$\Delta W = -\int_0^T I_t e^{-rt} dt - \int_0^T C_t^1 + C_t^1(q) e^{-rt} dt + \int_0^T \int_{g_t^1}^{g_t^0} q(g) e^{-rt} dg dt + \int_0^T (p_t^1 q_t^1 - p_t^0 q_t^0 + C_t^0) e^{-rt} dt \\ + \sum_{j=1}^{M} \int_0^T S_{jt} (q_{jt}^1 - q_{jt}^0) e^{-rt} dt, \qquad (1)$$

where:

I_t: HSR construction costs per year.

T: project life.

C_t^1: HSR fixed maintenance and operating cost per year.

$C_t^1(q)$: HSR annual maintenance and operating cost as a function of q.

r: social discount rate.

$q(g)$: passenger trips.

g_t^0 : generalized cost *without* the HSR project.

g_t^1 : generalized cost *with* the HSR project.

p_t^0 : price *without* the HSR project.

p_t^1 : price *with* the HSR project.

q_t^0 : demand quantity *without* the HSR project.

q_t^1 : demand quantity *with* the HSR project.

C_t^0 : annual avoidable cost of the conventional mode.

M: other markets in the economy.

S_{jt} : excess of benefits over costs in market j of a unit change in q_{jt}.

q_{jt}^0 : level of activity in market j and year t *without* the project.

q_{jt}^1 : level of activity in market j and year t *with* the project.

We distinguish between two types of agents in (1). Those affected in the primary market: direct users (existing, deviated and generated), producers, individuals affected by the externalities during the construction and operation of the project; and those affected in the secondary markets, i.e., the indirect effects in markets with distortions (basically intermodal effects). There are other candidates like the so-called wider economic benefits (excluded in equation (1) but discussed in this paper).

The main benefit comes from travel-time savings. We focus mainly on the measurement of time savings produced as a result of investing in a faster transport mode and the individual valuation of these time savings. However, HSR users usually include the higher reliability of HSR compared with air transport, and the higher comfort, as additional reasons for explaining why they choose HSR instead of other available alternative modes. A higher willingness to pay for enhanced quality or for higher safety may be left out following the resource cost approach, unless it is already included in the value of time.

It has been argued that the benefits of the time savings are underrepresented through the value of time. There may be agglomeration benefits from infrastructure investments due to better matching, learning and sharing. Some of the agglomeration benefits are external, hence not captured by the values of time for commuting (the way we estimate them), because people pay income tax. Individuals take only into account the potential net income increase due to shorter travel time when we measure their value of time. The proportion of the income increase (if any) that does not go to the individual (due to taxation) is external and should be added as a separate benefit (if unemployment decreases this part of the benefit could be significant).

Now, some of the agglomeration effect would be external to the individual and the company (in case of business travelers) even if there were no taxes. This is because other companies and workers benefit from the individual's time gain (matching/learning/sharing). This effect is not included in values of time, for business trips or for (private) commuting trips. To measure this part of the agglomeration effect is truly difficult. Nevertheless, in the case of HSR investments it seems unlikely that these additional benefits are significant due to the longer distances compared with the evidence of agglomeration benefits in true commuting services (Graham, 2007).

Environmental impacts are both a direct effect of the project (construction and operation) but there may exist positive externalities such as an indirect effect through the deviation of traffic from less environmental friendly transport modes (accounted for in expression (1) in the last term of the equation).

For illustrative purposes (the real calculus is done with all transport modes and as disaggregated as the data allow) let us see how the surplus approach in (1) is equivalent to the resource-cost approach. In the case of passengers already traveling by train, for example, without the project, the generalized cost is g^0, and the number of trips q^0. The generalized cost without the project includes the monetary component p^0, the total value of travel time, and other disutility elements related to the conventional train ($g^0 – p^0$).

Under these assumptions, the social surplus is equal to users´ surplus and producer´s surplus in the conventional train:

$$\left(g^{0}-g^{1}\right)q^{0}+\frac{1}{2}\left(g^{0}-g^{1}\right)\left(q^{1}-q^{0}\right)+p^{1}q^{1}-p^{0}q^{0}+C^{0}-C^{1}, \tag{2}$$

where C^0 represents the avoidable costs of the conventional train and C^1 represents here all costs (fixed and variable) of HSR.

With the resource-cost approach the introduction of HSR generates time-saving benefits for the existing and deviated traffic plus the additional net willingness to pay of the generated demand.

$$v\left(\tau^{0}-\tau^{1}\right)q^{0}+\frac{1}{2}\left(g^{0}-g^{1}\right)\left(q^{1}-q^{0}\right)+g^{1}\left(q^{1}-q^{0}\right)-v\tau^{1}\left(q^{1}-q^{0}\right)+C^{0}-C^{1}. \tag{3}$$

It is straightforward to show that both expressions lead to the same results. Ignoring transfers (p^0q^0) in (2) and given that $g^1-v\tau^1=p^1$ in (3), we get the following expression:

$$v\left(\tau^{0}-\tau^{1}\right)q^{0}+\frac{1}{2}\left(g^{0}-g^{1}\right)\left(q^{1}-q^{0}\right)+p^{1}\left(q^{1}-q^{0}\right)+C^{0}-C^{1}, \tag{4}$$

where v is the value of time and τ^0 and τ^1 the travel times, without and with the project respectively.

Hence, the direct benefits of HSR are the money value of time savings for existing traffic plus the additional revenue from generated (and diverted demand) and the value of the triangle between the generalized costs. To these benefits we have to add the change in costs (presumably negative with this technology).[6]

It is useful to distinguish between existing rail passenger-trips from deviated and generated traffic. The `rule of a half´ is applicable for all types of traffic but one should be careful when applying average time savings per passenger-trip category when there is no *existing traffic* but the whole traffic is either *deviated* or *generated* as it happens to be the case with bus, air and road passengers shifting to high speed trains.

[6] With data scarcity, or in a first approximation, it is possible to approach the benefits represented in both expression adding the time user benefits and the revenue of new traffic.

Additional benefits can be obtained from intermodal readjustment. In addition to the intermodal effect already measured in the HSR demand as a direct benefit obtained by users of other modes of transport who become HSR users, we have to add the effect of the reduction of traffic in the substitutive mode on the cost of traveling for the users who remain in the conventional mode once the project is implemented.

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). The condition for indirect effects to be translated into additional benefits (or costs) is that some distortion in the secondary market exists (see Table 1) and then there is a gap between the marginal social cost and the marginal willingness to pay in the equilibrium.

The secondary intermodal effects can be positive or negative depending on the sign of the distortion and the change in the quantity in the secondary market. The reduction of road congestion and airport delays has been identified as an additional benefit of the introduction of HSR. Expression (1) shows that the existence of this benefit requires the divergence between price and marginal cost. Where road or airport congestion charges are optimally designed, there are no additional benefits in these markets. Even in the presence of a distortion, a sufficiently high cross elasticity of demand with respect to the generalized cost in the secondary market is needed to have a significant economic impact.

5. *Ex-post* evaluation of the HSR Madrid-Seville

Before dealing with the evaluation of the Madrid-Seville HSR line, it is worth mentioning the scarcity of published information on costs and demand. The lack of transparency concerning the economic profitability of HSR in Spain is remarkable. The economic effects on the HSR lines circulated by the Spanish government have no relation whatsoever with the economic appraisal of projects, but rather with the type of impact studies where investment is not a cost but a benefit, including the multiplier effect, labor is not an input but an output, and transfers and relocation of economic activity are not considered, etc.

The economic evaluation of the Madrid-Seville line is based on the cost and demand information contained in de Rus and Inglada (1993) but this is the only common content of that original CBA and the present *in media res* CBA of the first Spanish HSR line. In what follows we describe the CBA of the Madrid-Seville and interpret the result of the density function of the net present values obtained through a risk analysis of the project.

Madrid-Seville was the first HSR line constructed in Spain. The 471 km line started its operation in April 1992. The investment period lasted from 1987 until 1993. Total investment was €2.1 billion (1986) and these costs were distributed during the construction period according to the real disaggregation of these costs per year as reported in de Rus and Inglada (1993). Investment costs are inclusive of indirect and income taxes.[7] The project is assumed to have an economic life of 50 years and for simplicity we ignore any potential residual value.[8]

The line allows the operation of high speed dedicated rolling stock and other conventional trains like Talgo to provide rail services between Madrid and Seville, Madrid-Cordoba, Cordoba-Seville and others O-D like high speed commuter services between Madrid and Ciudad Real.

Levinson *et al.* (1997) provide a description of operating and maintenance costs that is very useful for the allocation of labor cost and equipment and materials for shadow-pricing purposes. Sales and administration costs include labor costs for ticket sales and for providing information at the railroad stations, automated ticketing machines and travel agency commissions. Based on data from the French railways, the authors assumed these costs represent 10% of the

[7] The reason why we have not accounted for the investment costs net of taxes is because planning costs, land values and the construction costs of the stations and other facilities are not included in the investment cost of the line. Even so, real investment costs might possibly be substantially higher.

[8] The main results do not change when the usual *ad hoc* percentages of the investment are included at the end of the lifespan of the project.

passenger revenue. With the development of the new information technologies in the last decade, one should expect a decrease of these costs.

Train operations can be divided into four activities: train servicing, driving, operations and safety. Train operating costs consist exclusively of labor costs. Operations and safety on either high speed or conventional lines can be estimated on a per-train basis. The cost of the maintenance of electric traction installations and catenary depends on the number of trains running on the infrastructure, whereas the cost of maintaining the tracks depends on the number of train sets. Theoretically, the cost of maintenance of equipment is dependent upon the distance run by every train as well as the duration of use. The proportions of the cost of labor in the maintenance costs are 55% for maintenance of electric traction installations, 45% for maintenance of tracks and 50% for maintenance of equipment (Levinson *et al.*, 1997)

The maintenance cost of the infrastructure per kilometer is 100,000 €/km in 2009. From the description above, we assume half of these costs correspond to labor and in the case of the operation and maintenance of the rolling stock, we assume all costs are labor. Shadow pricing of labor is applied using a conversion factor of 0.9 according to some evidence for Spain (Del Bo *et al.*, 2009) and the other half of infrastructure maintenance is computed net of indirect taxes. The value added tax goes from 13% for the period 1987-1992; 16% for 1992-2010; and 18% from 2010 onwards (see Appendix 5.1 for more detailed information). The maintenance and operation cost per train was €2,841,774 in 1986 (de Rus and Inglada, 1993).

For the estimation of total operating costs we need the number of trains and the price of these trains. We assume the cost of a train follows a random uniform distribution with a range between €33,000 and €65,000 per seat in 2002, and each train has an average capacity of 330 seats and an economic life of 30 years (Campos and de Rus, 2009).

We assume demand is distributed uniformly during the day (no peak hours). The load factor follows a random uniform distribution with a minimum value of 0.6 and maximum of 0.7. The number of daily services required, given the load factor, the length of the route and the hours of operation and a contingency factor of 1.5 to allow for maintenance and other contingencies, is computed according to Campos *et al*. (2009). Trains operate 16 hours per day and do not exceed the maximum number of kilometers per year (500,000 km). The final number of trains in the evaluation is the maximum between these two previous rules.

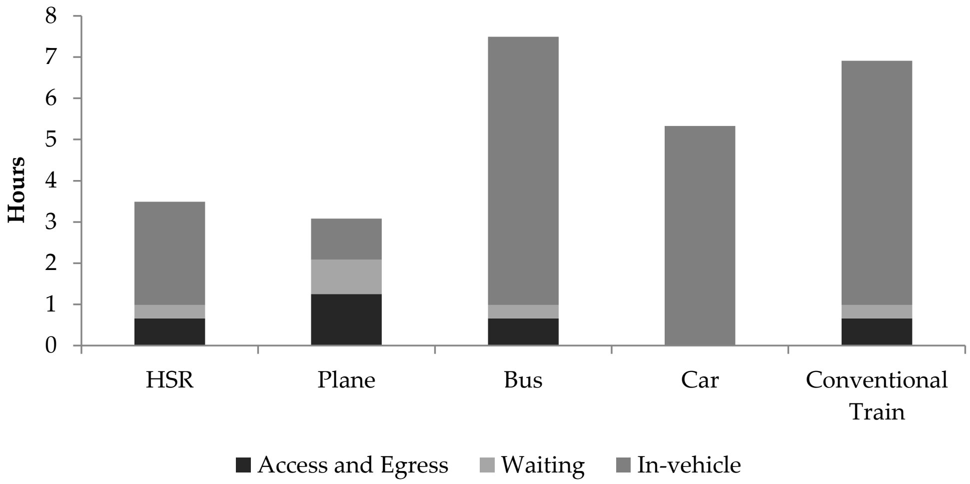
Other general assumptions affecting key parameters are the following: the annual growth rate of income is taken from the National Institute of Statistics until 2009. From 2010 to 2015, the estimated growth rate is equal to 1% according to the International Monetary Fund (IMF). For the rest of the evaluation period, the annual growth rate follows a random uniform variable between 1% and 4%, independent between years. The net present value is calculated at the beginning of 1987, with benefits and costs expressed in €1986. Prices are deflated with the CPI of the National Institute of Statistics. The social discount rate of the base case is 5% and the shadow multiplier of public funds is 1.

Demand is based on real data for the period 1992-2004, while for the rest of the project life we have projected the number of passenger-trips of previous years, assuming that the demand-income elasticity is equal to 1. In 1993, the first full year of operation, 2.8 million passenger-trips were transported in the whole line: 1.2 million between Madrid and Seville and 0.9 as commuter services between Madrid and Ciudad Real and other short distance O-D.

The estimation of the diverted traffic from the different modes per O-D and year is based on the demand of that year in the route multiplied by the percentage of the diverted traffic based on COST318 (1998). Passenger-trips completing the whole length of the line (Madrid-Seville) were initially air transport users (45%), bus users (2%), conventional train users (26%), car users (12%) and the rest (15%) corresponds to new trips that were not made previously on any transport mode.

In-vehicle time is around 2.5 hours and this is a substantial reduction with respect to conventional rail and road transport. On the contrary, air transport has a substantially lower flying time (approximately one hour). Modal split and the estimation of user benefits require going from in-vehicle time to door-to-door travel time and then, adding the money cost, to the generalized cost of travel. Let us have a closer look to the main long-distance O-D, Madrid-Seville and one of the short-distance O-D, Cordoba-Seville.

Figure 1. Door-to-door trip time (Madrid-Seville)



According to Figure 1 the faster way to travel between Madrid and Seville is by air. Door-to-door travel time is shorter, though the comparative advantage rests on the substantially shorter in-vehicle time as the access-egress and waiting time are higher when the airport infrastructure is involved. This is quite interesting because the higher values of access-egress and waiting time leave HSR in a better position when door-to door travel-time costs is the reference (Figure 2).

Figure 2. Time-saving benefits per passenger-trip (Madrid-Seville)

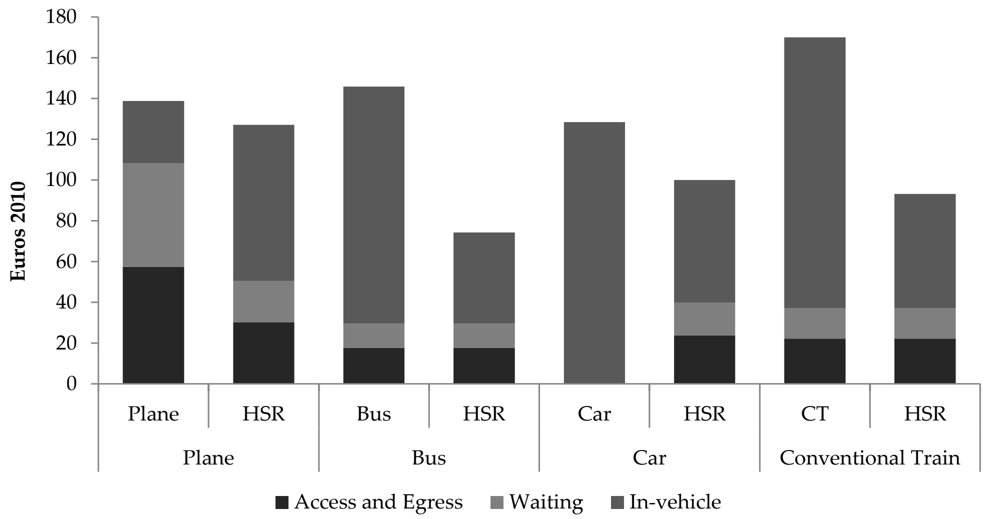
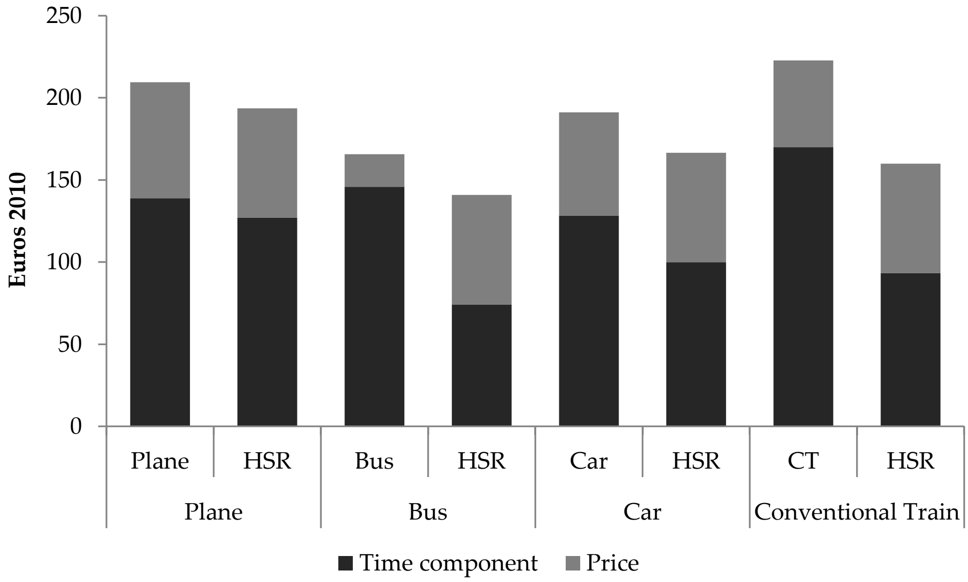


Figure 2 shows that average time benefits from deviated demand are mainly concentrated in passengers already using railways. The average time benefit is also high for passengers shifting from buses but is not relevant in absolute terms given the number of bus users. The money value per passenger-trip shifting from air transport is quite small and 45% of total demand comes from this mode of transport. However, individual modal choice is not based on resource costs but on the generalized cost of travel; i.e., door-to-door trip time multiplied by the value of time of passengers plus the money cost. Figure 3 is illustrative of the strong modal competition in this O-D.

Figure 3. Generalized cost per passenger-trip (Madrid-Seville)



The average generalized cost of HSR is quite close for air transport and car users. Only 12% of total passenger-trips were initially car users. It is worth pointing out that the similarity of the generalized costs of air, car and HSR is conditioned on the pricing policy of the government with respect to HSR infrastructure and, in the case of air transport, with the prevailing conditions in airports.

Cordoba-Seville, a representative O-D of other short-distance trips, shows the competitive advantage of cars. The fact that an estimated 20% of HSR passenger-trips were traveling initially by car may indicate a lower generalized cost due to other unknown components (e.g., parking is free for HSR users in some HSR stations) or even an overestimation due to the lack of reliable information.

Figure 4. Door-to-door trip time (Córdoba-Seville)

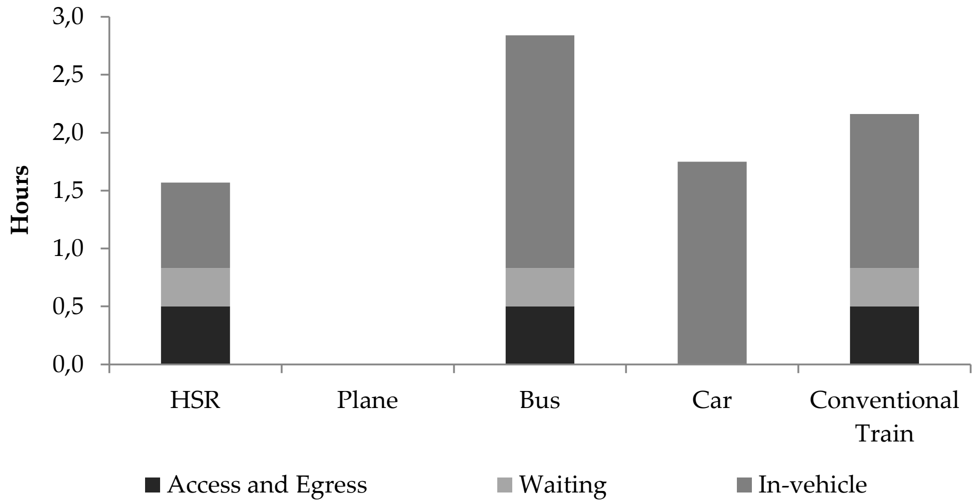


Figure 5. Time-saving benefits per passenger-trips (Córdoba-Seville)

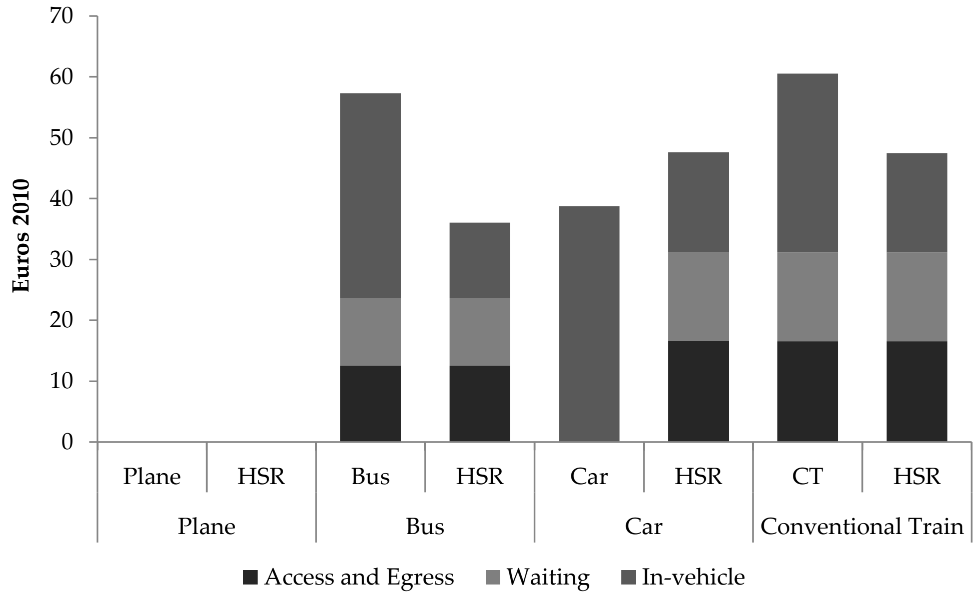
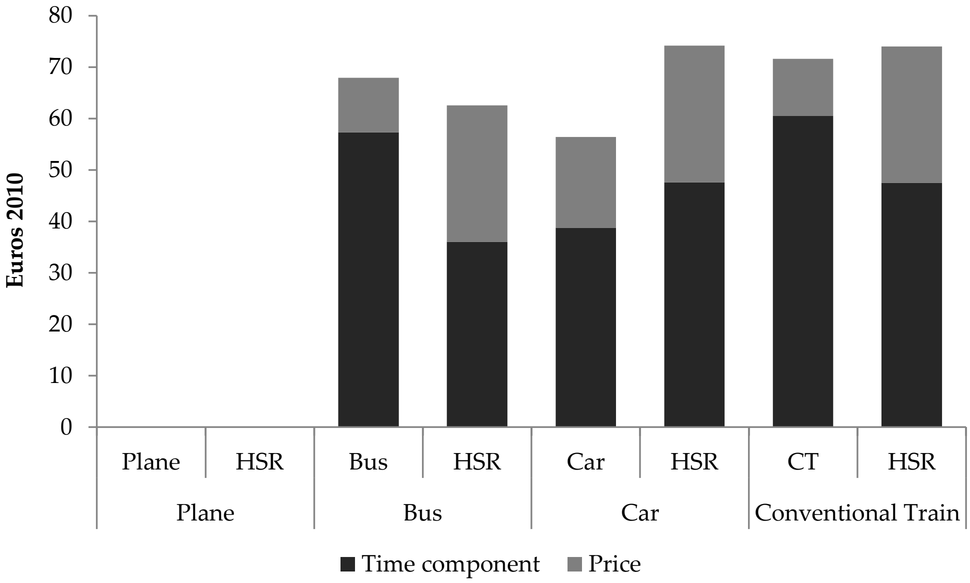


Figure 6. Generalized cost per passenger-trip (Córdoba-Seville)



Benefits from time savings are not as important as could have been expected after the introduction of high speed services as confirmed by Tables 2 and 3, below. Excluding the negative values of passenger shifting from cars to HSR, the percentage of time savings over total benefits is 34.9%, lower than the resource-cost savings in other modes over total benefits (42.7%). The time benefits from air and bus are quite small, and even negative for cars in some O-D pairs. The condition required for social profitability consisting in many passengers shifting to HSR, and willing to pay a high amount for the change, is not fulfilled in this corridor and this is a heavy burden for the social profitability of the project given the magnitude of the investment costs. 78.2% of the time benefits come from already existing rail users.

Social benefits do not only come from time savings but also from the additional willingness to pay from generated demand and the avoidable costs in the transport alternatives losing traffic. Additional passenger-trips of already existing users in the corridors, or from new users, account for 17.2% of total benefits and the resource costs avoided, thanks to the new rail line account for

42.7% of the total benefits of the project. The reduction of road accidents contributes to 5% of total benefits but the reduction of congestion is marginal. This not surprising as a new highway was built at the same time as the construction of the HSR line and the reduction of traffic is not enough to produce a significant increase in road speed.

The NPV is referred to at the beginning of 1987, when the construction started, but Tables 2 and 3, express the values in current units of 2010. This may seem trivial but many of the incomplete information about the construction costs of different lines built in different moments of time is provided without identifying the year when the line was built or whether the figures are in constant or current terms.

The expected 1987 net present value is negative, and is equal to €-2.27 billion in €2010, equivalent to 55% of the construction costs (€4.1 billion). The risk analysis shows that the probability of having a positive NPV is zero (Figure 7). In fact, the best result shown in the density function of NPVs is €-1.7 billion. Although one should be cautious, given the limited information available, the cost-benefit analysis of the line is conclusive in terms of the negative social value of this investment.

The results obtained in the economic evaluation of the HSR Madrid-Seville line may possibly rest on some inaccuracy affecting cost or demand figures but it reflects, we think, several undisputable facts: demand is extremely low in the first full year of operation (2.8 million passenger-trips). Only 1.2 million travel the whole length of the line; the other 1.6 million only use half of the length or less. The majority of passengers were already traveling by conventional rail, or by air where the time benefits of diversion are modest. The massive fixed costs of the line (60.6% of total costs) and the fact that variable costs are higher than the benefits from time savings plus generated demand, show that this investment requires a substantially higher volume of demand to be socially worthy.

The sensitivity analysis in Tables 2 and 3 shows the results are quite robust to a lower social discount rate (3%) or an increase in the time cost component of the generalized costs of all the alternative transport modes by 25% to account for willingness to pay for HSR higher comfort, service quality, or whatever. In both cases, the probability of a positive NPV is zero. The results show the importance of the avoidable costs in other modes of transport. Our assumptions are quite favorable to this resource-cost savings.

Table 2. Benefits of the HSR Madrid-Seville

	Benefits 2010*	%	Discount rate (3%)	25% increase in VOT
Infrastructure Investment	-4,115,670	60.6	-4,462,798	-4,115,670
Infrastructure Maintenance	-562,097	8.3	-882,418	-562,097
Rolling Stock Investment	-318,885	4.7	-434,782	-318,885
Rolling Stock Operation and Maintenance	-1,796,242	26.4	-3,006,700	-1,796,242
TOTAL COST	-6,792,895	**100**	-8,786,697	-6,792,895
Time savings	**1,580,567**	**34.9**	**2,710,696**	**1,975,709**
- Conventional train	1,235,903	27.3	2,120,121	1,544,879
- Car	138,848	3.1	237,971	173,560
- Bus	49,421	1.1	84,676	61,776
- Air transport	156,395	3.5	267,928	195,494
Generated demand	**780,681**	**17.2**	**1,302,319**	**861,224**
Cost savings in other modes	**1,934,446**	**42.7**	**3,166,381**	**1,934,446**
- Conventional train	785,714	17.4	1,287,343	785,714
- Car	391,093	8.6	640,900	391,093
- Bus	12,619	0.3	20,631	12,619
- Air transport	745,020	16.5	1,217,507	745,020
Accidents	**225,813**	**5.0**	**346,791**	**225,813**
Congestion	**6,323**	**0.1**	**11,623**	**7,903**
TOTAL BENEFITS	**4,527,830**	**100**	**7,537,810**	**5,005,096**
NPV (1987)	-2,265,066		-1,248,887	-1,787,800

* Values discounted to 1987 and expressed in thousands €2010. Discount rate 5%. VOT: Value of time

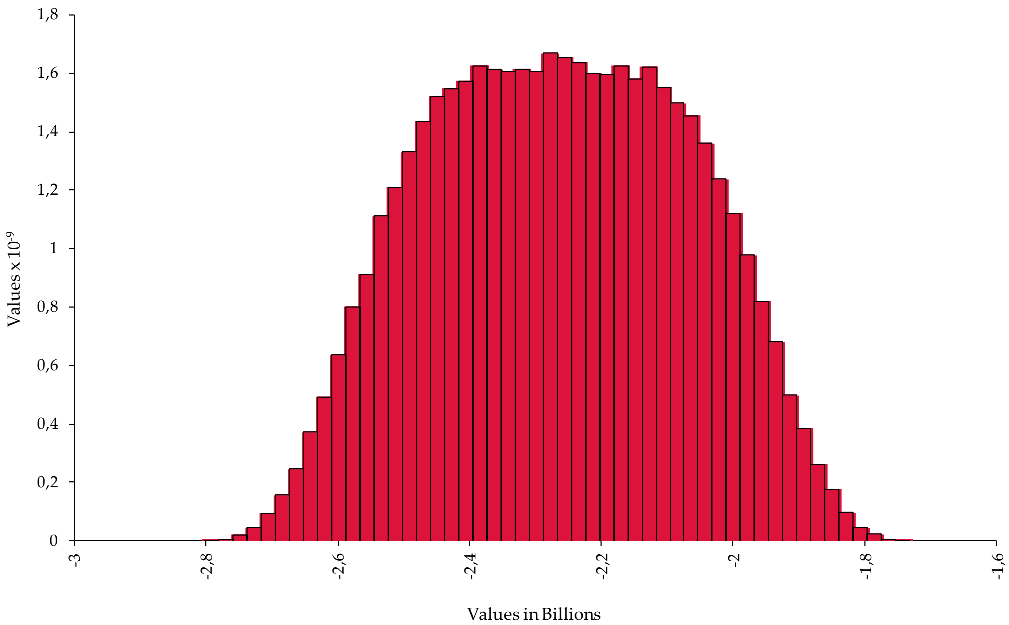
Table 3. Benefits of the HSR Madrid-Seville by O-D pairs

	Benefits 2010*	%	Discount rate (3%)	25% increase in VOT
Infrastructure investment	-4,115,670	60.6	-4,462,798	-4,115,670
Infrastructure maintenance	-562,097	8.3	-882,418	-562,097
Rolling Stock Investment	-318,885	4.7	-434,782	-318,885
Rolling Stock Operation	-1,796,242	26.4	-3,006,700	-1,796,242
TOTAL COSTS	-6,792,895	100	-8,786,697	-6,792,895
Madrid-Sevilla	**2,552,687**	**56.4**	**4,254,088**	**2,813,928**
Time savings	888,221		1,521,653	1,110,276
- Conventional train	589,022		1,009,082	736,278
- Car	100,575		172,299	125,718
- Bus	42,229		72,344	52,786
- Air transport	156,395		267,928	195,494
Generated demand	432,874		719,775	472,060
Cost savings	1,231,592		2,012,660	1,231,592
- Conventional train	321,082		524,711	321,082
- Car	155,023		253,338	155,023
- Bus	10,466		17,104	10,466
- Air transport	745,020		1,217,507	745,020
Madrid-Cordoba	**661,683**	**14.6**	**1,111,759**	**762,212**
Time savings	284,135		486,174	355,169
- Conventional train	245,775		420,537	307,218
- Car	32,560		55,712	40,700
- Bus	5,801		9,926	7,251
Generated demand	209,210		350,793	238,705
Cost savings	168,338		274,791	168,338
- Conventional train	111,634		182,229	111,634
- Car	55,165		90,051	55,165
- Bus	1,539		2,512	1,539
Cordoba-Sevilla	**95,252**	**2.1**	**160,716**	**106,017**
Time savings	32,980		57,039	41,225
- Car	0		0	0
- Conventional train	31,589		54,633	39,486
- Bus	1,391		2,406	1,739
Generated traffic Rest	28,455		47,797	30,975
Cost savings	33,817		55,880	33,817
- Car	12,024		19,868	12,024
- Conventional train	21,178		34,996	21,178
- Bus	615		1,016	615
Commuting Services	**878,947**	**19.4**	**1,471,358**	**972,399**
Time savings	340,319		584,976	425,399
- Conventional train	340,319		584,976	425,399
- Car	0		0	0
Generated demand	97,567		162,702	105,940
Cost savings	441,061		723,680	441,061
- Conventional train	293,764		481,999	293,764
- Car	147,297		241,680	147,297
Others O-D	**107,126**	**2.4**	**181,475**	**116,823**
Time savings	34,912		60,853	43,640
- Conventional train	29,198		50,893	36,498
- Car	5,714		9,959	7,142
Generated demand	12,575		21,251	13,545
Cost savings	59,639		99,371	59,639
- Conventional train	38,055		63,408	38,055
- Car	21,583		35,963	21,583
Accidents	**225,813**	**5.0**	**346,791**	**225,813**
Congestion	**6,323**	**0.1**	**11,623**	**7,903**
TOTAL BENEFITS	**4,527,830**	**100.0**	**7,537,810**	**5,005,096**
NPV (1987)	**-2,265,066**		**-1,248,887**	**-1,787,800**

* Values discounted to 1987 and expressed in thousands €2010. Discount rate 5%. VOT: Value of time

Figure 7. Probability distribution of the NPV Madrid-Seville

NPV1987 in €2010



6. *Ex-post* evaluation of the Madrid-Barcelona HSR line

We are unaware of any comprehensive cost-benefit analysis of the Madrid-Barcelona HSR line. In this section we undertake a full cost-benefit analysis of the investment in the Madrid-Barcelona HSR line. It is not an *ex ante* CBA as the construction started in 1999, and was completed in 2007, but it became partially in service between Madrid and Zaragoza in 2003 (services between Madrid and Barcelona in 2008). Nevertheless, although we are conducting this study in 2011, the official information available for the CBA is not as good as one would expect for a public investment. However, we have gathered some data from different sources and, based on some reasonable assumptions for the reconstruction of the unavailable information, have been able to calculate some sort of *in media res* NPV.

In what follows we describe the CBA of the Madrid-Barcelona HSR line and discuss the probability distribution of the net present values obtained in the risk analysis. The results seem to be robust within the ranges of the main parameters and variables, given the available information.

The investment in 621 km of high speed infrastructure joining Madrid and Barcelona allows a faster rail service in different O-D (Madrid-Barcelona, Madrid-Zaragoza, Zaragoza-Lleida among others). The construction started in 1999 and opened between Madrid and Zaragoza in 2003, and finally with Barcelona in 2008. The total investment cost (land costs and stations excluded) was €9.5 billion of 2008 (Sánchez-Borrás, 2010). In contrast with the evaluation of the Madrid-Seville line, where the actual construction costs per year were known, the investment costs of the Madrid-Barcelona line were distributed during the construction period. The investment costs of the route Madrid-Zaragoza were distributed within the period 1999-2003, considering the number of kilometers built per year. The same procedure is followed for Zaragoza-Barcelona during the period 2003-2007.

Investment costs are inclusive of indirect and income taxes. The reason why we have not accounted for the investment costs net of taxes is because planning costs, land values and the construction costs of the stations and other facilities were not included in the investment cost of the line. The project is assumed to have an economic life of 50 years, and for simplicity we ignore any potential residual value.[9]

The maintenance cost of the infrastructure per kilometer is 100,000 €/km in 2009. We assume half of these costs correspond to labor, and in the case of the operation and maintenance of the rolling stock, we assume *all* costs are labor. The shadow price of labor is based on Del Bo *et al*. (2009), where a conversion factor of 0.9 is estimated for Spain; and the other half of infrastructure maintenance is computed net of indirect taxes (see Appendix 6.1 for more detailed information). The maintenance and operation cost per train is 6.7 million in €1998 (de Rus and Inglada, 1993).

For the estimation of total operating costs we need the number of trains and the price of these trains. We assume the cost of a train follows a random uniform distribution with range between €33,000 and €65,000 per seat in 2002 and each train

[9] The main results do not change when the usual *ad hoc* percentages of the investment are included at the end of the lifespan of the project.

has an average capacity of 330 seats and an economic life of 30 years (Campos *et al*., 2009).

We assume demand is distributed uniformly during the day (no peak hours). The load factor follows a random uniform distribution within the range 0.6-0.7. The number of daily services required, given the load factor, the contingency factor, the length of the route and the hours of operation are computed according to Campos *et al*. (2009). Trains operate 16 hours per day and do not exceed the maximum number of kilometers per year (500,000 km).

Other general assumptions affecting key parameters are the following: the annual growth rate of income is taken from the National Institute of Statistics until 2009. From 2010 to 2015, the estimated growth rate is equal to 1% according to the IMF. For the rest of the evaluation period, the annual growth rate follows a random uniform variable between 1% and 4%, independent between years. The net present value is calculated at the beginning of 1999 with benefits and costs expressed in €1998 prices deflated with the CPI of the National Institute of Statistics. The social discount rate of the base case is 5% and the shadow multiplier of public funds is 1.

The HSR travel time between Madrid and Barcelona is around 3 hours, and many passengers benefit from these time savings, although as we will see, the picture is quite different depending on which transport modes passengers were initially traveling. Moreover, it is revealing to distinguish between the changes in generalized costs and the differences in resource costs, ignoring transfers.

For the period 2003-2009, the demand is based on real data while for the rest of the project life we have projected the number of passenger-trips of previous years, assuming that the demand-income elasticity is equal to 1.

In 2009, the HSR transported 5.5 million passenger-trips in the whole line: 2.6 million between Madrid and Barcelona; 1.9 million between Madrid-Zaragoza or Zaragoza-Barcelona and the rest between some other O-D.

The estimation of the diverted demand from the different modes per O-D and year is based on the demand of that year in the route multiplied by the percentage of the diverted demands that are presented in Appendix 6.1 under the heading "modal split". The distribution of the deviated demand is calculated using data from the National Association of Highways (ACESA, 2009), ADIF and our own estimation.

In the case of the O-D Madrid-Barcelona line, the origin of HSR passenger-trips is as follows: 43% (plane); 27.3% (train); 16.1% (car); 3.2% (bus) and 10.4% (generated). In the O-D Madrid-Zaragoza and Zaragoza-Barcelona: 2.7% (plane); 49.3% (train); 20% (car); 1.3% (bus) and 26.7% (generated). Let us concentrate in two of the main corridors, Madrid-Barcelona and Madrid-Zaragoza to follow the source of benefits.

Figure 8. Door-to-door trip time (Madrid-Barcelona)

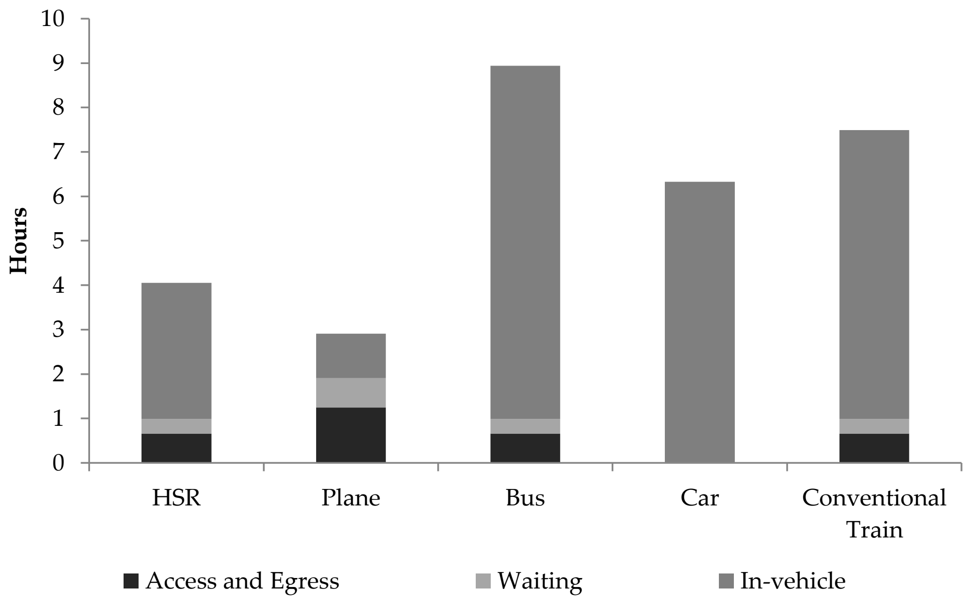


Figure 8 shows that the faster way to travel between Madrid and Barcelona is by air. Door-to-door travel time is shorter, though the comparative advantage rests on the substantially shorter in-vehicle time as the access-egress and waiting time are higher when the airport infrastructure is involved. Nevertheless, even accounting for the higher values of access-egress and waiting time, the door-to door travel-time cost of is still slightly favorable to air transport (Figure 9).

Figure 9. Time-saving benefits per passenger-trip (Madrid-Barcelona)

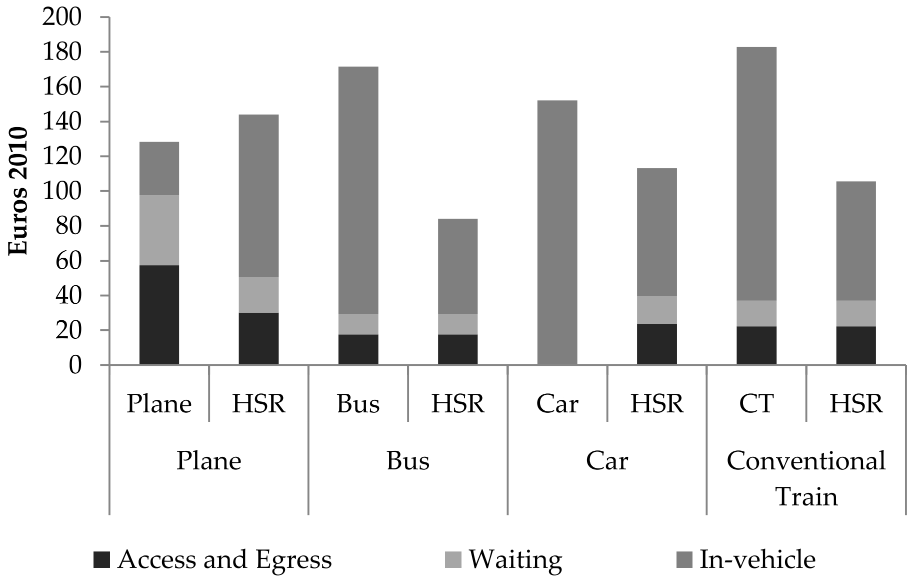
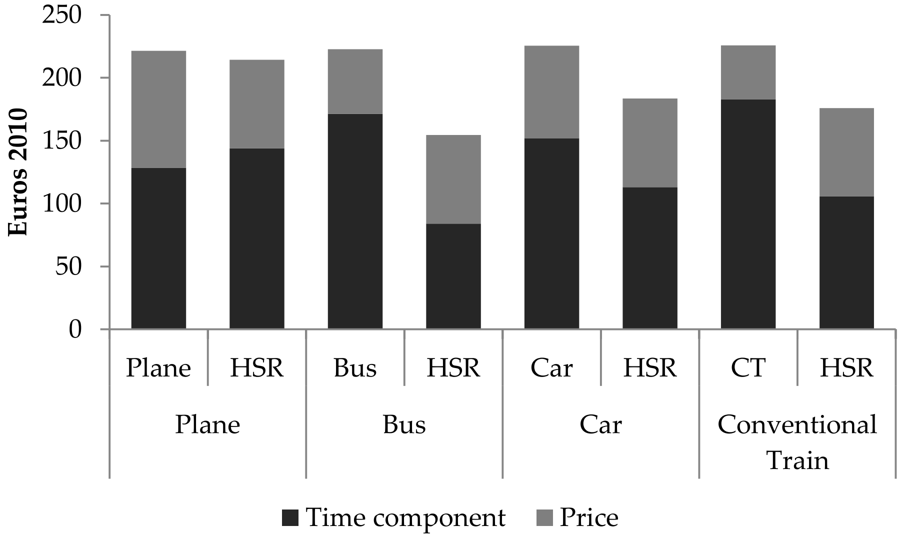


Figure 9 is illustrative in one sense. Average time benefits from deviated demand are mainly concentrated in passengers already using railways. The average time benefit is also high for passengers shifting from buses, but is not relevant in absolute terms given the limited number of bus users. The time benefits per passenger-trip shifting from air transport is negative and 43% of the deviated demand comes from this mode of transport (we assume zero savings in the evaluation).

However, individual modal choice is not based on resource costs but on the generalized cost of travel; i.e., door-to-door trip time multiplied by the value of time of passengers plus the money cost. Figure 10 is illustrative of the strong modal competition in this O-D.

Figure 10. Generalized cost per passenger-trip (Madrid-Barcelona)



The average generalized cost of HSR is similar for passengers initially traveling by air. The comparison of generalized costs of car and HSR does not consider that one option is to go by car between Barcelona and Madrid using the toll road, which would make the generalized cost by car higher. In any case, the participation of car passenger-trips in the deviated demand is quite low.

Air transport and HSR generalized costs are quite close, but we are using averages and the money cost by air is, in the case of some airlines, substantially lower than the average value behind Figure 10. The point is that the airlines still keep half of the air/rail market and this means that there are 50% of the passengers with lower generalized costs by air. From the information shown in Figure 10, the key importance of the monetary component of the generalized cost and, in particular, the pricing policy of the government with respect to the recovery of infrastructure costs (see Section 8), seem evident. The importance of the efficiency in airport management affecting delays and safety measures are also evident according to the proximity of the generalized costs.

The shorter O-D Madrid-Zaragoza shows that air transport has the lower in-vehicle time though the advantage of HSR is clear when door-to-door travel time is the benchmark (Figure 11). Nevertheless, looking at Figure 12, total time cost is quite close in the case of car trips. The reason is that although in-vehicle time is shorter by HSR, a car passenger-trip shifting to HSR has to add access-egress and waiting time, with higher value than in-vehicle time. The advantage of HSR with respect to air is maintained when we add the money costs as portrayed in Figure 13, and though the advantage of HSR rail remains unchallenged the pricing policy of the public sector with respect to the final modal split seems critical. For cars the situation is quite different. Figure 13 shows a small advantage of cars over HSR and a remarkable equality in all the transport modes but air.

Figure 11. Door-to-door trip time (Madrid-Zaragoza)

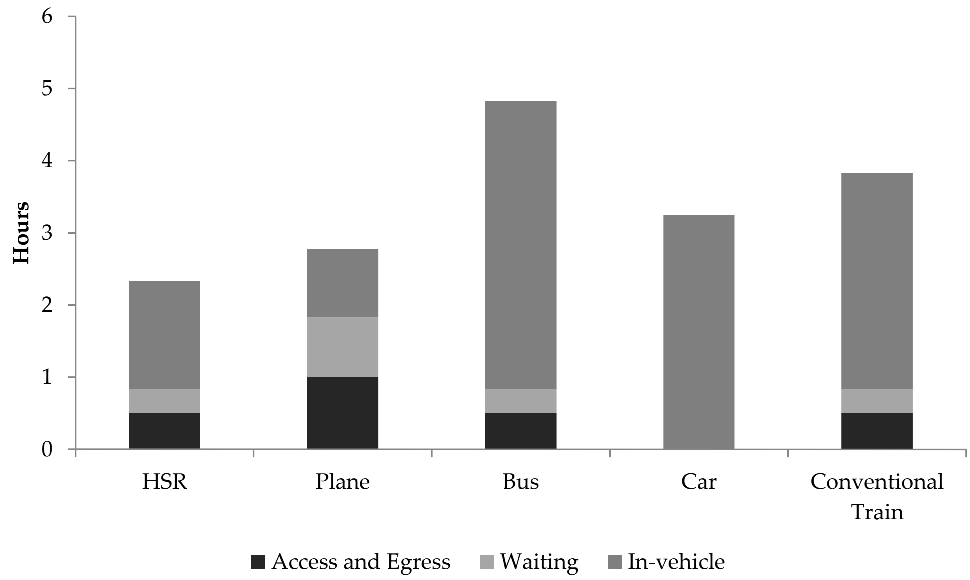


Figure 12. Time-saving benefits per passenger-trip (Madrid-Zaragoza)

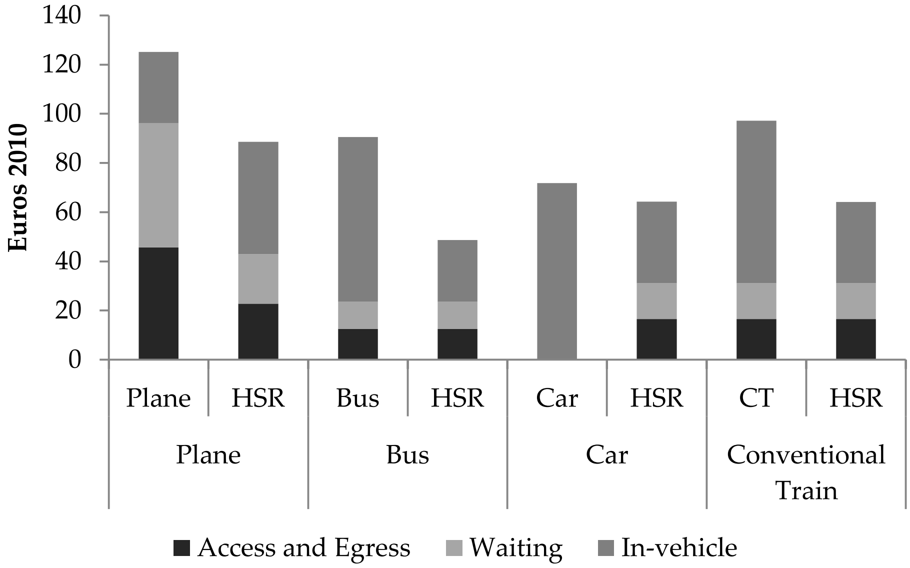
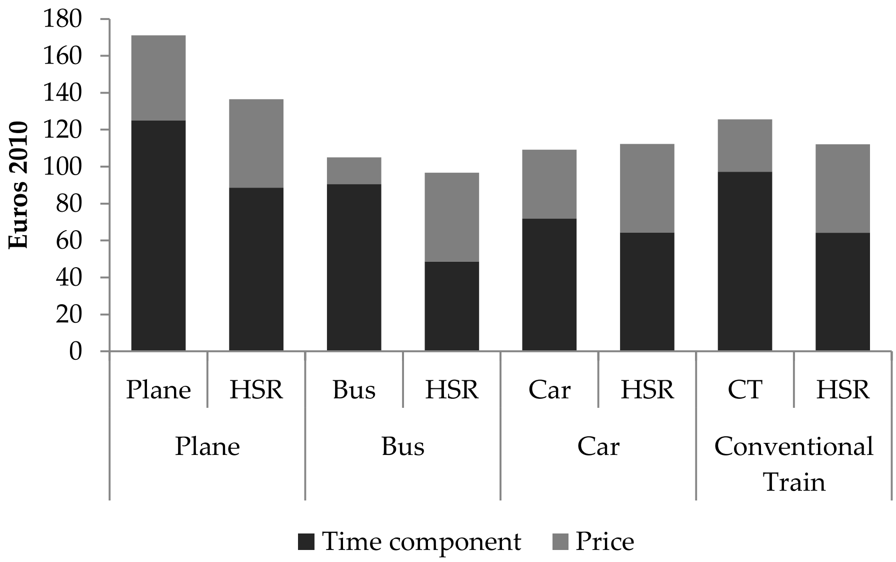


Figure 13. Generalized cost per passenger-trip (Madrid-Zaragoza)



The observation of Figures 8 to 13 points out the source of the social benefits from time savings. An inspection of Table 4 shows that total time savings represent 39% of the total benefits of HSR investment, basically from previous rail users. The time benefits from air, car and bus are quite small. The condition required for social profitability consisting of many passengers shifting to HSR and willing to pay a high amount for the change, is not fulfilled in this corridor and this is a heavy burden for the social profitability of the project given the magnitude of the investment costs. More than 70% of the time-saving benefits come from for already existing rail users.

Social benefits do not only come from time savings but also for the additional willingness to pay from new passenger-trips and the avoidable costs in the alternative modes of transport. Additional passenger-trips of new or existing users in the corridors, account for 15% of total benefits, and the resource costs avoided, thanks to the new rail line, account for 41% of the total benefits of the project. The reduction of accidents accounts for 4.6% of the benefits. Congestion savings are negligible.

The NPV of the Madrid-Barcelona HSR line refers to 1999, when the construction started, though Tables 4 and 5 express the values in Euros of 2010. This may seem trivial but many of the limited information about the construction costs of different lines built in different moments of time is provided without identifying the year when the line was built or whether the figures are in constant or current terms.

The expected 1999 net present value is negative, equals to €-5.26 billion in €2010, as shown in Tables 4 and 5, and this is 66.4% of the construction costs. The risk analysis shows that the probability of having a positive NPV is zero. In fact, the best result shown in the density function of NPVs is €-4.25 billion (see Figure 14). Although one should be cautious, given the limited information available, the cost-benefit analysis of the line is conclusive in terms of the low value for money of this investment.

The results obtained in the economic evaluation of the Madrid-Barcelona HSR line reflect several undisputable facts: demand is extremely low. Only 2.6 million passenger-trips travel the whole length of the line. The other 3 million only cover half of the length or less. The majority of passengers were initially traveling by conventional rail, or by air, where the time benefits are quite low. The massive fixed costs of the line (63.8% of total costs) and the fact that variable costs are higher than the benefits from time savings and generated demand show that this investment requires a higher volume of demand to be socially worthy.

The sensitivity analysis in Tables 4 and 5 shows the results are quite robust to a lower social discount rate (3%) or an increase in the time savings benefits of 25% to account for willingness to pay for HSR higher comfort, service quality, or whatever. In both cases the expected NPV is negative and the probability of a positive NPV is zero. The results show the importance of the avoidable costs in other modes of transport. Our assumptions are quite favorable to this resource cost savings. If this were not the case, the economic implication would be much more serious.

When the line was partially in operation, with trains running between Madrid and Zaragoza, and the extension to Barcelona was still under construction, de Rus and Román (2005) estimated the required first-year demand for a positive social NPV. In that paper we surveyed passengers in the Madrid-Barcelona corridor. From the estimated values of time and willingness to pay for comfort, the time savings and the sources of deviated demand, we figured out some demand thresholds required for a positive net present value. We showed that under different assumptions regarding the demand growth rate, proportion of generated demand, time savings and users willingness to pay for those savings, a demand above 10 million passenger-trips would be required in the first year of operation, twice the actual demand.

We have calculated the volume of demand required for a positive NPV within the cost-benefit framework of this report. The minimum demand required for a positive NPV in the first year of operation of the whole length of the line is 12.3 million passenger-trips (keeping the same distribution per O-D). This figure contrasts with the actual demand of 5.5 million passenger-trips in 2008.

Table 4. Benefits of the HSR Madrid-Barcelona

	Benefits 2010*	%	Discount rate (3%)	25% increase in VOT
Infrastructure Investment	**-7,923,236**	63.8	**-8,548,659**	**-7,923,236**
Infrastructure Maintenance	**-844,685**	6.8	**-1,335,589**	**-844,685**
Rolling Stock Investment	**-397,045**	3.2	**-532,523**	**-397,045**
Rolling Stock Operation and Maintenance	**-3,257,395**	26.2	**-5,632,903**	**-3,257,395**
TOTAL COST	**-12,422,362**	100	**-16,049,674**	**-12,422,362**
Time savings	**2,795,246**	**39.0**	**4,937,790**	**3,494,057**
- Conventional train	2,049,265	28.6	3,616,583	2,561,582
- Car	550,192	7.7	974,680	687,740
- Bus	158,727	2.2	282,271	198,409
- Air transport	37,062	0.5	64,256	46,327
Generated demand	**1,076,442**	**15.0**	**1,843,246**	**1,192,774**
Cost savings in other modes	**2,936,053**	**41.0**	**4,974,387**	**2,936,053**
- Conventional train	885,858	12.4	1,489,207	885,858
- Car	723,302	10.1	1,220,151	723,302
- Bus	62,977	0.9	107,295	62,977
- Air transport	1,263,916	17.7	2,157,734	1,263,916
Accidents	**329,969**	**4.6**	**590,943**	**329,969**
Congestion	**20,434**	**0.3**	**33,082**	**25,543**
TOTAL BENEFITS	**7,158,145**	**100**	**12,379,448**	**7,978,397**
NPV (1999)	**-5,264,217**		**-3,670,226**	**-4,443,965**

* Values discounted to 1999 and expressed in thousands €2010. Discount rate 5%. VOT: Value of time

Table 5. Benefits of the HSR Madrid-Barcelona by O-D pairs

	Benefits 2010*	%	Discount rate (3%)	25% increase in VOT
Infrastructure investment	**-7,923,236**	**63.8**	**-8,548,659**	**-7,923,236**
Infrastructure maintenance	**-844,685**	**6.8**	**-1,335,589**	**-844,685**
Rolling Stock Investment	**-397,045**	**3.2**	**-532,523**	**-397,045**
Rolling Stock Operation	**-3,257,395**	**26.2**	**-5,632,903**	**-3,257,395**
TOTAL COSTS	**-12,422,362**	**100**	**-16,049,674**	**-12,422,362**
Madrid-Barcelona	**3,856,107**	**53.9**	**6,710,367**	**4,254,165**
Time savings	1,460,888		2,607,969	1,826,110
- Conventional train	1,020,209		1,821,272	1,275,262
- Car	303,098		541,090	378,873
- Bus	137,580		245,607	171,975
- Air transport	0		0	0
Generated demand	422,689		732,249	455,524
Cost savings	1,972,531		3,370,149	1,972,531
- Conventional train	361,388		617,446	361,388
- Car	320,010		546,749	320,010
- Bus	57,595		98,403	57,595
- Air transport	1,233,539		2,107,551	1,233,539
Madrid-Zaragoza/Zaragoza-Barcelona	**1,802,450**	**25.2**	**3,059,621**	**2,053,128**
Time savings	735,290		1,274,816	919,113
- Conventional train	619,952		1,074,847	774,940
- Car	57,130		99,050	71,413
- Bus	21,147		36,664	26,434
- Air transport	37,062		64,256	46,327
Generated demand	524,172		887,794	591,028
Cost savings	542,987		897,011	542,987
- Conventional train	344,912		569,791	344,912
- Car	162,316		268,144	162,316
- Bus	5,382		8,892	5,382
- Air transport	30,377		50,183	30,377
Others O-D	**1,149,184**	**16.1**	**1,985,434**	**1,315,592**
Time savings (deviated traffic):	599,068		1,055,005	748,835
- Car	189,964		334,541	237,455
- Conventional train	409,104		720,464	511,380
Ggenerated traffic	129,581		223,203	146,222
Cost savings	420,535		707,227	420,535
- Car	240,976		405,257	240,976
- Conventional train	179,559		301,970	179,559
Accidents	**329,969**	**4.6**	**590,943**	**329,969**
Congestion	**20,434**	**0.3**	**33,082**	**25,543**
TOTAL BENEFITS	**7,158,145**	**100**	**12,379,448**	**7,978,397**
NPV (1999)	**-5,264,217**		**-3,670,226**	**-4,443,965**

* Values discounted to 1999 and expressed in thousands €2010. Discount rate: 5%. VOT: Value of time

Figure 14. Probability distribution of the NPV Madrid-Barcelona

NPV_{1999} in €2010

7. *Ex-ante* evaluation of the Stockholm-Gothenburg HSR line

The revision of the existing evaluations of the projected lines Stockholm-Gothenburg-Malmo shows different results regarding the expected economic profitability of the project. Nilsson and Pyddoke (2009), based on a CBA report commissioned by the Swedish National Rail Administration, report a negative NPV for the Stockholm-Gothenburg line and discuss whether some underestimation of the environmental benefits could compensate the poor socio-economic result obtained in the economic evaluation (benefits account for 80% of social costs). They examine whether the benefits derived from the release of capacity for freight and the contribution to the reduction of CO2 are high enough to reach a positive NPV.

In Jansson and Nelldal (2010) the starting point is that the Stockholm-Gothenburg line is socially worthy. They refer to two CBA reports by the consultant WSP and by the Royal Institute of Technology (KTH), both with a positive NPV. The benefits from freight, in WSP, are 14.7% of total benefits and 13.8% in KTH. The external effects (including accidents) are 22.4% and 13.2% of total benefits in WSP and KTH respectively. Therefore, the issue of the potential environmental benefits of the HSR investment in Sweden is noteworthy and so we deal with it separately at the end of this section.

In this paper, we do not try to estimate a new figure for the economic profitability of the HSR project in Sweden. The main reason is the lack of data. Moreover, we are unable to comment on the results obtained in previous evaluations as the demand data supporting the calculus of the social surplus are not disclosed in these studies. What we do here, based on Lindgren (2009), Swepro (2009), WSP (2010), de Rus (2010) and de Rus *et al*. (2009), is to start with some basic supply data on investment costs, some ranges on acquisition of rolling stock and operation and maintenance in Europe; and, on the demand side, we rest on the estimation of values of time and modal split with and without the project reported in Börjesson (2011). This last reference is crucial for the exercise below.

Instead of the calculus of the NPV, we invert the process and estimate the minimum demand volume compatible with a positive NPV, given a set of explicit assumptions on costs and demand. Then, we change the values of the main parameters to cover the most probable cases to obtain the corresponding demand thresholds within a wide range of possibilities. We focus on the Stockholm-Gothenburg, and only accounting for the direct benefits. We do not include the line to Malmo or the alleged benefits of freight transport (though we include this last benefit in the sensitivity analysis), congestion and accidents (none significant), nor environmental externalities (separately discussed).

Evidence from other studies and the results of the two Spanish lines evaluated in previous sections of this paper show that benefits deriving from the reduction of congestion and accidents are less than 5% of total benefits and, in the case of Sweden, the prediction of changes in modal split with the project show that car passenger-trips shifting to HSR are less than 3% of the total passenger-trips in the first year of operation.

The benefits of avoided road accidents should be lower than in the case of Spain because the lower percentage of victims in road accidents per inhabitant in Sweden. The number of killed people per million of inhabitants in road accidents in Sweden is considerably lower than most European countries. Thus, there were 39 victims per million of inhabitants for Sweden while Spain had a rate equal to 59 (Eurostat, 2009). In the case of the Stockholm region, the situation is even better with a rate of 17 victims per million of inhabitants. The value of a statistical life is, according to Heatco (2006), €1,122,000 in Spain and €1,870,000 in Sweden.

Once we obtain the minimum demand thresholds needed for a positive NPV under these assumptions, we conduct a sensitivity analysis with the introduction of freight benefits reported in Swepro (2009) and WSP (2010). A discussion of the potential environmental benefits is carried out at the end of the section.

The main assumptions and data of the exercise are the following. The construction period of the Stockholm-Gothenburg starts in 2010 and lasts until 2024 (WSP, 2010). The first year of operation is 2025 and the project life is 50 and 100 years alternatively. It may well be that 100 years is a too long a period, given technological change in rail and the competing modes of transport, but this is the length assumed in some of the existing reports in Sweden, and so we simulate the situation with this lifespan and also with 50 years. No residual value is considered.

The flow of benefits and costs are discounted with a 5% discount rate and alternatively with a 4% rate. The annual growth rate of income is based on IMF statistics until 2016. For the rest of the evaluation period, the annual growth rate is assumed to be 2.5%. Prices are deflated with the Swedish CPI. Benefits and costs are assumed to be realized at the end of the year. Benefits and costs are expressed in €2010. The shadow multiplier of public funds is 1. Exchange rate 1 € = 10 SEK.

Total investment costs are €10.5 billion (2008). Investment costs have been distributed during the construction period. VAT was not deducted, nor is cost overrun considered. The maintenance cost of the infrastructure is 100,000 €/km in 2009, 50% of infrastructure maintenance costs correspond to labor and VAT is 25% during the whole period. The tax is deducted from 50% of the non-labor maintenance costs. According to different sources in the rail industry, and considering the average wage in Sweden, the operation and maintenance costs of the rolling stock per seat-kilometer is assumed to be €0.06 in €2010. We assume that labor is the main component of this unit cost and that unit labor costs are constant or increase proportionally with real income.[10]

The cost of the HSR rolling stock in Europe varies widely depending on several technical characteristics and capacity options as explained in Section 2. We assume that the cost of a train set is the average between the minimum and the maximum values in the database (€33,000 and €65,000 per seat in 2002). The average capacity per train is 370 seats (de Rus *et al.*, 2009). VAT was not deducted in the acquisition of the rolling stock. The main reason is that the rolling stock is mostly an imported technology. The average life of a train is 30 years.

The number of daily services required, given the demand, the travel time, the load factor, the length of the route and the hours of operation are computed according to de Rus *et al.* (2009). Based on a previous formula, applying a contingency factor (1.5) is required, in order to deal with operating and maintenance constraints. Moreover, trains cannot exceed a maximum number of kilometers per year (500,000 km.). Therefore, the final number of trains is computed as the maximum between these two previous rules. Operating train time includes the time between train-trips. It is assumed to be 15 minutes. We assume the load factor equal to 0.65 and 17 hours of operation.

[10] In the first draft of this report, we used data from the UIC for the operating and maintenance costs. These figures seem to be incorrect and we have changed to a more reliable source. We truly appreciate the help of Pablo Vázquez (INECO) with the revision of the cost data.

Traffic deviation from conventional modes of transport to HSR reduces the activity in these modes and it is assumed that the average avoidable cost in other modes of transport equals their prices net of indirect taxes. These prices are taken from different sources and though they are approximations to the actual avoidable costs, we expect that any possible bias is in favor of the project. The average price for the airlines in the Stockholm-Gothenburg route is collected from different travel websites. This value is multiplied by 0.8 to account for the presence of the low-cost airlines in the corridor and shadow pricing. The average prices of a bus-trip are taken from the website of SWEBUS. A conversion factor of 0.9 is applied to account for shadow pricing. Prices of the conventional train are taken from the website of SJ. A conversion factor of 0.8 is applied to account for shadow pricing. The cost of a car-trip is approximated from different sources and follows the basic argument of Sections 5 and 6. An occupancy factor of 1.3 is assumed to convert passenger-trips into car-trips.

Annual demand is assumed to grow, according to the national forecast model, with a demand-income elasticity of 0.512 (Börjesson, 2011). Alternatively we introduce the value of 1. The generated and diverted traffic from the different modes and year are computed as the demand of that year in the route multiplied by the percentage of the diverted traffic of the following modal split proportions (Börjesson, 2011): diverted traffic from air: 4.44%; bus: 0.18%; car: 2.47%; conventional train: 71.61%. The coefficient of the generated traffic: 21.30%.

Time-saving benefits and the willingness to pay of generated demand are obtained with the 'rule of a half'. A basic parameter in this calculus is the value of time. Values of in-vehicle time for plane, bus, car and conventional train and for business and private purposes are taken from Börjesson (2011). Waiting-time values are assumed to be 1.5 times the corresponding values of in-vehicle time. Values of access/egress time are computed as 2 times the values of in-vehicle time (Wardman, 2004). The elasticity of the value of time with respect to income is 0.7 (Mackie *et al*., 2001; Heatco, 2006). Waiting times of HSR, bus and conventional train are assumed to be the same. Access and egress time of the HSR, bus and conventional train are assumed to be the same.

Table 6 summarizes the results of the simulations. It displays the minimum level of passenger-trips required for a positive NPV, given the assumptions and data described above. A quick look shows how these figures compare with the forecasted demand in this corridor in its first year of operation. Börjesson (2011) predicts 1.6 million for the Stockholm-Gothenburg corridor in 2010, a figure that it is far from the demand thresholds required for the investment to be socially worthy in the more realistic cases.

Table 6. First-year demand thresholds for a positive NPV

(passenger-trips, millions)

				Project life (years)			
				50		100	
				% passengers travel the whole length		% passengers travel the whole length	
				100	50-50	100	50-50
Labor costs grow with income	yes	Elasticity*	0.512	(10.3 –12.8)	(19.8 – 24.6)	(8.2 – 11)	(16.6 – 21.8)
			1	(6.3 – 8.1)	(10.5 – 13.7)	(3.6 – 5.5)	(5.7 – 8.9)
	no		0.512	(7 – 8.9)	(10.5 – 13.5)	(4.9 – 7.1)	(7.4 – 10.6)
			1	(5 – 6.6)	(7.6 – 10)	(2.9 – 4.5)	(4.2 – 6.7)

Note: In brackets, first year passenger-trips with a 4% and 5% discount rate.

(*) Demand-income elasticity

In the cases where the demand-income elasticity is assumed to be 0.512 (the value estimated for Sweden), labor costs grow proportionally with income and half of the passenger-trips travel the whole length of the line, the demand thresholds for a NPV equal to zero go from 17 to 25 million of passenger-trips in the first year operation.

There are other more favorable scenarios where the required demand levels for the first year of operation could be lower but the underlying assumptions are then somewhat unrealistic.

The released capacity for freight transport has been argued to be one of the benefits of the construction of HSR infrastructure in Sweden. According to Jansson and Nelldal (2010), "the High-Speed Line also releases capacity on the Southern and Western Main Trunk Lines for freight and fast regional trains. At the moment there are conflicts here, especially between high-speed trains on the one hand and regional and heavy goods trains on the other. With high-speed trains using the High-Speed lines, the Southern Main Line can satisfy the industry's growing need for efficient export and import of raw materials. It is important for the industry to be able to offer direct, high-capacity, highly punctual trains to the continent."

To conclude this exercise, Table 7 recalculates the minimum demand volumes compatible with a positive NPV including the alleged benefits derived from the release of capacity for freight transport. The inclusion of freight benefits in the calculus of the demand thresholds has been done according to WSP (2009) which considers that these benefits have a net approximate present value of €640 million (2010). Given that there exist some uncertainty around these figures because it also requires new investments in terminals and lines, we consider a minimum value of €580 million and a maximum of €1 billion (2010).

The way in which we deal with the uncertainty of freight benefits in the calculus of the minimum volumes of demand compatible with a positive NPV, is to add the expected present value of freight benefits of €790 million to the benefits of the project. The figures do not show any dramatic change with respect to the demand threshold of Table 6. Moreover, we have recalculated the demand thresholds of tables 5 and 6 with an operating and maintenance cost per seat-km of €0.05 without significant changes in the results.

Table 7. First-year demand thresholds for a positive NPV including freight benefits

(passenger-trips, millions)

<table>
<tr><td colspan="4" rowspan="4"></td><td colspan="4">Project life (years)</td></tr>
<tr><td colspan="2">50</td><td colspan="2">100</td></tr>
<tr><td colspan="2">% passengers travel the whole length</td><td colspan="2">% passengers travel the whole length</td></tr>
<tr><td>100</td><td>50-50</td><td>100</td><td>50-50</td></tr>
<tr><td rowspan="4">Labor costs grow with income</td><td rowspan="2">yes</td><td rowspan="4">Elasticity *</td><td>0.512</td><td>(9.3 – 11.4)</td><td>(17.9 – 21.8)</td><td>(7.4 – 9.8)</td><td>(15 – 19.4)</td></tr>
<tr><td>1</td><td>(5.7 – 7.2)</td><td>(9.5 – 12.2)</td><td>(3.2 – 4.9)</td><td>(5.1 – 7.9)</td></tr>
<tr><td rowspan="2">no</td><td>0.512</td><td>(6.2 – 7.8)</td><td>(9.4 – 11.9)</td><td>(4.4 – 6.2)</td><td>(6.6 – 9.4)</td></tr>
<tr><td>1</td><td>(4.5 – 5.8)</td><td>(6.8 – 8.8)</td><td>(2.6 – 3.9)</td><td>(3.8 – 5.9)</td></tr>
</table>

Note: In brackets, first year passenger-trips with a 4% and 5% discount rate.
(*) Demand-income elasticity.

Environmental benefits

The results obtained in this paper show that, in a wide range of circumstances, the social benefits of HSR investment do not cover total social costs for any demand volume, and in the best scenarios the required volume of demand for a positive NPV seems to be too high compared with the potential traffic volumes in the corridor. Nevertheless, as we have already mentioned, these conclusions do not account for the potential environmental benefits of the project. Would the inclusion of these benefits change the likely poor social profitability of this project?

The stronger defense of investing in HSR, as a policy instrument for the mitigation of global warming, can be found in Åkerman (2011). The analysis deals with the Stockholm-Gothenburg-Malmo line using a life-cycle perspective. The author estimates that the construction and maintenance of the line during 60 years produce 4 million tons of CO2 (66,000 tons per year) and 20% of these emissions are due to permanent deforestation. The author estimates a life-cycle reduction of 550,000 tons per year in CO2-equivalents thanks to changes in modal split. These environmental benefits come from freight-traffic diversion from road to HSR (60%) and passenger-traffic diversion from road and air to HSR (40%). Hence it is crucial to see the assumptions behind the substitution effects in order to consider the feasibility of compensating the 66,000 tons of CO2 of construction and maintenance of the HSR line (in contrast, Kageson, 2009 shows a net reduction 90,000 tons for a 500km HSR line, ignoring the emissions during construction).

One key assumption in Åkerman (2011) is that half of the diversion of traffic from trucks to train rests on shifts from international traffic. The release of capacity in the old track, thanks to the construction of a new HSR line for passengers, is a necessary condition, according to the author, but not a sufficient condition for the increased rail freight. He proposes further measures to materialize the change with the project: increased axle load, development of intermodal freight, improved capacity across the Öresund Strait and in Denmark, and a fully deregulated rail freight market in the EU.

The other half of the environmental benefits in Åkerman (2011) comes from the deviation of passenger traffic from road and air to HSR. The argument justifying the substitution effect is somewhat weak. It is basically based on the assumption that changes in modal split observed in some European routes in operation, with special mention to the Spanish lines and the Paris-Lyon, can be transferred to the Swedish lines. The author assumes an air/rail market share of 80% for the O/D Stockholm-Gothenburg and 65% for the O/D Stockholm-Malmö.

This new modal split implicitly assumes that HSR prices are going to be heavily subsidized in Sweden. HSR pricing is crucial for HSR demand as the generalized prices are quite close given the actual travel times. The forecasted demand for the Swedish lines is considerably lower than the actual demand in the Paris-Lyon line, and the fixed cost per km is higher in Sweden. In the case of Madrid-Seville and Madrid-Barcelona the demand volumes are, to some extent, closer to the Stockholm-Gothenburg and the Stockholm-Malmö but the prices are heavily subsidized and even so, the HSR in the Madrid-Barcelona line has not yet gone beyond 50% of the air/rail market share. Unless pricing is explicitly addressed, the projected market shares are somewhat speculative.

In the case of traffic deviation from cars to train the above argument also applies. Besides, one should not expect dramatic changes as long as the option of traveling by car within these distances has additional advantages (e.g. the marginal cost of an additional passenger is zero). Moreover, the previous existence of the air transport alternative plus a reasonable good conventional train service between the main O/D recommend some prudence when forecasting the deviation of passenger-trips from cars to HSR.

The comparison between the negative externalities during the construction of the line and the positive externalities from the diversion of traffic from road and air to HSR is further analyzed in Kageson and Westin (2010). The results do not support the belief that investing in HSR is good for the environment. Using a Monte Carlo simulation Kageson and Westin estimate, using more than 10 million annual one-way trips, the traffic volume required to balance the CO2 emission from the construction of a 500 km line. The authors conclude that from a climate point of view it may be better to upgrade existing lines and to try to make people substitute air travel by modern telecommunications rather than investing huge amounts of resources in making us travel faster and more.

Nilsson and Pyddoke (2009) analyze whether the investment in the HSR Stockholm-Gothenburg line may be justified as a cost-effective way of reducing carbon dioxide emissions. Based on a study commissioned by the Swedish National Rail Administration where social benefits only cover 80% of total costs, they try to answer the question of whether the environmental benefits are higher than those included in the Rail Administration report and also whether there is underestimation of the benefits or overestimation of costs. The authors do not have any evidence of any systematic bias and conclude that the investment in the Stockholm-Gothenburg line is not an efficient alternative for mitigating global warming for the following reasons.

The operation of the HSR line between Stockholm and Gothenburg would reduce 150,000 tons of CO2 emissions per year from aircraft, trucks and passenger road traffic which amounts to 0.7% of annual transport sector emissions. The authors do not include the emissions during the construction period. Kageson (2009) estimates that the embedded emissions generated from the construction, maintenance and deconstruction of the railway track amount to a total of 110,000 tons per year.

The value used for reduced emissions of CO2 in the economic evaluation of the line is SEK 1.50 per kilo. Nilsson and Pyddoke (2009) consider that a more reasonable value may be about SEK 0.40 per kg. "Using the assumptions otherwise made by the Swedish National Rail Administration, a simple reverse calculation shows that CO2 emissions would have to be valued at more than SEK 8 per kilo for Götalandsbanan to be cost-effective for society. In terms of taxation of petrol this corresponds to almost SEK 19 /litre or a petrol price of more than SEK 30 per litre. In light of this it is difficult to see railway investments as a cost- effective climate policy instrument."

Nilsson and Pyddoke (2009) conclude that the poor results associated with this project is mainly due to the fact that investment is a weak instrument for achieving significant changes in emission volumes defending the internalization of externalities: "An effective environmental policy requires general policy instruments (for example fuel taxes) that target all passengers, not only the few who travel on a specific route. Railway investments are generally therefore an inefficient policy instrument." This leads to our next section where the key issue of pricing and changes in modal split is covered.

Before concluding this brief account on the existing studies of the potential environmental impact of the HSR project in Sweden it is worth it to stress the intrinsic difficulties with the construction of a plausible contrafactual. The base case for a lifespan of 50 or 100 years from 2020 onwards requires a high proportion of speculation about how environmental externalities develop. The expected environmental benefits of the HSR investment are dependent on what is assumed to happen with the alternative mode of transport during the life time of the project and this implies plenty of guessing.

The construction of the contrafactual has to include predictions on the construction of highways and airport infrastructure avoided and the development of new technologies which may reduce the environmental externalities of road and air transport. Also, it needs to account for a more efficient way to handle congestion and safety, the application of more efficient pricing policies internalizing the external effects and therefore reducing the effect of HSR investment as a second best environmental policy.

8. Intermodal effects, pricing and CBA

The generalized cost of travel includes three basic components: time, quality and money, understanding "quality" in a broad sense to include from comfort to safety. The time component is far from being homogeneous. It includes access-egress, waiting and in-vehicle time. In medium- distance corridors like the ones evaluated in this paper, we have seen how close the time component may be between HSR and the alternatives, and this concedes a key role to the pricing policy of the public sector regarding the access to HSR infrastructure.

The 500-600 km intercity corridor with road, air and rail transport in open competition have a modal-split equilibrium that is very sensitive to small changes in the generalized costs of each mode of transport. The differences between air transport, road and rail are evident, but they have several things in common. On the supply side, they all need infrastructure to provide services combining vehicles, labor and energy. In addition, infrastructure and operation may be vertically integrated or unbundled. On the demand side, they all involve a transport service carrying passengers who have to pay different generalized costs in terms of money, time, and quality.

Air and road transport are vertically unbundled and different operators use a common infrastructure, sometimes with free access and sometimes with payment of an access fee (toll, price, etc.). Usually the operators are private and the infrastructure is public or privately operated under a concession contract. Road and air transport services are vertically separated from the infrastructure operator, and railways are unbundled in some cases and vertically integrated *de facto* in the case of high speed trains operated by a single firm with the exclusive use of dedicated infrastructure.

Buses and cars share the same roads, competing airlines share airports, and HSR is technically operated as a single business, even if, from an organizational standpoint, the maintenance and operation of the infrastructure are separated from service operations. HSR has other advantages over airlines beyond vertical integration, reflecting some structural differences. Airports and airlines serve a large number of markets using the same airport capacity, and it is not clear that airport congestion management would be better with vertical integration. The HSR advantage in this case is that capacity is used to serve a very small number of markets (O-D pairs), and this makes it possible to reach very high levels of reliability.

These differences on the supply side have significant impacts on the demand side. The vertical integration of infrastructure and operation in the case of HSR is a significant advantage with respect to air transport in terms of the generalized costs of travel. HSR is more reliable than air transport, and though it increases in-vehicle time with respect to air transport, it reduces access and egress (on average) and waiting time. Airport and airline managers do not necessarily have the same objectives and, as a matter of fact, the generalized cost advantage of HSR with respect to air lies outside the travel-time segment of the trip. In the case of roads, the differences are even clearer. Road infrastructure and operations are vertically separated. In contrast to the single operator of HSR, there are many users driving their own cars with free access in many cases to a limited-capacity infrastructure. Road transport has the advantage of reducing access and waiting time to almost nothing and the cost disadvantage appears in the travel-time segment.

Investment in HSR changes the equilibrium in the interurban corridor through its impact on the generalized cost of rail travel. Compared with conventional rail, HSR services barely affect access, egress and waiting time. The main impact is on travel time with a magnitude depending on the prevailing operating conditions of the conventional rail. Passengers shifting from road transport benefit from travel-time reductions but lose in terms of access, egress and waiting time. Those shifting from air transport may benefit from lower access-egress and waiting time, but lose in terms of in-vehicle time. When the whole door-to-door time is considered and weighted with the values of the time of each component, we have found that, given the actual differences in the time-cost component, the modal choice may be highly dependent on the money component.

Figures 15 to 18 show the generalized cost differential as well as the price differential between HSR and its alternatives. One would expect the generalized cost to be always lower for HSR as none would shift mode otherwise. The negative dark bar confirms that this is the case for all the transport modes with some exceptions: car in the case of the O-D Madrid-Zaragoza and Cordoba-Seville and the conventional train in the case of Cordoba-Seville. The higher generalized cost for HSR with respect to cars in Cordoba-Seville and Madrid-Zaragoza is incompatible with the fact that the HSR has deviated demand from cars in these O-D. There are two explanations for this inconsistency. First, the values in Figures 15 to 18 are averages and so are compatible with generalized costs below average for some users. Second, the absolute positive values of the differences in generalized costs are low enough to be compensated by any other unobserved elements of the actual generalized cost of car users.

In the case of the O-D Cordoba-Seville the time saving is low and the increase in price offsets the time advantage. Beyond data incompleteness, it is possible for rail users to shift to HSR and to lose surplus in the process as long as the new HSR services substitute the conventional trains.

Figure 15. Generalized cost and price differential of HSR with respect to other transport modes (e.g., HSR-car)

Madrid-Barcelona

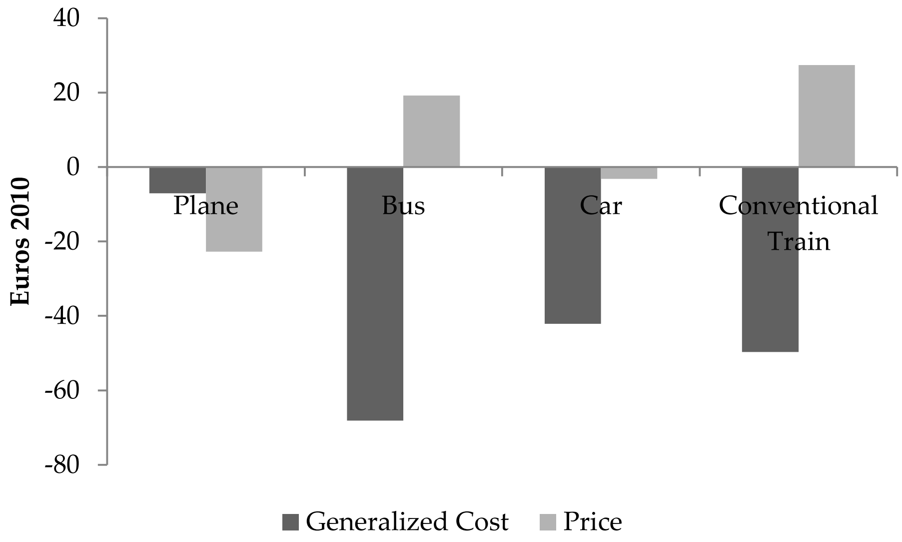


Figure 16.Generalized cost and price differential of HSR with respect to other transport modes (e.g., HSR-car)

Madrid-Zaragoza

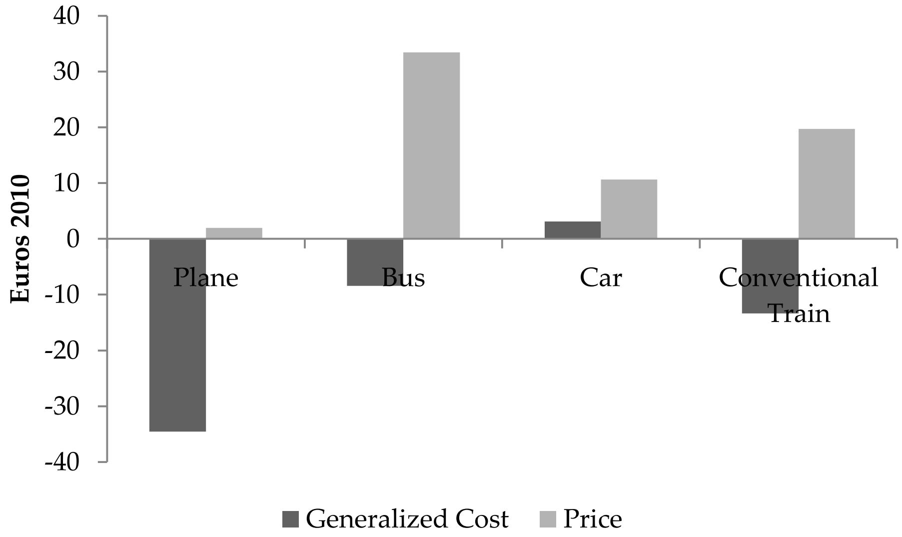


Figure17.Generalized cost and price differential of HSR with respect to other transport modes (e.g., HSR-car)

Madrid-Seville

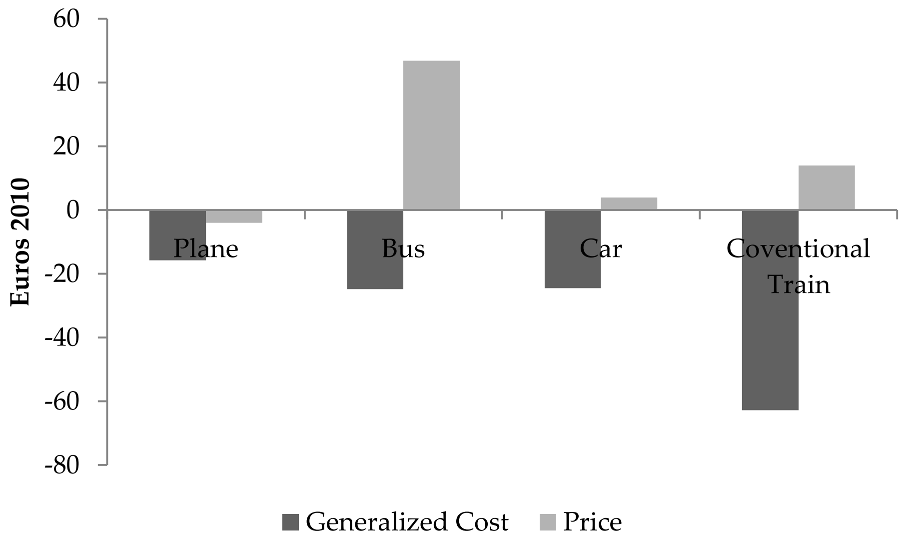
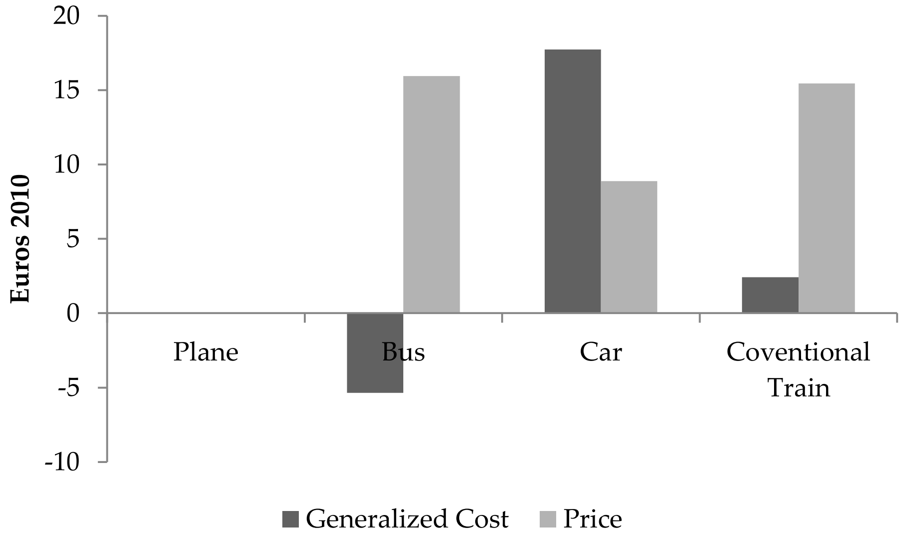


Figure 18. Generalized cost and price differential of HSR with respect to other transport modes (e.g., HSR-car)

Cordoba-Seville



Figures 15 to 18 hint at the consequences of pricing on modal split in the corridor and eventually for the social profitability of the project. The differential of prices is negative for Madrid-Barcelona, explaining that it is the price component that explains the negative differential in the generalized cost. In other words, the average user loses time benefits with the change but he is compensated with money. The fact that the modal split air/HSR is 50/50 confirms the economic implication of potential increases in HSR prices.

In the case of Madrid-Zaragoza, the price differential is almost zero and the HSR has a lower generalized cost not explained by the money component. Therefore a different pricing policy would not bring about as much effect as in the Madrid-Barcelona O-D. This is apparently the case in Madrid-Sevilla, though the differential in the generalized cost is quite low, which indicates that the success of the HSR in its competition with air is dependent on the low prices charged by the railways in the corridor and hence also leaves the problem of intermodal competition and pricing unsolved.

It seems clear (equity issues aside) that for the user´s choice to be socially optimal, prices should reflect the opportunity costs of his choice. Efficiency requires a sound pricing policy that not only allows the transport user to choose the best option within a transport mode but also when choosing between air, rail or road transport.

Let us assume that supplier-operating costs, variable maintenance and operating infrastructure, and external costs are already included in the generalized cost. How much should a rail operator be charged for the use of the infrastructure in a particular time or demand conditions? In principle, the answer is the `marginal social cost´ of running the train in that particular situation. Given the presence of economies of scale, significant indivisibilities and fixed and joint costs, pricing according to marginal social costs is far from being an easy task.

Charging according to short-run marginal cost is incompatible with cost recovery when the infrastructure rail network is built and there is excess of capacity, as is the case of the HSR lines in this paper. Some critics argue that the natural alternative is long-run marginal costs. Short-run marginal cost is equal to the change in total costs when new demand is added, given a constant network capacity. Long-run marginal cost accounts for the change in total cost allowing for an optimal adjustment of capacity.

Long-run and short-run marginal costs are equal assuming perfect demand forecast and perfect divisibility of capital, but both assumptions are unrealistic in transport and consequences of choosing a pricing principle are quite important in practical terms. For the case of HSR investment, short-run marginal cost pricing means prices below average costs and the need for public funds to cover infrastructure costs (see Rothengatter, 2003; Nash, 2003).

With a fixed capacity, any additional demand willing to pay in excess to the additional cost imposed to the system should be attended. In the extreme case, when capacity is well above demand (forecasting error, indivisibilities or both) short-run marginal cost can be very low compared to average cost. Many argue that passengers should only pay the short-run marginal costs but there are other reasons to charge about the strictly avoidable cost. The first reason is the problem of financing the infrastructure costs. Additional taxation needed to cover the gap has an additional cost in terms of the distortion imposed on the rest of the economy. The second problem is related to incentives, as subsidization usually reduces effort to minimize costs. Another drawback comes from the way in which capacity costs are covered, as users only pay variable costs and non-users pay capacity costs. In addition to the equity side (it is difficult to think of HSR passengers as equity targets) we face a dynamic efficiency question: are the users willing to pay for capacity? In the corridors where this is not the case, the government would be providing more capacity than optimal.

Even assuming that users are willing to pay for capacity (given prices equal to short-run marginal costs), it may be argued that demand is receiving a misleading signal in terms of the cost of expanding capacity in the long term. It may well be that a price structure which includes some charges for long-term replacement costs would be associated with a social surplus insufficient to justify the investment.

The consequences of charging according to the short-run marginal cost on the expansion of HSR lines are significant. Low prices favor the reallocation of demand from the competing modes and encourage demand generation, with a feedback on the future expansion of the network. Pricing according to short-run marginal cost leaves a key question unanswered: are the rail users willing to pay for the new HSR capacity? Unless this question is answered before investment decisions are taken, marginal-cost pricing is not a guarantee for an efficient allocation of resources.

The social marginal cost of a passenger-trip in particular mode of transport, in a particular place and time, has three different parts: the user marginal cost (user cost and the share of the producer cost –infrastructure and vehicles- included in the price), to cost to the other users and the rest of society (congestion, external cost of accidents and environmental externalities) and to the taxpayers (the share of the producer cost that has been subsidized).

Revenue is far from covering total costs. It might be argued that economies of scale and strong indivisibilities justify the deficits, but the question is that users should be willing to pay for the HSR infrastructure before new lines are built. HSR prices act as signals that transport users take as key information on where, how and when to travel, or even whether to travel or not. When infrastructure costs are not included in transport prices, according to the rationale of short-term marginal social cost, the problem is that the price signal is telling consumers that it is efficient to shift from road or air transport to rail transport, and this, of course, could be true in the short-term when optimal prices are not affected by the fixed costs of the existing HSR network, but the world is dynamic.

The problem is that prices that do not include fixed infrastructure costs (around 60% of total costs) which act as long-term signals for the consumers in their travel decisions, and consequently in the future allocation of resources between transport modes or between transport, education or health. An extensive HSR network can be developed based on suboptimal prices decided by the government which keep no relation to the opportunity costs of its existence, but once the network is built bygones are bygones, and the speculation on the counterfactual with a different allocation of resources and their effect on welfare is not very practical.

The defense of cost-benefit analysis in this context is quite relevant. Even accepting that short-term marginal cost is the right pricing policy, investing in a new HSR line requires that the willingness to pay for capacity be higher than the investment costs and any other demand unrelated to cost during the lifetime of the infrastructure. This does not solve the problems of fair competition between different transport modes or the equity issue of taxpayers paying HSR fixed costs, but at least it puts a filter on the most socially unprofitable projects.

9. Conclusions

The investment in HSR infrastructure is one of the feasible `do something´ alternatives to deal with transport-capacity problems in passenger intercity corridors. It is not the only one but the economic case for this option is more likely when there are capacity constraints in the conventional rail network, roads and airports; and the release of capacity generates additional benefits for freight, long-haul flights and other side effects of the marginal capacity that avoid major investments. Another potential benefit of HSR investment is the reduction of environmental externalities, though this depends on the volume of demand deviated from less environmentally friendly transport modes and whether the demand is high enough to compensate the negative externalities during construction, the barrier effect, noise and visual intrusion.

The direct benefits of HSR in terms of time savings, willingness to pay of generated traffic and avoidable costs in competing modes, are usually not enough to compensate for the fixed construction costs and. The magnitude of direct benefits depends on the prevailing conditions without the project. The benefits also depend upon whether there is an upgraded conventional railway able to run above 150km and convenient air services. When this is the case, it is difficult to find a socially profitable investment based exclusively on time savings, generated traffic and cost savings in the conventional modes unless the demand is above 10 million passenger-trips.

The economic evaluation of long-lived infrastructure requires a careful construction of the contrafactual and there are many assumptions that might seriously bias the results. This is the case of transport pricing during the lifespan of the project. Pricing policy needs to be explicitly treated. We need to consider how the alternative transport modes are going to be charged. For example, the government could charge air and road transport below social marginal cost and then justify a massive rail investment as a second-best policy to change the modal split, or it could optimally price all transport modes and then evaluate the optimal way to expand capacity. The final result may be quite different.

The results obtained in the economic evaluation of the HSR Madrid-Seville and Madrid-Barcelona may possibly rest on some inaccuracy affecting cost or demand figures but it reflects, several undisputable facts: demand is extremely low in the first full year of operation (2.8 million passenger-trips and 5.5 million respectively). Only half of this demand travels the whole length of the line. The majority of passengers were already traveling by conventional rail, or by air where the time benefits of diversion are modest. The massive fixed costs of the line require a substantially higher volume of demand to justify the investment.

In the case of the Stockholm-Gothenburg line, instead of the calculus of the net present value (NPV), we invert the process and estimate the minimum demand volume compatible with a positive NPV, given a set of explicit assumptions on costs and demand. Then, we change the values of the main parameters to cover the most probable cases to obtain the corresponding demand thresholds within a wide range of circumstances. We focus on the Stockholm-Gothenburg, and only accounting for the direct benefits.

Evidence from other studies and the results of the two Spanish lines evaluated in this paper show that benefits deriving from the reduction of congestion and accidents are less than 5% of total benefits and, in the case of Sweden, the prediction of changes in modal split with the project show that car passenger-trips shifting to HSR are less than 3% of the total passenger-trips in the first year of operation. Once we obtain the minimum demand thresholds needed for a positive NPV under these assumptions, we conduct a sensitivity analysis with the introduction of freight benefits reported in previous studies. A discussion of the potential environmental benefits is also carried out.

In the cases where the demand-income elasticity is assumed to be 0.512 (the value estimated for Sweden), labor costs grow proportionally with income and half of the passenger-trips travel the whole length of the line, the demand thresholds for a NPV equal to zero go from 17 to 25 million of passenger-trips in the first year operation. There are other more favorable scenarios where the required demand levels for the first year of operation could be lower but the underlying assumptions are then somewhat unrealistic.

The released capacity for freight transport has been argued to be one of the benefits of the construction of HSR infrastructure in Sweden. To conclude this exercise, we recalculate the minimum demand volumes compatible with a positive NPV including the alleged benefits derived from the release of capacity for freight transport. The results do not show any dramatic change with respect to the previous demand threshold.

There is a dynamic aspect worth considering. Socially profitable or not, once the HSR infrastructure is built the costs are sunk, and this irreversibility affects more than half of the total costs (even higher for low density lines). Once the line is built, the marginal cost of additional traffic is quite low compared with the *ex ante* marginal cost. Prices much lower than total average costs are common in many HSR lines around the world, fostering demand and the expansion of a network in regions or countries where there were better transport solutions for their accessibility and mobility needs.

Finally, it is worth emphasizing that in this paper we have addressed the normative question 'should a country invest in HSR infrastructure?' Another different but related positive question is 'why some countries have decided to invest in HSR? ' This last question leads directly to the institutional design and set of incentives of each country. This is really important in practical terms because the public nature of these investments, jointly with the separation of decision and financing as it happens to be the case in the EU with the cofinancing of HSR projects, can explain investment decisions that had not been taken without the supranational funding. A similar game is played between national and regional government in countries where these projects are supported from the national budget.

Appendix 5.1. Madrid-Seville. Basic data and assumptions

GENERAL ASSUMPTIONS
First year of construction: 1987
Last year of construction: 1993
First year of operation: 1992
Project life: 50 years
Discount rate: 5%
Annual growth rate of income; National Institute of Statistics until 2009; from 2010 to 2015, 1% according to the IMF. For the rest of the project life, the annual growth follows a random uniform variable between 1% and 4%, independent between years.
Benefits and costs are discounted at the end of 1986/beginning of 1987 and expressed in €1986.
Prices are deflated with the CPI of the National Institute of Statistics.
The shadow multiplier of public funds is 1.
COSTS
The elasticity of labor costs with respect to income is equal to 1.
Investment
1.- The total investment is €2.07 billion (1986) as reported in de Rus and Inglada (1997).
2.- Investment costs have been distributed according to de Rus and Inglada (1997).
3.- VAT (Value added tax) was not deducted as investment costs do not include the cost of stations and other facilities.
4.- Labor share in investment costs is 30% according to Regulation 3650/1970. In this case, labor costs keep constant during the construction period.
5.- Labor shadow price is not applied for the same reason of VAT in investment costs.
6.- The residual value of the infrastructure is zero.
Maintenance and operation
1.- 50% of the infrastructure maintenance costs corresponds to labor.
2.- VAT: 13% for the period 1987-1992; 16% for 1992-2010 and 18% from 2010. The tax is only deducted from the 50% of the maintenance cost.
3.-In case of the operation and maintenances costs of the rolling stock, we assume all costs are labor and a conversion factor of 0.9 (based on Del Bo *et al.*, 2009) for shadow pricing.
4.- The maintenance cost of the infrastructure is 100,000 €/km in 2009.
5.- The maintenance and operation cost per train is €2,841,774 in 1986 (de Rus and Inglada, 1997).
Acquisition costs of the rolling stock
1.- It follows a random uniform variable between €33,000 and €65,000 per seat in 2002 (Campos and de Rus, 2009).
2.- The average capacity per train is 330 seats (Campos and de Rus, 2009).
3.- VAT is not deducted in the acquisition of the rolling stock. The main reason is that the rolling stock is mostly imported.
4.- The life of a train is 30 years.
Number of trains
1.- The number of daily services required, given the demand, the travel time, the load factor, the length of the route and the hours of operation are computed according to Campos *et al*. (2009).
2.- Based on previous formula, it is required to apply a contingency factor (1.5), in order to allow for maintenance. Trains cannot exceed a maximum number of kilometers per year (500,000 kms.).
3.- The final number of trains is computed as the maximum between these two previous rules.
4.- Operating rail trip time includes the time between train-trips. It is assumed to be 15 minutes.
5.- Demand is constant along the day. Given that some passengers do not travel from Madrid to Seville, a correction factor (0.8) is applied.

6.- The load factor follows a random uniform variable between 0.6 and 0.7.
7.- The hours of operation of a representative train are 16.
8.- Given that demand is very low in the first years of operation, the number of trains is taken from International Union of Railways (UIC) data.
AVOIDABLE COSTS
1.- It is assumed that the average avoidable cost of each mode of transport is equal to the price net of taxes.
2.- The average cost of air transport is collected from ICAO database. The cost per kilometer for Iberia is equal to €0.15 (2009). This value is multiplied by 0.8 to account for the presence of other airlines in the corridor and shadow pricing.
3.- The average coach fares are taken from the website of ALSA and SOCIBUS. A conversion factor of 0.9 is applied to account for shadow pricing.
4.- The average cost of the car is computed using several sources including experts of the industry and Spanish Road Association. The average cost includes fuel net of tax, 50% of depreciation, and other costs.
5.- Prices of the conventional train are taken from the website of RENFE. A conversion factor of 0.8 is applied to account for shadow pricing.
DEMAND
1.- For the period 1992-2004, the demand is based on real data while for the rest of the project life the number of passenger-trips is forecasted.
2.- Forecasted demand is computed as the number of passenger-trips of the previous year multiplied by the annual growth rate of income and its corresponding elasticity.
3.- The demand-income elasticity is equal to 1.
4.- The generated and diverted demand from the different modes per route and year is computed as the demand of that year in the route multiplied by the percentage of the diverted demand in "modal split".
TRAVEL TIMES AND VALUES OF TIME
1.- HSR in-vehicle time is computed as a weighted average of the different types of HSR services taken from the website of RENFE.
2.- Door-to-door travel time of plane, bus, car and conventional train (de Rus and Inglada, 1997).When information is not available, it is assumed that access-egress time is equal to half an hour.
3.- Values of in-vehicle time of plane, bus, car and conventional train are random uniform variables between values reported by Heatco (2006) and those based on de Rus and Román (2005) considering that Madrid Sevilla is identical to Madrid-Barcelona and the rest of the routes are equal to Madrid-Zaragoza.
4.- Values of waiting time are 1.5 times the values of in-vehicle time (Wardman, 2004).
5.- Values of access-egress time are 2 times the values of in-vehicle time (Wardman, 2004).
6.- Waiting times of the HSR, bus and conventional train are identical. The HSR waiting time is taken from de Rus and Román (2005).
7.- Access and egress times of the HSR, bus and conventional train are identical. The access-egress time of the high speed rail is taken from de Rus and Román (2005).
8.- The elasticity of the value of time with respect to income is equal to 0.7 (Mackie *et al*., 2001; Heatco, 2006).
Correlation matrix
1.- The correlation between the values of time of the same mode of transport in the different routes is 1.
2.- The correlation between the values of time between modes of transport is 0.5
GENERALIZED COSTS
1.- The generalized costs are defined as 'the price of each mode plus the money value of the invested time' and they are used to compute the willingness to pay of the diverted demand.
2.- In the case of the HSR, prices are taken from the website of RENFE.

3.- In the case of the HSR, the generalized cost is obtained as a weighted average of each type of passenger (diverted from each mode).

MODAL SPLIT
Madrid-Sevilla: The modal split is based on the document COST318 (1998)
Diverted demand from the plane (45%)
Diverted demand from the bus (2%)
Diverted demand from the car (12%)
The load factor of the car is 1.3
Diverted demand from the conventional train (26%)
Generated demand: 15%
Madrid-Cordoba:
Diverted demand from the bus (1.33%)
Diverted demand from the car (20%)
Diverted demand from the conventional train (49.33%)
Generated demand: 29.34%
Sevilla-Cordoba:
Diverted demand from the bus (1.33%)
Diverted demand from the car (20%)
Diverted demand from the conventional train (49.33%)
Generated demand: 29.34%
Commuter services:
Diverted demand from the car (45%)
Diverted demand from the conventional train (45%)
Generated demand: 10%
Weights of the group "Other": proportional to the demand in the group, for the calculation of the prices, different times and values of these times
Madrid-Puertollano (19.91%)
Madrid-Ciudad Real (34.33%)
Ciudad Real-Sevilla (19,01%)
Ciudad Real-Córdoba (4,63%)
Ciudad Real-Puertollano (6,61%)
Puertollano-Sevilla (9,99%)
Puertollano-Córdoba (5,50%)
"Other"
Diverted demand from cars (45%)
Diverted demand from conventional train (45%)
Generated demand: 10%
CONGESTION
1.- It is estimated from the hourly data on the average intensity of demand and the average speed of vehicles (Ministerio de Fomento, 2007). We use different demand stations along the route from the database.
2.- Given previous data, we make a regression between the average speed and the number of vehicles for each demand station because of the variability between hours.
3.- Using the car-load factor, the number of cars are transformed to the number of passenger-trips to distribute the diverted demand from the road between the number of hours of operation of the HSR.
4.- Using the regression coefficient, the reduction of the speed in the road according to the diverted demand is computed. The reduction of the speed is transformed into time according to the distance between demand stations.
5.- Finally, the savings of congestion are computed as the time savings of the route multiplied by the

value of in-vehicle time
ACCIDENTS
1.- In order to compute the accident savings, the value of a statistical life is required and the causalities avoided because of the diverted demand.
2.- The value of a statistical life, severe and slight injured is collected from IMPACT (2008) while the number of causalities avoided per kilometerkilometer is obtained from DGT (2006).
3.- Given previous values, we compute the number of vehicles-kilometer per route multiplied by the rate of causalities avoided per kilometer and the value of a statistical life.

Appendix 6.1. Madrid-Barcelona. Basic data and assumptions

GENERAL ASSUMPTIONS
First year of construction (ZAR): 1999
Last year of construction (ZAR): 2003
First year of construction (BAR): 2003
Last year of construction (BAR): 2008
First year of operation (ZAR): 2003
First year of operation (BAR): 2008
Project life: 50 years
Discount rate: 5%
The annual growth rate of income is taken from the National Institute of Statistics until 2009. From 2010 to 2015, the estimated growth rate is equal to 1% according to the IMF. For the rest of the project life, the annual growth rate follows a random uniform variable between 1% and 4%, independent between years.
Prices are deflated with the CPI of the National Institute of Statistics.
Benefits and costs are discounted at the end of 1998/beginning of 1999 and expressed in €1998.
The shadow multiplier of public funds is 1.
COSTS
The elasticity of labor costs with respect to income is equal to 1.
Investment
1.- The total investment is €9.5 billion (2008) as reported in Sanchez-Borrás (2010).
2.- Investment costs have been distributed during the construction period. The construction of the route Madrid-Zaragoza is distributed in the period 1999-2003 considering the number of kilometers built per year. The same procedure is followed in the route Madrid-Barcelona for the period 2003-2007.
3.- Value added tax (VAT) was not deducted as the investment costs do not include the stations and other facilities.
4.- Labor share in investment costs is 30% according to Regulation 3650/1970. In this case, labor costs keep constant during the construction period.
5.-The shadow price of labor is not applied for the same reason of VAT in investment costs.
6.- The residual value of the infrastructure is zero.
Maintenance and operation
1.- 50% of the infrastructure maintenance costs corresponds to labor.
2.- VAT is 16% in the period 2003-2010 and 18% from 2010. The tax is only deducted of the 50%

of the non-labor maintenance costs.
3.- The conversion factor for labor is 0.9 (based on Del Bo *et al*., 2009).
4.- In case of the operation and maintenance costs of the rolling stock, we assume that labor cost share is 100% and a conversion factor of 0.9
5.- The maintenance cost of the infrastructure is 100,000 €/km in 2009.
6.- The maintenance and operation cost per train is €6,674,875 in 1998 (de Rus and Inglada, 1997).
Acquisition of rolling stock
1.- The acquisition of rolling stock follows a random uniform variable between €33,000 and €65,000 per seat in 2002 (Campos and de Rus, 2009).
2.- The average capacity per train is 330 seats (Campos and de Rus, 2009).
3.- VAT was not deducted in the acquisition of the rolling stock. The main reason is that the rolling stock is mostly imported.
4.- The life of a train is 30 years.
Number of trains
1.- The number of daily services required, given the demand, the travel time, the load factor, the length of the route and the hours of operation are computed according to Campos *et al*. (2009).
2.- Based on previous formula, applying a contingency factor (1.5) for maintenance is required. Moreover, we assume trains do not exceed a maximum number of kilometers per year (500,000 kms.).
3.- The final number of trains are computed as the maximum between these two previous rules.
4.- Operating rail trip time includes the time between train-trips. It is assumed to be 15 minutes.
5.- Demand is constant along the day. Given that some passengers do not travel from Madrid to Barcelona, a correction factor (0.8) is applied to take into account this fact.
6.- The load factor follows a random uniform variable between 0.6 and 0.7.
7.- The hours of operation are 16.
8.- Given that demand is very low in the first years of operation, the minimum number of trains is taken from the information provided by the UIC.
AVOIDABLE COSTS
1.- It is assumed that the average avoidable cost in other modes of transport is equal to their prices net of taxes.
2.- The average cost of air transport is collected from the ICAO database. The cost per kilometer in Iberia is equal to €0.15 (2009). This value is multiplied by 0.8 to account for the presence of the low cost airlines in the corridor and shadow pricing.
3.- The average prices of the bus are taken from the website of ALSA. A conversion factor of 0.9 is applied to account for shadow pricing.
4.- The average cost of the car is computed using several sources: experts of the industry and the Spanish Road Association. It includes fuel net of tax, depreciation and other costs.
5.- Prices of the conventional train are taken from the website of RENFE. A conversion factor of 0.8 is applied to account for shadow pricing.
DEMAND
1.- For the period 2003-2009, the demand is based on real data while in the rest of the project life the number of passenger-trips is forecasted.
2.- The forecasts of the demand are computed as the demand of the previous year multiplied by the annual growth rate of income and its corresponding elasticity.
3.- The income-demand elasticity is equal to 1.
4.- The generated and diverted demand from the different modes per route and year is computed as the demand of that year in the route multiplied by the percentage of the diverted demand that are presented in this chart under the title "Modal Split".

VALUES OF TIME
1.- HSR in-vehicle time is computed as a weighted average of the different types of HSR services taken from the website of RENFE.
2.- Door-to-door of the plane, bus, car and conventional train (de Rus and Román, 2005).
3.- Values of in-vehicle time for plane, bus, car and conventional train are random uniform variables between values reported by Heatco (2006) and those based on de Rus and Román (2005).
4.- Values of waiting time is 1.5 times the values of in-vehicle time (Wardman, 2004).
5.- Values of access-egress time is 2 times the values of in-vehicle time (Wardman, 2004).
6.- Waiting times of HSR, bus and conventional train are the same. The HSR waiting time is taken from de Rus and Román (2005).
7.- Access and egress times of the HSR, bus and conventional train are identical. The access-egress time of the high speed rail is taken from de Rus and Román (2005).
8.- The elasticity of the value of time with respect to income is equal to 0.7 (Mackie *et al*., 2001; Heatco, 2006).
Values of time in "Other" are the same as in Madrid-Barcelona or Madrid-Zaragoza
Values of time of Madrid-Lleida are identical to Madrid-Barcelona
Values of time of Madrid-Tarragona are identical to Madrid-Barcelona
Values of time of Zaragoza-Lleida are identical to Madrid-Zaragoza
Values of time of Zaragoza-Tarragona are identical to Madrid-Zaragoza
Values of time of Lleida-Barcelona are identical to Madrid-Zaragoza
Values of time of Rest are identical to Madrid-Barcelona
Correlation matrix
1.- The correlation between the values of time of the same mode of transport in the different routes is 1.
2.- The correlation between the values of time between modes of transport is 0.5.
GENERALIZED COSTS
1.- The generalized costs are defined as the price of each mode plus the invested time in monetary terms and they are used to compute the willingness to pay of the diverted demand.
2.- In the case of the HSR, prices are taken from the website of RENFE.
3.- In the case of the HSR, the generalized cost is obtained as a weighted average of each type of passenger (diverted from each mode).
MODAL SPLIT
The load factor of the car is 1.3
Madrid-Barcelona: The modal split has been estimated from the data in ACESA (2009).
Diverted demand from the plane: Our own (43%)
Diverted demand from the bus: ACESA calculates this figure according to origin-destination matrix of ADIF (3.25%)
Diverted demand from the car: ACESA (16.07%)
Diverted demand from the conventional train: ACESA assumes that conventional train demand is completely diverted to high speed rail (27.29%)
Generated demand. It is derived from the first year of operation as the difference between our estimation of diverted demand and the total HSR passenger-trips (10.39%).
Madrid-Zaragoza: Based on de Rus and Román (2005).
Diverted demand from the plane (2.67%)
Diverted demand from the bus (1.33%)
Diverted demand from the car (20%)
Diverted demand from the conventional train (49.33%)
Generated demand (26.67%)

Weights of the group "Other": proportional to the demand in the group. It is used for the calculation of the prices, different times and values of these times
Madrid-Lleida (27.4%)
Madrid-Tarragona (33.6%)
Zaragoza-Lleida (6%)
Zaragoza-Tarragona (6.5%)
Lleida-Barcelona (7.9%)
Rest (18.6%). They are identical to the Madrid-Lleida.
"Other"
Diverted demand from the car (45%)
Diverted demand from the conventional train (45%)
Generated demand (10%)
CONGESTION
1.- It is estimated from the hourly data on the average intensity of demand and the average speed of vehicles (Ministerio de Fomento, 2007). We use different points along the route from the database.
2.- Given previous data, we make a regression between the average speed and the number of vehicles for each demand station thanks to the variability between hours.
3.- Using the car-load factor, the number of cars are transformed to the number of passenger-trips to distribute the diverted demand from the road between the number of hours of operation of the HSR.
4.- Using the regression coefficient, the reduction of the speed in the road according to the diverted demand is computed. The reduction of the speed is transformed into time according to the distance between demand stations.
5.- Finally, the savings of congestion are computed as the time savings of the route multiplied by the value of in-vehicle time
ACCIDENTS
1.- In order to compute the accident savings, the values of a statistical life and the causalities avoided are required because of the diverted demand.
2.- The value of a statistical life, severe and slightly injured, is collected from IMPACT (2008) while the number of causalities avoided per kilometer is obtained from DGT (2006).
3.- Given previous values, we compute the number of vehicles-kilometer per route multiplied by the rate of causalities avoided per kilometer and the value of a statistical life.

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