ECONOMIC EVALUATION OF TRANSPORT PROJECTS AND POLICIES: METHODOLOGY AND APPLICATIONS

Part 2:

Cost-benefit analysis of railway projects: high-speed lines and suburban lines

September 1, 2020

Authors:

Ginés de Rus University of Las Palmas de Gran Canaria, FEDEA

Javier Campos University of Las Palmas de Gran Canaria

Armando Ortuño Universidad de Alicante

M. Pilar Socorro University of Las Palmas de Gran Canaria

Jorge Valido University of Las Palmas de Gran Canaria

External advisors:

Per-Olov Johansson Stockholm School of Economics

This technical report was commissioned to the authors by the Independent Authority of Fiscal Responsibility (AIReF) for the Spending Review on Transport Infrastructure. It is funded by the EU via the Structural Reform Support Programme (SRSS). This paper reflects only the authors' view and does not imply a policy position of the European Commission or the AIReF, neither are responsible for any use that may be made of the information it contains. This technical report has benefitted from long and fruitful discussions with the staff at AIReF, in particular, Santiago Fernández, Milagros Paniagua, Ángel Martínez and Fernando de la Cámara.

CONTENTS

1. INTRODUCTION

The economic assessment of rail investment projects relies on the same cost-benefit analysis (CBA) principles that are applied in other transport modes. However, these general rules should also take into account the technical and economic peculiarities of a sector which is defined not only by its capacity to provide fast and regular services to a large number of passengers and freight volumes in a safer way than other modes, but also by its high (and often sunk) construction, operation and maintenance costs. Rail transport is also characterized by large economies of scale and density, which was traditionally argued in many countries to justify market structures based on vertically integrated public monopolies, with limited opportunities for competition.

Over the past few decades, however, and in order to reverse the progressive decline of rail transport as compared to other competing modes in Europe, the European Union has embraced a restructuring process based on the separation of infrastructure management from the provision of services and the progressive liberalization of the sector in order to foster competition either 'on the tracks' or 'for the tracks'. The increasing number of public and private partners currently involved in the rail sector makes it even more relevant to properly quantify and analyse the distribution of profits and losses between them when undertaking any new project and, in fact, becomes an essential component of the overall decision-making process.

Even though the government remain in most EU Member States the responsible for many rail transport investment and policies, the economic evaluation of rail projects have to take into consideration not only their effects on the public sector budget, but also the economic impacts for all the other key stakeholders in the society: the infrastructure manager, the (public and private) service operators, the users of railways and other competing modes and, in general, the effects on related players in other sectors, when relevant. Although some minor projects may still be decided at the level of the infrastructure manager or the operators, larger ones (for example, opening a new rail line, upgrading or closing existing services, building new infrastructure, etc.) are increasingly affected by these complex relationships. The decision about them becomes harder and requires a more comprehensive assessment, with sound and well-established economic criteria.

This is the main focus of this document, which builds on the document entitled *A GENERAL METHODOLOGY FOR COST-BENEFIT ANALYSIS IN TRANSPORT*, described in detail in

PART I,[1] as well as the already existing guidelines and manuals on this issue to provide indications and examples on how to carry out the CBA of rail projects. From a methodological point of view, our main reference is **PART I** which develops an analytical evaluation model where transport projects are interpreted as perturbations in the economy affecting the social welfare of different individuals at different moments in time, as compared with the counterfactual, the situation without the project. Using that approach, after this brief introduction, **Section 2** starts by discussing how rail transport projects should be defined from the point of view of their *ex-ante* assessment, particularly focusing on the different roles played by the different stakeholders in the sector. The rest of this document focuses on passenger rail undertakings (building a new line, expanding an existing network, etc.) although the main ideas are also extensible to freight projects. **Section 3** analyses the particular relevance of demand projections in the adequate definition of rail projects. **Section 4** examines in more detail some of the most relevant technical features of these projects, particularly distinguishing between inter-urban high-speed rail (HSR) undertakings and other related to commuting or suburban railways, which operate primarily within a metropolitan area, connecting travellers to a central city from the suburbs or adjacent suburbs. **Sections 5** and **6** will be respectively devoted to discussing the application of the CBA methodology to each of these rail projects types, providing in each case a hypothetical example to illustrate the most salient elements of the assessment process. **Annex A** finally reviews some of the most recent economic evaluation guidelines, and **Annex B** enumerates a set of variables and data sources needed for performing the CBA of rail projects.

[1] De Rus *et al*. (2019).

2. KEY ELEMENTS IN DEFINING A RAIL PROJECT

2.1. Project definition and alternatives

As in any other transport project, the *ex-ante* evaluation of rail investments starts with the adequate identification of the project within the context of a wider investment program at a regional, national or European scale. This first step delimits the scope of the analysis, the society of reference, and clarifies which agents may or not may be involved in its analysis. From a technical perspective, the project should then be defined by all the (engineering) elements needed to make it operable (e.g. main and secondary tracks, stations, depots and other auxiliary infrastructure, energy and communication installations, rolling stock, etc.). However, from an economic assessment perspective, the project definition should avoid unrelated elements or those that are not necessary to make it operable (e.g. buildings not related to train operations, roads not required by/for rail project, etc.) but it should include any other element necessary to make the project operative.

Most (large) passenger rail projects require a previous planning exercise which clarifies what is its final objective and how it can be achieved. Some projects, for example, may be intended to address very specific problems (e.g. bottlenecks or lack of capacity); others, to improve current transport conditions (e.g. slow connections or poor quality services) and, in many cases, they respond to other social needs (e.g. increased accessibility, reduced environmental nuisances). Since undertaking a project entails the simultaneous decision of not undertaking any of the other feasible options, in order to assess the economic convenience of a project, an adequate range of alternatives should be always considered.

One of the possible counterfactual options to consider is the ‘do-minimum alternative’, which implies carrying out as little investment and maintenance as possible to keep current transport markets working without excessive deterioration of services. In the case of railways, this can be interpreted as following the standard pattern of renewal and maintenance of the existing infrastructure and rolling stock (which, of course, would result in significantly different traffic levels than those foreseen under the project).

On the contrary, the ‘do-nothing’ alternative is often incompatible with the normal operation in the existing network and, thus, it is usually not a valid reference. In many cases, notably in the assessment of high-speed lines, the ‘do-minimum’ is not defined as the investment needed to provide the capacity required by expected normal traffic growth (referred to as ‘avoided investment’). Instead, the comparison should be performed between the new project (i.e. the high-speed line) and an ‘avoided’ major alternative (such as track doubling). In cases where the saturation of the conventional rail network requires capacity expansions, the construction of a new high-speed rail line should be also evaluated as an alternative to the improvement and extension of the conventional network, with the additional advantage of freeing up capacity. Obviously, this additional capacity is valuable inasmuch demand exceeds existing capacity. In these circumstances, additional capacity may absorb the traffic growth between cities served by HSR and may also release capacity on existing lines to satisfy other traffic (such as suburban or freight demand).

Thus, there may be 'do-something' alternatives that can be defined in a variety of ways, depending on the project size and scope.[2] Sometimes an alternative is simply an extension or improvement of another (e.g. an additional link). In this case, if the basic alternative is acceptable, it is the extra investment what must be appraised. Comparisons become more complex when several interlinked projects are evaluated. If network effects are relevant (as in the case of suburban railways), the implementation of related projects and their timing could have important effects on the profitability of the whole investment. One possible way to handle such cases is to carry out appraisals of the whole investment and of each of its individual components, to reach both an optimal project selection and their scheduling period. However, this is quite difficult in practice, and an individual appraisal of each project is performed. In this case, it is important to take into account each project specific timetable and, in any case, avoid double-counting of the same network benefits.

In fact, the traditional view when defining (particularly, urban and suburban) rail projects has been to consider investments leading to a continuous improvement process rather than options representing a major change in the network. This is due to the integrated character of the rail system that often prevents the spreading of advantages (notably those derived from innovation) to the whole network. Speed restrictions or old electrification and signalling systems can, for instance, make inefficient the deployment of modern rolling stock on upgraded sections. However, the increasing development of high-speed networks (which require dedicated infrastructure and even different track gauges, as in Spain) is changing this approach, and some experts argue for slightly different assessment approaches to different rail projects, as discussed below (UIC, 2018). In all cases, the definition of alternatives for a rail project should always take into account the implications for the whole transport system and, for larger projects, even the wider economic benefits (WEB) on the territory, when they exist and can be accounted for.

---

[2] See Turró (2004) and de Rus *et al.* (2019) for additional discussion. The *Railway Project Appraisal Guidelines* (RAILPAG), as well as – for example – the different rail investment guidelines used by the Spanish Rail Infrastructure Manager (ADIF) and other international institutions are discussed in **Annex A**.

2.2. The role of different stakeholders in the assessment of rail projects

When compared to the selected counterfactual, many investments in the railways sector involve costs and benefits for a wide range of institutions, companies and individuals for several years. Many of these are actual cash flows that constitute the main basis for the assessment of the project for some of these stakeholders (infrastructure managers or service operators) which mostly care for the project global profitability and its sustainability in financial terms. However, other costs and benefits are not directly reflected in financial flows (e.g., part of the travel time savings), and/or appear in other sectors (competing transport modes) and/or are not internalized by the users or the producers (external costs). All these elements are essential in the economic evaluation of rail projects using CBA, whose ultimate aim is to quantify how much the wellbeing of each of the affected agents is changed by the project, both for efficiency and distributional reasons.

CBA thus adopts a social perspective, evaluating rail projects by taking into account all their benefits and costs, notwithstanding the fact that the assessment may involve making unpopular decisions and lead to reject or delay projects with large popular support but with social costs above their social benefits. Unfortunately, it is not infrequent the case where rail projects have been undertaken in many countries under temporary political pressures or misguided social concerns, and CBA results have been ignored or misinterpreted (ECA, 2018). CBA should be viewed as a decision tool that both contribute to choose projects that increase efficiency and helps to identify the distribution of social benefits and costs among the different involved stakeholders, adding transparency and accountability to the decision process.

As mentioned above, the restructuring process in the EU railways has foreseen the separation of infrastructure and services, at least from the point of view of their financial accounts.[3] Some Member States have pursued a complete vertical disintegration of the sector and even (partially or fully) privatized their network, whereas other countries have opted for a compromise solution where the ownership (and ultimate the responsibility on investment programs) are still under government control, and day-to-day administration (including investment appraisal) are surrogated into a public body with some degree of financial autonomy.[4]

[3] See Nash *et al.* (2013) or Laurino *et al.* (2015) for a wider discussion of different rail restructuring models in Europe and around the world.

[4] This is, for example, the Spanish model, where – in accordance with the 2015 Railways Sector Law – the *Ministry of Transport, Mobility and Urban Agenda* has delegated into a separated agency ADIF the management and investment decisions on the existing rail infrastructure (tracks and stations). Since 2014, high-speed lines are administratively separated into *ADIF – Alta Velocidad*.

In any vertically unbundled rail transport sector, the infrastructure manager should be always considered as a separate key player from the point of view of project appraisal, as it could have its own sources of income (track access charges, tolls, rentals…) and different costs (including investments). A single rail project will usually affect only one infrastructure manager. However, there is a possibility of dividing the national network among several managers (at the regional level) and works on international sections are also likely to affect at least two managers. It is relevant to note that the existence of close ties between (state-owned) network managers and (state-owned) service operators could imply the existence of perverse incentives in the overall rail system, yielding the vertical disintegration in these cases ineffective: the sector would be acting 'de facto' as in the old vertically integrated monopoly model.

For that reason, sometimes there is a need for an (independent) regulatory agency, overseeing the relationships among infrastructure owners, infrastructure managers and, logically, service operators, even in the case that they all are public bodies. This regulator could certainly affect project decision-making depending on its influence on price-setting policies (particularly, track access charges), service levels (if there exist or not public service obligations), overview of intermodal and intramodal competition (if there are several operators) and its belligerence in preventing abuses of dominant position.

Regarding the firms that provide transport services, the introduction of competition promoted by the EU regulations has sought to erode the traditional monopolistic position of the (mostly public) incumbent companies on their national or regional networks. This means that it is no longer adequate to look at the rail system as an isolated monopolistic system. Not only have infrastructure and operations become counterparts; competing operators will try to obtain the best deal from any new investment. It is, thus, necessary to take into account this competition on the project and anticipate its effects on the evolution of prices, traffic forecasts, market shares and the subsequent distribution of costs and revenues in the rail market. In addition, any major rail investment could also have an impact on the distribution of traffic flows and on the performance of other transport modes (intermodal competition), which will have to be included in the traffic forecasts, and in the estimation of the social benefits and costs.

Transport users are not only affected in financial terms by costs changes that are translated into monetary prices, but also obtain other benefits of the project (in the form of time savings, safety and comfort improvements, etc.) which may have positive and negative signs across different transport modes. Users and non-users also share the costs of the project, either as ultimate taxpayers or in the form of externalities. The sign and amount of the external effects are not always easy to quantify, but can have an important weight in the decision-making, particularly when environmental concerns tend to position railways in a more favourable public opinion view as compared to road or air travel.

Other stakeholders may be finally of interest. Investment on rail projects is directly undertaken by construction companies, suppliers of equipment and services, etc. Maintenance and operations may also involve external companies, mobilizing labour and capital outside the rail sector. Landowners could also be affected through expropriation or changes in the value of their properties. Relocation decisions and the functioning of other related markets can be also affected by large projects, as well as the overall competitiveness level of the economy. However, the risk of double-counting is high, and any measurement of indirect effects of rail projects – either at the micro or macro level – should be supported by a well-established case-by-case methodology and specific data-based analysis. The alternative of justifying large rail investments for unproven WEB or the 'overall gains of enlarged competition' is still very frequent.

3. DEMAND FORECASTING AND RAIL PROJECT ASSESSMENT

After defining the project, the next step in its evaluation process in order to identify and measure its effects is to make a detailed demand analysis. This requires assessing the existing demand for the various types of users (typically using data provided by current service suppliers or statistical offices) and the future demand (based on reliable models that take into consideration reasonable economic forecasts, alternative sources of supply, elasticity of demand to relevant prices and income, etc.). Both ‘with-the-project’ and ‘without-the-project’ passenger traffic quantifications are essential to formulate projections, although the demand analysis should always provide forecasts adapted to the technical and economic characteristics of each project, particularly including the effects of pricing policies and the foreseeable reaction of all the relevant stakeholders to changes in the generalized prices. Depending on the data available and the dedicated resources, different techniques (for example, regression models, logit models, trend extrapolations, qualitative methods, etc.) can be used for demand forecasting, and their results may obviously differ.

In general, since transport projects affect transport users’ modal distribution, the sources of diverted traffic (those that are deviated from competing modes to railways) must be clearly identified, as well as the amount of generated (new) demand associated with the rail project (either in the form of new users or as new trips by existing users). It is important to distinguish between travel purposes (business, commuting, leisure, etc.) since the users’ value of time differs across them, and between routes or specific sections. Particular attention should be paid to identifying whether the project belongs to a network (as in the case of many suburban rail projects), because its demand (and consequently its financial and economic performance) is highly influenced by issues of complementarity and accessibility that should be explicitly taken into account in the assessment.

In practice, although there are different procedures for carrying out the demand analysis in rail projects, they all typically include at least three elements. For example, when it comes to the construction of a new passenger rail line (e.g. a new high-speed corridor), it is required to:

1. …build a database, usually in the form of a detailed origin-destination (OD) matrix, that identifies the most relevant OD relationships between the cities/stations affected by the project. This matrix should include all the available data (existing demand, number of services, frequencies, average speed, monetary prices, etc.) for all the current transport alternatives (road, air transport and

conventional rail), as well the most relevant parameters (for example, unit costs estimates) required for an *ex ante* CBA;

2. …estimate the modal distribution, in particular the generation and distribution of new and existing trips according to a generalized price traffic model that determines what happens 'without-the-project' and 'with-the-project'. The resulting modal split must be consistent with all the economic and technical parameters of the model (for example, prices and capacity restrictions), and

3. …forecast the evolution of the demand over the evaluation period, which should be defined in accordance to the economic life of the assets involved in the project. For investments in rail infrastructure, a reasonable horizon lies between 30 and 50 years, although the shorter the period, the higher the residual value to consider at the end of the evaluation. Traffic forecasting should be based on estimated gross domestic product (GDP) projections and the corresponding income elasticity.

The use of generalized prices – which include monetary prices, the value of travel time and other disutility costs borne by users – as the central element in demand prediction models is not only common in transport literature, but also fairly consistent with the socio-economic definition of transport projects in CBA, viewed as exogenous interventions in a transport market, which shifts its initial equilibrium and affects prices, costs and time. However, the relative importance of each of these components may differ in practice.

For example, with respect to price elasticities, rail demand for most intercity rail monetary prices is relatively inelastic for low prices but quickly becomes elastic as the price increases. Revenues sharply decline for unit prices above €0.1 per passenger-km, although there are significant differences associated with specific services and routes. When travel time is reduced, rail transport becomes much more attractive as compared to its road and air competitors, particularly, in medium and long-distance routes (between 200 and 500 kms). Average speed is thus a key determinant of users' modal choice: rail market shares in many European corridors where travel time is below 2.5 hours are above 80%, while for routes where it exceeds 3.5 hours, they often fall below 50%. Similarly, increases in frequencies lead to lower waiting times. In these cases, the elasticity of demand with respect to frequency is always positive, although not linear, since, for example, services with low initial frequency are more sensitive to the increase in frequency compared to others with lower frequencies. In the case of medium and long distance, from 16 daily frequencies the increase in demand is negligible. On the other hand, the sensitivity of demand to frequency increases with train speed.[5]

In the demand analysis of urban and suburban rail projects other factors are also considered prior to proceed with the assessment process. Of particular interest in several European countries is the fact that most suburban rail services in metropolitan areas are subject to public service obligations and existing regulations set up a series of prerequisites that must be fulfilled in order to authorize new projects. For example, in Spain, these include (among others) that the population served by a suburban line, within a maximum radius of one kilometre from the stations should be above the threshold of 100,000 inhabitants (although other factors such as employment and level of economic activities are also considered), and that the estimated demand levels should be above 20,000 or 5,000 daily passenger-trips for new lines or new stations, respectively. In practice, however, these limits are too restrictive and rarely met even by existing lines. For this reason, since 2017 they have been softened by using 'global efficiency and sustainability' criteria that represent, on average, the economic and financial results of the existing suburban lines. This results in a minimum demand of 8,000 passenger-trips per day as the practical threshold to implement a new suburban service line, provided that minimum services of 30 trains per direction per day are also established.

Finally, there are several additional factors that are relevant for the demand analysis of rail projects and should be included in the project assessment process when the information is available. The sensitivity of traffic estimates is critical with respect to, for example, demographic and socio-economic changes (in the users characteristics, their travel preferences and their willingness to pay), the industrial and logistics structure of the affected area (location of economic and social activities), the strategies of competing modes, government policies (including subsidies and taxes) and, of course, the pace of technological change, with particular effects on the rail industry in the present context of development of some alternatives (levitation trains, hyperloop, etc.) that could render current rail technology as obsolete in just a few decades.

[5] See García Álvarez (2016), for example, for references in the case of Spain.

4. THE COSTS OF BUILDING AND OPERATING RAIL PROJECTS

4.1. High-speed rail projects

As defined in UIC (2018), high-speed rail (HSR) is a grounded, guided and low grip transport system that comprises at least three different technical elements: upgraded infrastructure or new lines designed to run at a maximum speed of 250 km/h or more, dedicated rolling stock with *ad hoc* designed trainsets, and new operational rules, communication and maintenance systems that allow the provision of high-quality passenger transport services. Although this commercial speed is the main reference for HSR, on medium-distance routes without air competition, lower values (above 200 km/h) are also acceptable in Europe if the services include specific trainsets), no-trackside signals, long-range control centres and geographical or temporal separation of freight and passenger traffics.

4.1.1. The construction costs of a high-speed line

According to the relationship between the infrastructure to be built with the pre-existing rail infrastructure, there are at least five different types of HSR projects: large corridors isolated from other lines, network integrated corridors, smaller extensions or new sections of existing corridors, large singular projects and smaller projects complementing the conventional network, including high-speed lines that connect airports with nearby cities, or the improvements in conventional infrastructure to accommodate higher-speed services.

In general, building an HSR infrastructure in any of these cases requires a specific design in order to remove all technical issues that might reduce the trains commercial speed, including roadway-level crossings, sharp curves, excessive gradients and other orographic limitations. For this reason, it is difficult to compare the construction costs of different HSR projects. In many projects, land and planning costs, and the cost of main stations are excluded in the infrastructure construction costs, and the average cost of an HSR line per kilometres around the world ranges from €10 to €40 million in 2009 prices, according to different sources.[6] The existing HSR lines in Europe typically exhibit even lower values (from €5 to €25 million in Spain and France) especially in projects developed on less densely populated areas and dedicated for passenger trains only (UIC, 2018).

[6] See Campos and de Rus (2009) or Campos *et al*. (2009) for international references. More recent, but equivalent values can be found in Preston (2013) and UIC (2018).

Most high-speed lines are built within five to six years of taking possession of the required land, so long as tunnels and viaducts are not numerous or long. The distribution of the construction investment over this period is not uniform and depends on technical, economic and even political factors. Although the administrative procedures may be slightly different across countries, once the decision has been made to construct a high-speed line they usually include public enquiries to ensure the adequate balance between public and private interests, environmental studies of the affected areas before the project, including a list of potential alleviation measures if needed and the design of the institutional and financial scheme to determine who will carry out the project and how it will be financed, within the corresponding regional, national or European setting.

In Spain, for example, the overall planning and investment scheduling of rail projects corresponds to the Ministry of Transport, Mobility and Urban Agenda, whereas the economic assessment (of the whole project or divided into sections) is performed by the infrastructure manager (ADIF). Once the line to be executed has been chosen, an *Environmental Impact Study* is carried out for each section, considering their integrated and separate effects on the entire corridor, according to the existing environmental regulations. An *Informative Study* of each section is also performed, in order to determine all the technical aspects necessary for the project practical execution. These engineering studies include different layouts and solutions to overcome the terrain obstacles and deal with more difficult areas. Specific aspects such as desired speed, section length, number and size of viaducts and tunnels, earthworks, impact on existing infrastructure, or geotechnical characteristics of the terrain are also considered. Once these studies have been concluded, they are qualitatively evaluated using a multi-criteria analysis in which the specific weight of each aspect analysed is scored and adjusted. There is no a homogenous weighting methodology, and it may vary substantially across projects, which ultimately suggests the existence of discretionary factors that increase the subjectivity in the choice of the final alternative by ADIF. The chosen alternative is finally developed through a *Building Project* which defines with precision all the details and phases of the execution of the works, including cartography, geological and geotechnical studies, platform projects, construction projects for track assembly, electrification projects, installation projects and acoustic and vibration protection projects. All these elements are summarized into the *Technical Terms of References*, which are used to determine the initial budget and the tendering conditions for private construction companies.

As discussed above, most HSR construction contracts are based on pre-defined unit cost references (in euros per kilometre) that depend on the case-specific orography (from flat to hilly terrain) and the geological-geotechnical risks of each project. Thus, infrastructure construction costs (excluding land,[7] planning and stations)[8] are more or less proportional to the length of each section and include the materials and labour costs, which must be valued at their corresponding opportunity costs. Labour costs typically represent around 10% of investment costs. The exact route length by rail between two points depends on the radius of the curve joining those points, which in turn, is determined by the maximum operational speed: the higher the speed, the less sinuous the route and, therefore, the shorter the length. These elements are geometrically calculated using a trajectory coefficient function, which estimates the increase in length with respect to the straight line between those two points.[9]

The second element that significantly defines the total cost of HSR infrastructure is the percentage of viaduct and tunnel sections over the total length of the line. These percentages also depend on the local orography and the maximum speed, since using less winding routes on uneven terrain requires a greater usage of this type of infrastructure. In general, on flat and semi-flat terrains these percentages are between 1-10%, but quickly increase to 25-90% for abrupt terrains. The unit cost of viaduct and tunnel sections ranges from €5 million per kilometre in relatively flat surfaces to €40 million in most difficult terrains. For tunnels, their cost per kilometre depends on the cross-section (in square metres) and may vary between €25-35 million for double-track tunnels and between €50-70 for double-tube ones.

Once the rail platform has been prepared, the track must be installed on it. In this case, a choice must be made between installing the track on ballast or on plate, a decision which is conditioned by the maximum design speed of the section and by the type of section. Ballastless solutions have also been used on several projects, whereby the track is laid directly onto concrete slabs. Both solutions provide the same level of performance for operation. The unit costs in each case varies across projects and may be estimated between €0,5 million and €2 million per kilometre in most cases.

Additional components of infrastructure costs, such as the unit cost of turnouts, electrification, communications, signalling or security systems can be also obtained from existing HSR projects around the world, but they notably differ across countries. In Spain, for example, the average cost of these elements is usually in the range of €2.0

[7] Although they notably differ across countries depending on their legal framework, the average land acquisition costs, estimated on the basis of previous high-speed projects in Spain and classified according to the type of land vary between €2.5 per square metre for non-urban land and €75 for urban terrains (García Álvarez, 2016).

[8] High speed stations are necessarily few to increase commercial speed. However, this does not mean that they all should become an (expensive) 'architectural' reference for each city (ECA, 2018).

[9] See González Franco (2015), for example. There are also reference values included in ADIF investment guidelines, as reviewed in **Annex A**.

to €2.5 million per kilometre, except for very rough stretches where, from higher speeds, they are close to €3 million.[10] In general, and individually considered, each of these elements usually represents between 5% and 10% of the total investment. Other minor items (supervision, quality control, etc.) may represent between 1% and 5% of total investment.

4.1.2. Estimating the costs of operating and maintaining a high-speed line

Once the infrastructure has been built, the operation of HSR services involves two types of costs: those related to the operation and maintenance of the infrastructure itself, and those related to the provision of transport services. The degree of vertical integration existing between the infrastructure manager and the firm(s) that provides rail transport services determines which one is responsible for each of these costs and may vary across countries, making comparisons always difficult.

The first cost category includes labour, energy and materials expenses associated with traffic management and the operation and maintenance of the guideways, terminals, stations, signalling and other auxiliary systems. Some of these costs are fixed and depend on operations routinely performed in accordance with technical and safety standards. In other cases, such as in track maintenance, the cost is determined by traffic intensity, which reflects the wear associated with the vertical forces supported by the track and its deformations due to excessive settlement of embankments or damage to structural elements. Therefore, these costs will be conditioned by the traffic that supports the line (number of *Trains* per year) and in the case of high-speed in Spain, has been estimated for example (in euros per kilometre) as:

$$C_{TRACK} = 5.920 + \left[(TrainCost) \times 0.0034 \times (Trains) \right],$$

where the *TrainCost* parameter ranges between €0.22 and €0.40 per train-km according to the train model. The maintenance cost functions for turnouts follows a similar pattern, since the wear generated by the trains on these elements also depends on the traffic volume. Although there are different types of turnouts depending on the speed of entry and exit, an average estimate for Spain can be provided for example by:

$$C_{TURNOUTS} = 30.154 + \left[(TrainCost) \times 0.0119 \times (Trains) \times (Turnouts / km) \right],$$

where the *TrainCost* parameter now ranges between €0.06 and €0.11 per train-km depending on the specific train model. The maintenance costs functions for the signalling and safety systems can be also approximated using similar fixed and variable

[10] See Martín Cañizares (2015).

costs functions, whereas for stations, their costs are proportional to its size and intensity of use. In general, most of these infrastructure operation and maintenance activities require specialized personnel and labour costs usually account for about 50% of total costs. In sum, and according to UIC (2018), the average operation and maintenance of one kilometre of new high-speed line costs can be estimated in €90,000 per year.

With respect to the costs associated with the provision of HSR services, they can be divided into three main categories: acquisition of rolling stock, operation and maintenance of rolling stock (mainly, labour costs) and overheads.[11] In order to estimate the provision of train services required to meet the expected demand, the assessment process should rely on an *operating plan* that defines how the new line will be operated. To dimension the train fleet, it is not only necessary to know the annual demand of the line, but also whether the technical characteristics of the trains make them capable to operate within the specific construction parameters of the line. The *operating plan* must therefore determine two aspects: the number of trains required each year (including the replacements) and their type (in terms of capacity, maximum speed, architecture, power, traction, gauge width, axle weight, signalling system, etc.). In Europe, the acquisition costs range between €40,000-80,000 per seat, although the reported price for a 350 trainset may reach €30-35 million, according to UIC (2018). Technical factors such as composition, mass, weight, power, traction, tilting features or internal configuration may affect this average price.

Deciding the number of trains on a particular corridor requires estimating the daily demand in each direction using annual and monthly estimates, once corrected by seasonality coefficients in order to avoid service disruptions and minimize idle capacity. Then, it is relatively simple to calculate the number of services per direction by dividing daily demand over the number of seats on the train multiplied by the target load factor set by the operator (usually between 90-95%, although sometimes a lower percentage such as 70% may be acceptable). From the daily services, the frequency and the number of trains for a basic service can be easily obtained from simple calculations, adding a number of extra trains (contingency factor) for replacing those in maintenance, rotations, repositioning or breakdowns.

Regarding the rolling stock operation costs, the unit costs estimates change in accordance to the operating plan of the line. In Spain, the values range from 0,02€ to 0,09€ per seat-km depending on the model and the commercial speed.[12] In UIC (2018) the maintenance of a high speed train (with an annual average usage of 500,000

[11] This final component is difficult to generalize. It includes sales and administration costs and, in some projects, it is estimated at around 10% of the passenger-trip revenue (Campos and de Rus, 2009).

[12] See González Franco (2015).

kilometres) is estimated in €2 per kilometre, which yields €1 million per year. This amount, however, does not include energy consumption and other operating costs, which may increase this amount by tenfold.

4.2. Suburban rail projects

In contrast to high-speed projects, which generally consist of the construction of a new line that totally or partially replaces conventional rail and aims to compete against road and air transport, suburban rail projects present a greater diversity of typologies. In general, they typically include interventions on intercity rail markets over distances of less than 75 km, either consisting on minor improvements of existing infrastructures or in larger greenfield developments that involve new stations and/or new services. According to ADIF (2018), they include the greenfield building of new lines and layout variants (whose assessment share several common features with HSR projects), but also the construction of additional tracks on existing lines (track splitting, building of a third or fourth track), the construction of new stations, terminals and/or car parks on existing lines (including freight terminals, park & ride facilities or public transport interchanging stations), track renewal, refurbishment of existing stations, re-electrification or improvement in security or communication facilities, new tunnels or viaducts and even the suppression or protection of level crossings to reduce accidents.[13]

In the case of greenfield suburban projects, and provided that the minimum demand thresholds (see **Section 3**) are met, they may require the execution of a series of investments to adapt the pre-existing infrastructure to the new needs. The decision to bring the suburban line into service may entail the construction of new stations to improve the accessibility. Evidently, the cost of a new commuter station is directly related to its estimated demand which, in turn, will condition its size. In Spain, the range of construction costs can be estimated using as a reference the *Infrastructure Plans of the Barcelona and Madrid Suburban* centres carried out by the Ministry of Public Works in 2009 and 2018, respectively. In the case of Barcelona, the construction of five new stations on the network was programmed with a unit cost of between €7-17 million,

[13] In Spain, *Cercanías* (suburban) services are only 30 years old, since the public operator, *Renfe*, did not create a commuter unit until 1989, around the metropolitan areas of Madrid and Barcelona. Suburban services in 12 additional areas were later implemented, increasing frequencies, commercial speed and capacity provision. In recent years, several strategic investments have been undertaken in the Spanish network to favour suburban services. However, since they are based on the existing Iberian gauge (1.668m), as opposed to the standard or international gauge of 1.435m for HSR, they compete for funding with medium and long distance services, with whom infrastructure, rolling stock and planning criteria are shared.

at an average of €11 million per station. In Madrid, the construction of four new stations has been set at €37 million, with an average cost of €9 million per station. [14]

However, in the implementation of suburban services is usually more common to assess projects related to the rehabilitation or renovation of existing stations. These projects require a series of specific actions depending on each case and, consequently, the refurbishment costs may vary significantly. Again, using Spain as a reference, it is possible to obtain an average cost per station from the most recent projects in Barcelona and Madrid. In the first case, a total investment of €394.5 million was estimated for the modernization of 84 stations of the network, with an average cost of €4.7 million per station. Similar figures correspond to Madrid, where an investment of €350 million was estimated for the renovation of 88 stations, with an average cost of €4 million per station.

Finally, it should be noted that in order for suburban rail services to be integrated with the pre-existing network, it will be necessary to interconnect them with other lines or the urban public transport network, including the metro, tram, regional railways or bus stations. Therefore, interchange stations are essential to reduce transfer times and increase the area of influence of destinations. Sometimes, the execution of interchange stations is very expensive due to the difficulty of connecting two or more railway networks at different levels or the need to provide the necessary road infrastructure to build an intermodal node. In general, the average cost of such facilities ranges between €35 and €55 million but it heavily depends on the network complexity.

With regard to suburban rail projects related to changes in the operating conditions of the services, the calculation of the number of daily services must take into consideration that in order to meet the 'global efficiency and sustainability' requirements stated in **Section 3**, there must be a minimum of 30-40 services per day per direction. The maximum number of services on a line would be around 100 per direction, which would mean one train every 10 minutes throughout the day, which would correspond to large urban agglomerations.

The specific frequency (which may differ along the day and on weekends) depends on the estimated demand and the number of stations. The denser and longer the line, the higher the frequency, although, shuttle or semi-direct services may be usually

[14] In addition to its size (demand), the cost of building each station is determined by its specific location, the functional characteristics and land costs. According to data from the Ministry of Transport, Mobility and Urban Agenda, land prices in Madrid or Barcelona are between 10 and 30% higher than in other Spanish cities with significant suburban transport networks such as Valencia, Bilbao or Seville, which may serve as a correction factor for this estimate.

interpolated at peak times or on a regular basis. The location of the stations is also relevant. In general, due to network effects central stations have larger demand than those located on limited branches. In any case, account should also be taken of the volume of economic activities, their seasonality and the existing employment in the area of influence of the suburban project, as well as the provision of services offered by other transport modes. Taking into account all these variables, the procedure for estimating the number of trains is quite similar to that described for HSR lines.

The acquisition costs of suburban rolling stock in Spain is difficult to estimate after more than a decade of the last significant purchase of rolling stock for commuter trains by *Renfe*. However, it has recently announced the decision to carry out a tender for the purchase of 211 high-capacity trains for the large suburban centres, for an amount of 2,270.5 million euros. Of these 211 trains, 176 of them will be 100 meters, while another 35 will reach 200 meters. Taking these figures as a reference, the average cost of acquiring a commuter train would be €10.75 million per train.

With respect to the operating and maintenance costs of suburban lines, the lack of data disaggregation as published by *Renfe* and ADIF makes it difficult the possibility of carrying out a detailed analysis of the costs of operating these services, and of operating and maintaining the corresponding railway infrastructure. However, in a recent report (Ministerio de Fomento, 2017), the total costs of operating the suburban services operated by *Renfe* were globally estimated at €607 million (in euros of 2019) during 2015. This means that, if this amount is divided by the number of trains-km offered on the 2015 commuter services, a unit cost of €14.15 per train-km is obtained. However, these costs also include the payments made by the *Renfe* to ADIF, as access fees and service costs for the use of the network so that the figure corresponds to both the cost derived from the operation and maintenance of the network and the cost of operating the commercial service. According to Vasallo *et al.* (2017) and additional information from the Ministry of Transport, Mobility and Urban Agenda, the unit cost can be further broken down into a unit network maintenance cost of €6.28 per train-km and €7.87 per train-km corresponding to suburban operating unit costs.

5. COST-BENEFIT ANALYSIS OF HIGH-SPEED RAIL PROJECTS

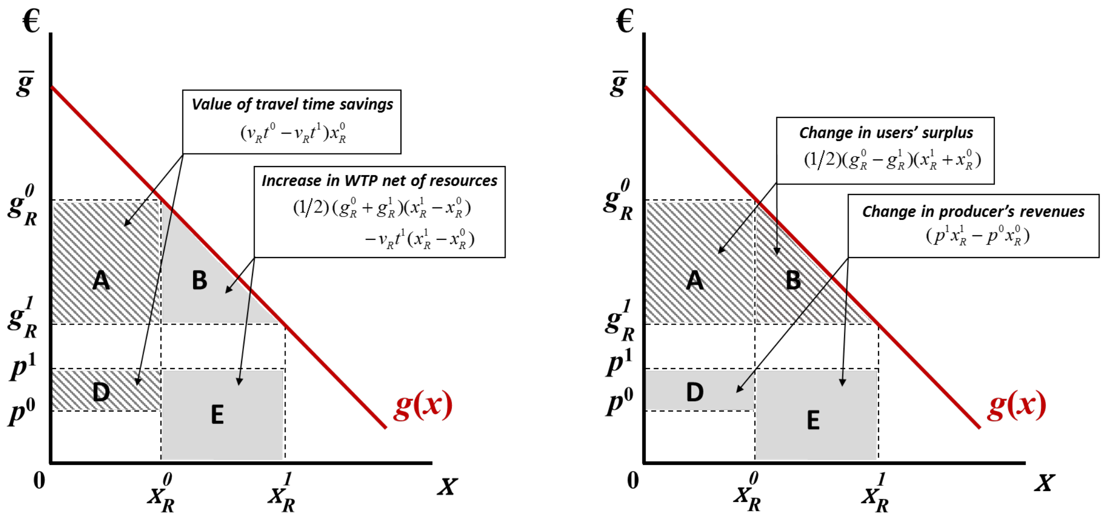
From an economic point of view, a transport market in equilibrium can be interpreted in two different, but equivalent, ways. On one hand, it can be seen as a particular allocation of resources associated with the transport activity performed by the interaction of different stakeholders (government, infrastructure managers, transport service producers, users and the rest of the society), whose results can be measured in terms of (generalized) prices and levels (and quality) of service. On the other hand, the distribution of these results implies gains and/or losses for each these social agents, which can be in turn measured in terms of the surpluses obtained by each group. If a rail transport project (e.g. building a new line) is then defined as an exogenous perturbation in the initial equilibrium (as compared to the corresponding counterfactual), the assessment of its welfare effects can be correspondingly addressed from two different, but equivalent, approaches: by identifying and measuring the changes in the use of existing resources and the willingness to pay (*WTP*) of the new users, or alternatively, by identifying and measuring the changes in the surpluses of each of the relevant group of social agents.

5.1. Measuring changes in social welfare

To illustrate these ideas,[15] consider a transport project consisting in constructing and operating a new HSR line to replace an existing conventional rail service, as depicted in **Figure 5.1**, where $g(x)$ represents a linear estimation of the inverse demand function in the rail market in terms of the users' generalized price, that is, $g = p + vt$, where p represents monetary prices, v is the value of travel time and t is total travel time. To simplify the analysis, the investment and operating costs have not been represented. The initial equilibrium ('without-the-project') is given by (g_R^0, x_R^0), where g_R^0 represents the generalized price for conventional train users: $g_R^0 = p^0 + v_R t^0$, with p^0 and t^0 denoting the conventional train monetary price and total travel time, respectively, and v_R is the value of time for rail users. x_R^0 is the existing rail demand. Assuming that the project implies a reduction in the generalized price $(g_R^0 > g_R^1)$ due to a significant reduction in travel time ($t^1 < t^0$) that compensates the fact that HSR services are more expensive than the price of conventional rail services ($p^1 > p^0$). Note that $(x_R^1 - x_R^0)$ represents the generated demand of the new rail service.

[15] This section is based on the general model already presented in **PART I**.

Figure 5.1. Changes in social welfare associated with existing and generated demand in the rail market

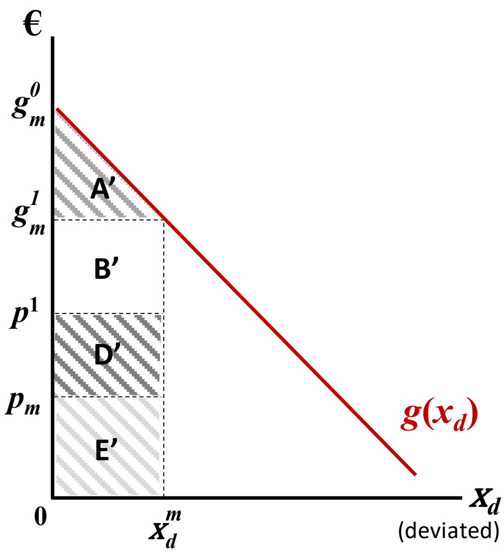


For each of the years within the evaluation horizon, the welfare effects of this HSR project (denoted as ΔW) can be firstly measured through the changes in the use of resources and the changes in the willingness to pay for the new trips, as depicted on the left panel of **Figure 5.1**. Assuming that the willingness to pay of existing traffic has not changed, the value of their time savings can be considered as a positive change in resources, as defined by **areas A + D**, and calculated as $(g_R^0 - g_R^1)x_R^0 + (p^1 - p^0)x_R^0$ or, equivalently, $(v_R t^0 - v_R t^1)x_R^0$, whereas the increase in the users' willingness to pay for the new trips (net of the time they spend on these trips) is given by **areas B + E**, or $(1/2)(g_R^0 + g_R^1)(x_R^1 - x_R^0) - v_R t^1 (x_R^1 - x_R^0)$. Therefore, for the existing and generated demand in the rail markets, we have that the increase in social welfare (disregarding all investment and operating costs that will be considered latter on) is given by:

$$\Delta W_R = (v_R t^0 - v_R t^1)x_R^0 + \frac{1}{2}(g_R^0 + g_R^1)(x_R^1 - x_R^0) - v_R t^1 (x_R^1 - x_R^0). \quad \textbf{(5.1)}$$

We may now analyse the effects of the project on other competing transport markets using **Figure 5.2**, where x_d represents the deviated demand from each of the other relevant modes in this corridor (car, bus, air transport, for example), and g_m^0 represents the generalized price for the users of the alternative transport mode: $g_m^0 = p_m + v_m t_m$, with p_m and t_m denoting the alternative transport mode monetary price and total travel time, respectively, and v_m is the value of time for these users. Defining the indifferent user of alternative transport mode *m* as the user whose total travel time (that includes access, egress, waiting and in-vehicle time) is such that $g_m^0 = p^0 + v_m t^0$, all those users with higher total travel time than the indifferent user decide to travel on the alternative transport mode. Once the new HSR service is introduced, the generalized price is reduced to $g_m^1 = p^1 + v_m t^1$ and, due to this reduction, x_d^m represents the deviated demand from mode *m* to the rail market. The new indifferent consumer is such that for the new generalized price $g_m^1 = p_m + v_m t_m$.

Figure 5.2. Changes in social welfare associated with deviated demand



The net benefit associated with the HSR line is then given by the total willingness to pay of the deviated users, that is, **area A' + B' + D' + E'**, minus the time they invest in the new mode (**area B'**). We consider that all other modes are competitive, and their marginal costs correspond to their respective initial prices. For this reason, the benefits from deviated demand comes from time savings of those deviated users from mode *m* (**areas A' + D'**)[16] and resources saved from the operator of this mode (**area E'**). Therefore, for the deviated demand of the mode *m*, we have that the increase in social welfare (disregarding the HSR operating costs of this deviated demand, that will be considered latter on) is given by:[17]

[16] Note that time savings of deviated users (represented by **areas A' + D'**) is different that $(1/2)v_m(t^0 - t^1)x_d^m$ unless $p_m = p^1$.

[17] As indicated by Nash (2014), it is not straightforward to estimate the effects on other modes associated to improving rail services. The consequence is not only traffic diversion but the changes in capacity usage, external costs and commercial strategies in the other modes. Since many of these effects have opposite signs, the assumption 'price equals marginal costs' just simplifies the analysis, assuming that most of these consequences cancel out each other.

$$\Delta W_d = \frac{1}{2}(g_m^0 + g_m^1)x_d^m - v_m t^1 x_d^m . \quad \textbf{(5.2)}$$

The second procedure to identify and measure the welfare effects of a HSR investment project consists of estimating the changes in the surpluses of all the social agents involved in this project. This approach is useful to analyse how the social benefits and costs of the project are distributed across different stakeholders, making transfers explicit (including taxes and without shadow price adjustments) and providing a first glance at who wins and who losses as a result of the project.[18] Since all changes in surpluses are finally added together, the transfers net out and the overall result in terms of social welfare will be equal to the one obtained through the changes in resources and willingness to pay approach.

To illustrate this idea, we can use the right panel of **Figure 5.1**, which represents again what happens in the rail market. The change in the surplus (Δ*CS*) of the existing and new users associated with the reduction in the generalised price from g_R^0 to g_R^1 is respectively given by **areas A + B**, or the 'rule of one-half' $(1/2)(g_R^0 - g_R^1)(x_R^1 + x_R^0)$. The change in producers' revenues is defined by **areas D + E**, or $(p^1 x_R^1) - (p^0 x_R^0)$. Taxpayers' surplus (Δ*GS)* is not represented either. It would include the taxes paid by users, as the difference between seller and buyer prices, and the taxes paid by producers over their production factors. Revenues must be therefore computed net of taxes and transfers between different agents must be now made explicit. The change in workers' surplus (Δ*WS*, not represented, and assumed to be zero) would include the adjustments between what they receive and their private opportunity costs according to their initial occupation,[19] whereas the externalities should be estimated and quantified through the changes in the surplus of the rest of society (Δ*RS*). Therefore, for the existing and generated demand in the rail markets, we have that the increase in social welfare (disregarding all investment and operating costs that will be considered latter on) is given by:

$$\Delta W_R = \frac{1}{2}(g_R^0 - g_R^1)(x_R^1 + x_R^0) + (p^1 x_R^1 - p^0 x_R^0) . \quad \textbf{(5.3)}$$

With respect to what happens in other transport markets, **Figure 5.2** shows that the change in deviated users' surplus is now given by **area A'**, and the change in HSR

[18] The distinction between different agents does not mean that they are the final beneficiaries of the transport improvement. The existence of fixed factors, such as land, though it does not change the value of the final result of the project, may completely modify the distribution of the social surplus.

[19] See **PART I** for an in-depth discussion of this idea.

producer's revenues by **areas D' + E'**, that is, $p^1 x_d^m$. Under the simplifying assumption that there is competition in all other modes, the change in their producers' surpluses is zero:

$$\Delta W_d = \frac{1}{2}(g_m^0 - g_m^1)x_d^m + p^1 x_d^m. \qquad \textbf{(5.4)}$$

As expected, both approaches lead to the same result in term of the corresponding resulting areas, as well as in terms of their analytical expressions: the sum of **(5.1)** + **(5.2)** is equal to **(5.3)** + **(5.4)**.

The change in the operating and investment costs (not represented in previous figures), (C^0 – C^1) completes the total change in social welfare, where C^1 corresponds to the costs of the HSR for existing, generated and deviated demand, and C^0 to the (avoided) costs of conventional train.

It is quite important to note that, when changes in social welfare are measured using the methodological approach based on changes in the use of resources and in the willingness to pay, internal payments that represent transfers between different agents (e.g. access charges paid by operators to infrastructure managers) are cancelled out and all prices and costs must be then valued at their social opportunity costs. This implies, for example that costs must be computed net of taxes (when the input supply is perfectly elastic) and that labour (and other input) costs must be corrected according to their shadow price, when applicable.[20] Moreover, changes in external costs are also assumed to be included in (C^0 – C^1).

Alternatively, when the increase in social welfare is measured using the changes in the surpluses of different agents, prices for producer surplus must be valued net of taxes, costs must be computed with taxes and, in general, there is no correction for shadow pricing. Moreover, changes in external costs are excluded from the producer's costs and are included in the rest of society surplus (ΔRS).

Taking into account all these considerations, the change in social welfare measured by both approaches coincides:

$$\begin{aligned}\Delta W &= \Delta CS + \Delta PS + \Delta WS + \Delta TS + \Delta RS = \\ &= \Delta WTP - \Delta Resources,\end{aligned}$$

[20] See **PART I** for further details on this issue.

and they both can be used to calculate the *social net present value* (NPV_S) of the project by adding the discounted changes in social welfare over the evaluation period ($h = 1 \dots T$) using the corresponding social discount rate (r):

$$NPV_S = \sum_{h=0}^{T} \frac{\Delta W_h}{(1+r)^h}.$$

In any case, it should be underlined that once one of the methods is chosen, it is necessary to be consistent with it: incorrect use of any of them easily leads to double counting. In most cases the decision depends on the degree of disaggregation of the available information and, for that reason, the change in willingness to pay and resources approach is more common in practice. However, the sum of net surpluses always makes it easier to identify who (in principle) wins and who loses with the project.

Finally, when only the stream of revenues (px) and producers' costs (cx) are considered, from the point of view of producer surplus, the financial profitability of the project is given by the *financial net present value*(NPV_F):

$$NPV_F = \sum_{h=0}^{T} \frac{\Delta PS_h}{(1+r_f)^h},$$

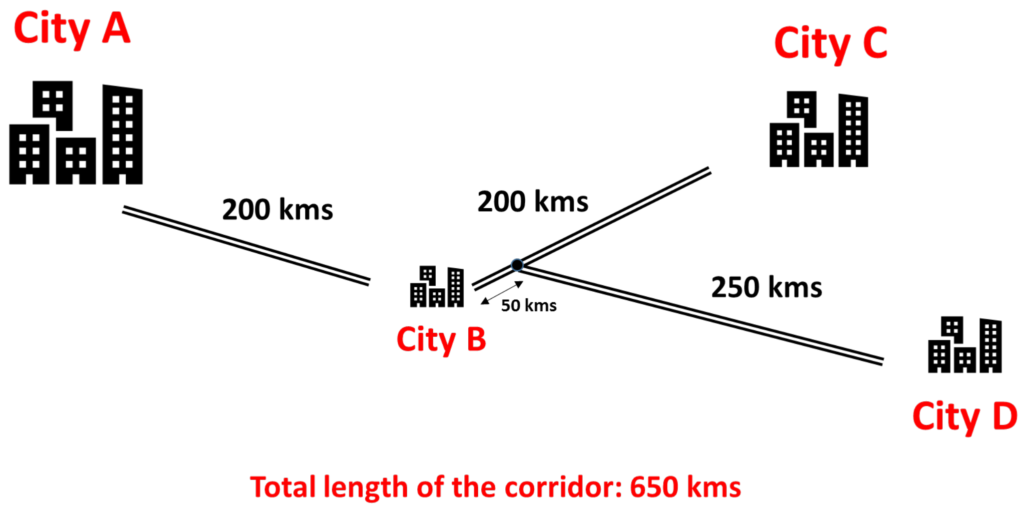
where r_f represents the financial discount rate.

5.2. The cost-benefit analysis of a new high-speed rail line in practice

In this section we provide a practical illustration of the methodology by evaluating a rail project consisting in constructing and operating a new high-speed rail line connecting three large cities (*A*, *C*, and *D*), with one shared intermediate stop at smaller city *B*. The total length of the network, 650 kms, can be divided into five (sub)sections, as depicted in **Figure 5.1**, {*ABC* (400 kms), *AB* (200 kms), *BC* (200 kms)*, ABD* (500 kms), and *BD* (300 kms)}, and there four alternative modes (air transport, buses, cars and conventional train) that currently provide their services on them. After the construction of the HSR line, the conventional train services will be discontinued. Infrastructure and HSR services will be managed and operated by two different companies.

We assume that the construction of subsections *AB* and *BC* starts in the beginning of the year 2020 and lasts 5 years, and therefore the full section *ABC* starts operating at the beginning of year 2025. The construction of subsection *BD* starts in 2025 and takes 3 years, so that the full section *ABD* is operative at the beginning of 2028. We will perform an *ex ante* CBA by estimating the NPV_S of this project evaluating all monetary magnitudes in euros of 2019, with an evaluation horizon of 50 years (2020-2069) and using a social discount rate of 3%.

Figure 5.3. Project description: a tale of four cities



The project will be compared against a 'do-nothing' alternative, where the described corridor continues to be served by the four initial modes. To do so we will make the suitable assumptions about costs and demand parameters, as described below. To the extent that more reliable or disaggregated information becomes available, it should be used to replace or complete these assumptions, especially in cases of *ex-post* CBA.

5.2.1. Assumptions about costs and demand parameters

As described in the previous sections, the costs of building and operating a new HSR line can be grouped into four major items. First, *Infrastructure construction costs,* that include planning and expropriation of land, construction works (including materials and labour), as well as the construction of stations. Although these values depend on the specific characteristics of the project (orography, land value, etc.), for the purposes of the example in this section, we will assume an average construction cost of 15,000,000 euros per km, in line with recent suggestions by UIC (2018). Thus, the total construction costs of the project (650 kms) amount to 9,750,000,000 euros, that will be accordingly distributed during the construction years (2020-2027) according to the following percentages: 10%, 10%, 20%, 20%, 15%, 10%, 10% and 5%. We will assume that, after 50 years, and due to technical obsolescence, the residual value of the infrastructure is zero.

Infrastructure operation & maintenance costs are also estimated using an average value of 100,000 euros per km, once each network section starts operating. Again, this average value is in line with UIC (2018) suggestions. It includes several components (electrification, signalling systems, track characteristics, weather conditions, etc.) that may vary depending on the intensity of operations and the characteristics of the rolling stock.

Rolling stock acquisition costs are estimated for this exercise using a unit value of 30,000,000 (in 2019 euros) for a single-model train of 350 seats with an economic life of 30 years (UIC, 2018). Again, this single model assumption is used for the sake of simplicity, since there are many trainset alternatives and, of course, different ones can be combined within the same HSR line. Finally, *rolling stock operation & maintenance costs* are estimated as 10,000,000 (in 2019 euros) per train and year, as suggested in Campos *et al.* (2009).

We have assumed a constant VAT rate of 20% during all the evaluation horizon for all the relevant markets.[21] With respect to the shadow price of labour, we have finally assumed an average value of one, as a weighted estimation of an unemployment opportunity costs of less than one (as in the shadow wages estimated by Florio *et al.*, 2011) and a higher than one value for diverted labour from the rest of the economy (considering the lost value of the marginal productivity of labour in the private sector, taking into account, for example, indirect taxes or social security contribution paid by employers), as discussed in **PART I**. Costs are assumed to grow in real values according to the real income growth rate, assuming a cost-income elasticity equal to one. All the annual cost parameter assumptions are finally summarized in the following table.

Table 5.1. Cost parameters assumptions

Parameter	Value	Unit
Infrastructure construction costs	15,000,000	€ /km
Infrastructure operation and maintenance costs	100,000	€ /km
Rolling stock acquisition costs	30,000,000	€ /train
Rolling stock operation and maintenance costs	10,000,000	€ /train

With regard to the demand parameters, we need an estimate of the total number of users in the corridor and of the modal split 'with-the-project' for each of the five sections described in **Figure 5.3** during each of the years included in the evaluation horizon. This estimation can be addressed according to different procedures, as described above, and faces an unavoidable degree of uncertainty. In this example, it would be arbitrary to

[21] We have considered that all non-labour costs are national, non-diverted from other economic activities, and subject to the same indirect tax rate.

assign any demand volume to the line. On the contrary, it is more informative to reverse the process and instead of estimating the demand and then the corresponding net present values of private and social benefits and costs, to calculate the *minimum demand* that makes NPV_F and NPV_S equal to zero and discuss their implications for the project. In particular, we will calculate the *minimum demand* requirements corresponding to the first year of operation in each section and, after that, assume that the demand will grow at the same rate that real income, with a demand-income elasticity of one. For the purposes of this exercise, the average real income annual growth rates from 2019 to 2025 have been approached from IMF estimates for the Spanish GDP, whereas for the rest of the life time of the project we have assumed decreasing rates of demand growth in order to consider demographic changes and the empirical evidence on existing HSR lines.

The demand estimation for the HSR line is completed assuming an exogenous modal split summarized in **Table 5.2**, where it is considered that air transport services only operate in sections *ABC* and *ABD* (i.e., city *B* has no airport) and, in subsection *AB* there is no diverted demand from the bus.

Table 5.2. HSR demand by origin and section

HSR demand	***Section ABC***	***Section ABD***	***Subsection AB***	***Subsection BC***	***Subsection BD***
…diverted from air transport	30%	40%	0%	0%	0%
…diverted from the bus	10%	10%	0%	10%	10%
…diverted from the car	25%	10%	40%	20%	20%
…diverted from conv. Train	25%	35%	55%	65%	65%
Generated demand	10%	5%	5%	5%	5%

For each of the five modes (including HSR), **Table 5.3** summarizes travel times for each section, disaggregated into three main components: access/egress time, waiting time and in-vehicle time. The different values of travel time have been calculating for each mode using HEATCO (2006) values and assuming different travel motive distributions (between business, commuting and other motives) in the long sections (ABC + ABD) and in the shorter ones (AB + BC + BD). We have also assumed waiting times of 20 minutes for all modes (40 minutes for air transport), access/egress times of 40 minutes (ABC + ABD) and 30 minutes (AB + BC + BD), with 75 minutes for air transport. In the case of car, we have assumed these times to be zero. These values, summarized in **Table 5.4**, will be used to calculate time savings. According to European Commission (2015), a waiting time and an access/egress value of time correction factor of 1.5 with respect to in-vehicle time has been assumed, as well as that these values grow over time according to the evolution of real income, with an elasticity of 0.5.

Table 5.3. Travel time by mode and section

(in hours)	*Section ABC*	*Section ABD*	*Subsection AB*	*Subsection BC*	*Subsection BD*
HSR					
Access/egress time	0.66	0.66	0.50	0.50	0.50
Waiting time	0.33	0.33	0.33	0.33	0.33
In-vehicle time	1.80	2.37	0.90	0.92	1.53
Air transport					
Access/egress time	1.25	1.25	-	-	-
Waiting time	0.66	0.66	-	-	-
In-vehicle time	1.08	1.42	-	-	-
Bus					
Access/egress time	0.66	0.66	0.50	0.50	0.50
Waiting time	0.33	0.33	0.33	0.33	0.33
In-vehicle time	4.25	5.00	-	3.25	2.75
Car					
Access/egress time	0	0	0	0	0
Waiting time	0	0	0	0	0
In-vehicle time	3.52	4.00	1.73	2.27	3.23
Conventional train					
Access/egress time	0.66	0.66	0.50	0.50	0.50
Waiting time	0.33	0.33	0.33	0.33	0.33
In-vehicle time	4.00	5.00	2.00	2.00	3.00

Table 5.4. Value of travel time by mode

(in euros 2019 per hour)	*In-vehicle time*		*Access/egress time*		*Waiting time*	
Sections	*ABC ABD*	*AB BC BD*	*ABC ABD*	*AB BC BD*	*ABC ABD*	*AB BC BD*
Air transport	30.96	–	46.44	–	46.44	–
Bus	9.53	10.07	14.30	15.10	14.30	15.10
Car	15.90	17.98	23.85	26.97	23.85	26.97
Conventional train	15.90	17.98	23.85	26.97	23.85	26.97

In order to complete the basic assumptions of the model we need to estimate prices and unit costs for each of the modes and sections of the network. In the first case, as showed in **Table 5.5**, we have relied on assuming a single exogenous (average) monetary price for each air transport, bus, and rail passenger compatible with real projects on comparable distance. In the case of car users, however, the estimation operating costs has followed a more disaggregated approach, taking into account its components (in terms of fuel, lubricants, repairs, insurance, and so on), the fact that some of these face different taxes (for example, fuel), and the average number of occupants (1.7). For the remaining unit avoidable costs, we have simply converted them into shadow prices assuming a tax rate of 10%, as showed in the table. The resulting values are comparable to real examples in the Spanish case (see Betancor and Llobet, 2015).

Table 5.5. Prices and unit costs by mode and section

(in euros 2019 per passenger-trip)	*Section ABC*	*Section ABD*	*Subsection AB*	*Subsection BC*	*Subsection BD*
Prices					
HSR	40.00	40.00	20.00	20.00	20.00
Plane	100.00	100.00	-	-	-
Bus	30.00	35.00	-	18.00	20.00
Car	62.45	74.95	30.34	35.69	53.53
Conventional train	30.00	30.00	15.00	15.00	15.00
Avoidable unit costs					
HSR	-	-	-	-	-
Plane	90.00	90.00	-	-	-
Bus	27.00	31.50	-	16.20	18.00
Car	43.37	52.04	21.07	24.78	37.17
Conventional train	27.00	27.00	13.50	13.50	13.50

5.2.2. Benefits and costs calculations

Once the main parameters of the evaluation have been stated, in this section we briefly describe the methodology used to calculate the benefits and costs to be used in the CBA. As described in expressions **(5.1)** and **(5.2)** above, the approach based in the changes in resources and in the willingness to pay of new users allows us to obtain – for each section and year – the following benefits:

1. …the money *value of time savings* for conventional train users and for deviated passengers (from air transport, bus and car). These savings are calculated with respect to HSR travel time, adding the changes in access/egress time, waiting time and in-vehicle time, according to **Table 5.3**. The corresponding values of time are those in **Table 5.4**, which are assumed to grow over the evaluation horizon according to the variation of real income,

2. …the *savings in operating costs* associated with conventional train users and deviated demand from other modes, multiplying the corresponding traffic figures by the unit costs,

3. …the willingness to pay for the new services of generated traffic (net of resources), according to the generalized prices (g) per mode and section for each year. Thus, for mode m, this is given by

$$g_m^0 = p_m + {}^{access}v_m \cdot {}^{access}t_m + {}^{wait}v_m \cdot {}^{wait}t_m + {}^{in}v_m \cdot {}^{in}t_m \,,$$

for the 'without-the-project' situation, where p_m represents the monetary price of the initial mode, and the other components represent the value of access, waiting and in-vehicle time, respectively.

For the 'with-the-project' case, the corresponding definition would be:

$$g_m^1 = p^1 + {}^{access}v_m \cdot {}^{access}t^1 + {}^{wait}v_m \cdot {}^{wait}t^1 + {}^{in}v_m \cdot {}^{in}t^1 \,,$$

where prices are expressed without taxes.

With respect to the costs, the annual investment (net of taxes) is obtained by distributing the total investment during the construction period. A similar tax correction should be performed to obtain the annual infrastructure operating and maintenance costs, which are calculated by multiplying the unit costs by the number of kilometres in operation each year.

In order to determine rolling stock costs, the number of trains bought every year and the size of the fleet must be first calculated. To do so, we first obtain the daily demand (one way) for the whole network (assuming 365 days of operation) and then the number of required daily services, given by

$$DS = \frac{Daily\,demand}{Seats \times Load\ factor} \,,$$

where the (target) load factor (defined as the ratio of seats-km over passenger-km) is set at 70% on average. Assuming a maximum of 16 hours of operation per day, the (minimum) number of required trains to meet the demand results from

$$Trains = \frac{2 \times (t_{HSR} + t_{ST})}{16} \cdot DS \,,$$

where t_{HSR} represents the total travel time in the section (that is, only in section *ABC* until 2027, and the average of network sections *ABC* and *ABD* from 2028 onwards) and t_{ST} is the time between trains (e.g. 0.5 hours). The number of trains obtained from the previous expression defines a basic service. Both contingency factors (to avoid disruptions due to breakdowns or periodical maintenance) and the existence of technical limits (for example, a maximum number of kms for train and year) imply that the final number of trains could be larger. We assume that they are bought the year they are needed and replaced when they reach their maximum economic life of 30 years. Once the number of trains is known, the acquisition and operation and maintenance costs are calculated straightforwardly from the references in **Table 5.1**, although their values should be corrected (shadow prices).

Alternatively, when social benefits and costs are calculated using the methodological approach based in the social agents' surpluses, the changes in users' surplus for each network section and year must be obtained using expressions **(5.3)** and **(5.4)** for existing and deviated demand, respectively, using tax-included prices. Although these tax revenues are then attributed to taxpayers' surpluses and are cancelled out when all the benefits and costs are aggregated, the separation into different groups allows us to identify the supposed gains and losses of each group. With respect to changes in producers' surpluses, they have been assumed to be zero in all alternative (competitive) transport modes. In the case of rail, they are calculated by the difference between the new revenues for the HSR operator (from the deviated and generated demand) minus the acquisition, operation and maintenance costs of the rolling stock and minus the access charges (which represent a cost for the operator). For the infrastructure manager, its surplus is given by these revenues (the access charges) minus the infrastructure investment and operation costs. In both approaches, external costs savings have been also calculated just considering accident costs savings and congestion costs savings, as described in detail below.

5.2.3. Financial evaluation

Suppose first that we conduct a financial evaluation of this HSR project from the point of view of the rail infrastructure and HSR service operators. In that case, the NPV_F expressed in 2019 euros is defined as:

$$NPV_F = \sum_{h=2020}^{2069} \frac{\Delta PS_h^{INFRASTRUCTURE} + \Delta PS_h^{SERVICES}}{(1+r_f)^{h-2019}}, \qquad \textbf{(5.5)}$$

where r_f is the financial rate of discount (in this case, 4% according to European Commission, 2015). According to the assumptions and parameters already defined, what we are interested at is the value of the initial demand x^1, such that $NPV_F(x^1) = 0$.[22] This value can be estimated using a spreadsheet to calculate the elements in expression **(5.5)** and the resulting minimum demand is approximately 54.4 million passenger-trips. In this case, as showed in **Table 5.6**, the producer surplus of the HSR operator would be negative, but the surplus of the infrastructure manager (net of investment costs) would be positive and compensate it.

[22] We estimate the total demand of the network in the initial year (that is, 2025 for section *ABC* and 2028 for section *ABD*) and distribute it across modes according to the exogenous modal split.

Table 5.6. Financial evaluation: a first result

	Actual values in euros 2019
Δ Producer surplus (HSR operator)	-34,440,947,505 €
Δ Producer surplus (Infrastructure manager)	42,750,057,045 €
Δ Producer surplus (Infrastructure manager)*	-8,309,109,779 €
MINIMUM DEMAND FOR $NPV_F = 0$	**54,469,202 passenger-trips**

* Only investment costs

Note that, since it only includes the surpluses of the rail operators, this result can be interpreted as the financial result from the point of view of private investors or, even from the viewpoint of the public sector when both producers are public firms (although vertically unbundled). However, in this latter case, it may be also useful for the Government to evaluate the project including taxpayers' surpluses, in order to assess the full impact on public finances. In this case, the expression to evaluate becomes

$$NPV_F = \sum_{h=2020}^{2069} \frac{\Delta PS_h^{INFRASTRUCTURE} + \Delta PS_h^{SERVICES} + \Delta GS_h}{(1+r_f)^{h-2019}}, \quad \textbf{(5.6)}$$

and the resulting minimum demand for the first is much higher, well above 137.3 million passenger-trips This is due to the fact that the loss of taxpayers' surplus is increasing in the number of trips.

5.2.4. Economic evaluation

We now turn to the calculation of the NPV_S, which is defined as:

$$NPV_S = \sum_{h=2020}^{2069} \frac{\Delta W_h}{(1+r)^{h-2019}}, \quad \textbf{(5.7)}$$

with a social rate of discount of 3% (according to European Commission, 2015). As discussed, the changes in social welfare can be defined via the changes in resources and willingness to pay or via the changes in the surpluses of the relevant social agents, both approaches yielding the same result.

In both cases, the minimum demand for the first year of operation that makes expression **(5.7)** equal to zero is approximately 6,001,182 passenger-trips, that is, approximately 11% of the minimum demand required in **Table 5.6**. As summarized in **Tables 5.7** and **5.8**, with this demand value, the largest benefits of this project arise from cost savings associated with deviated demand (particularly in the case of air transport and car users), whereas the highest costs (apart from investment) correspond to rolling stock operation and maintenance. From the point of view of surpluses, users deviated from air transport benefit most from the project, as well as the infrastructure manager *before* considering the investment costs. External costs savings (which corresponds to changes in the surplus of the rest of the society) are positive and have been calculated using per pass-km rates obtained from European Commission (2019).

Table 5.7. Economic evaluation: the change in resources and willingness to pay approach

	Actual values in euros 2019
Time savings (conventional train existing users)	3,131,206,209 €
Time savings (deviated from air transport)	-1,484,147,794 €
Time savings (deviated from bus)	425,945,864 €
Time savings (deviated from car)	-501,613,889 €
Costs savings (conventional train existing users)	1,854,227,942 €
Costs savings (deviated from air transport)	6,834,240,236 €
Costs savings (deviated from bus)	657,099,380 €
Costs savings (deviated from car)	2,119,777,856 €
Willingness to pay (generated demand)	1,028,366,340 €
Investment	-7,256,275,030 €
Infrastructure maintenance costs	-1,455,372,473 €
Rolling stock acquisition costs	-721,694,057 €
Rolling stock operation and maintenance costs	-6,456,384,354 €
External cost savings	1,824,622,560 €
MINIMUM DEMAND FOR $NPV_S = 0$	**6,001,182 passenger-trips**

Table 5.8. Economic evaluation: the change in surpluses approach

	Actual values in euros 2019
Δ Users surplus (conventional train)	2,444,455,119 €
Δ Users surplus (air transport)	3,072,012,364 €
Δ Users surplus (bus)	237,492,710 €
Δ Users surplus (car)	663,206,368 €
Δ Users surplus (generated traffic)	321,129,124 €
Δ Producer surplus (HSR operator)	-5,088,632,356 €
Δ Producer surplus (Infrastructure manager)	4,563,104,227 €
Δ Producer surplus (Infrastructure manager)*	-8,638,422,655 €
Δ Producer surplus (conventional train)	0 €
Δ Producer surplus (air transport)	0 €
Δ Producer surplus (bus)	0 €
Δ Producer surplus (car)	0 €
Δ Taxpayer surplus	601,031,329 €
Δ Rest of society surplus	1,824,622,560 €
MINIMUM DEMAND FOR $NPV_S = 0$	**6,001,182 passenger-trips**

* Only includes investment costs.

6. COST-BENEFIT ANALYSIS OF SUBURBAN RAIL PROJECTS

Although suburban rail transport has become a fundamental element for addressing the mobility needs of residents and visitors in large metropolitan areas, there are no particular rules or differentiated criteria for the CBA of this type of transport projects. In most European countries these services are still provided by public monopolies, with subsidized prices, although there are services (for example, lines connecting airports to city centres) that are provided by private operators.[23] The main difference of these projects with respect to, for example HSR projects, probably arises from the fact that transport demand in most suburban contexts is met by a network of different modes (conventional rail, metro, tram and buses) in coordination and/or competition not only among themselves, but also with private transport, taxis and other emerging mobility platforms (ride-sharing services, for-hire vehicles, etc.). The existence of these 'network effects' implies that suburban rail projects must be assessed in connection with the related markets, taking explicitly into account the changes that the project introduces on the travel patterns and modal decisions of the users, as well as other indirect effects in the overall metropolitan area.

6.1. Time savings, accessibility and congestion effects in suburban rail projects

As with other transport projects, one of the main gains associated with improved suburban rail infrastructure, or with better suburban rail services is the saving of travel time. This social improvement appears first in relation to existing rail users, who can benefit from reduced in-vehicle travel time (as discussed in **Section 5.1**) when faster services are introduced. However, a second feature of scheduled rail services provided in network areas is the reduction of users' average waiting time when the frequency (e.g. trains per hour) of services increases as the number of users does. This is the so-called 'Mohring effect', which is a positive externality, whose economic value should be quantified in the project assessment. Finally, a third source of total time savings for existing users may be also associated with building new stations or improving their accessibility elements (for example, enlarging parking facilities). In this case, it is access/egress time what is reduced for existing users.

When analysing accessibility gains in suburban rail projects, it is important not to double count or miscalculate them into other additional benefits. Accessibility refers to the capacity of being reached or accessed by various transportation modes, and changes in accessibility may result into one of the key direct impacts of these projects. However,

[23] In Spain, suburban rail services are operated both by the public national operator (*Renfe*) and by other operators under the control of regional governments. Infrastructure management corresponds to *ADIF*.

and depending on the specific focus of the analysis, most of the economic benefits associated with accessibility improvements are captured via reductions in travel time (due to lower waiting or access times, shorten paths or reduced journeys). Sometimes broader network indicators in terms of the number of available travel options (per day or as the total number of combinations between origins and destinations) may be also used, but they often reflect similar effects. In any case, the evaluation of accessibility changes due to a rail project should not only focus on the total amount of travel time savings but also on whether the changes are balanced or not among different areas. For example, most studies suggest that intercity accessibility improves (due to travel time savings) after the building new suburban stations or extending/enhancing existing commuter lines, but in some other cases the impacts are restricted only to larger and/or most saturated areas.

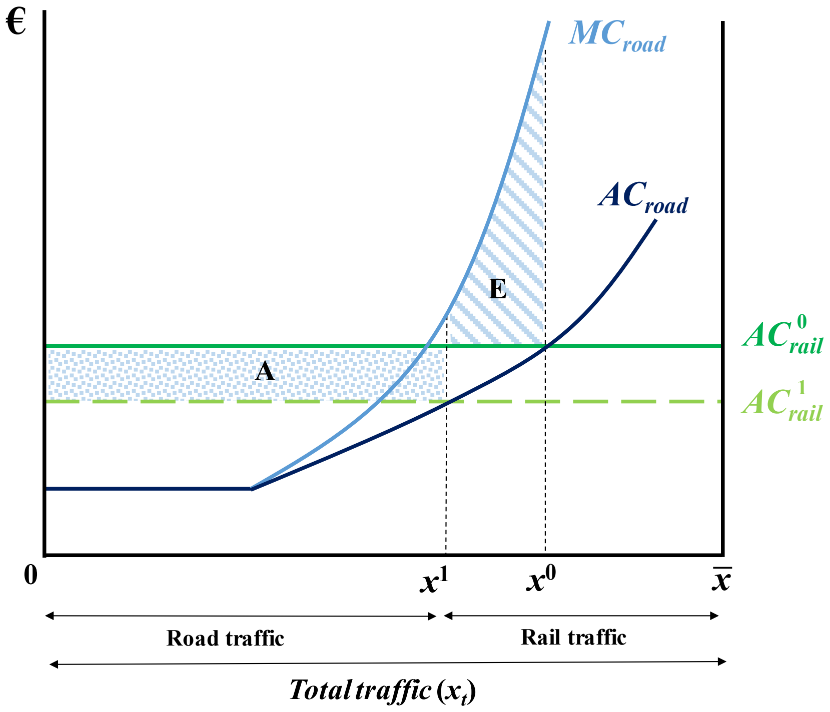
Regarding suburban rail users deviated from alternative transport modes (particularly those diverted from road transport), the value of their time savings (and in fact, the changes in their generalized prices) is calculated in the same way as discussed in **Figure 5.2** with no specific new features associated with the CBA general methodology. However, of particular interest in many rail transport projects in metropolitan areas are their effects on road congestion which, in fact constitute one of the targets of rail investments. Congestion typically appears in the road network of urban and suburban areas as the number of infrastructure users increases and vehicles are progressively delayed when travelling. Slower average speeds and longer queues increase users' travel time and their generalised price, reducing social welfare.

Congestion costs may be reduced when road users change to improved alternative modes, such as new stations or links built for suburban rail. This cost reduction may be temporal or last for few years if road demand continues to grow or if new road users are generated when driving conditions improve. The benefits for the road users due to the project can be estimated as we do with the rest of indirect effects in secondary markets. When the price is equal to the marginal cost (the free flow situation) there is no additional benefit beyond the direct benefits measured in the primary market. However, when there is congestion and the social marginal cost is above the private marginal cost, the reduction of the congestion externality is an additional benefit of the rail project.

The measurement of these indirect benefits is illustrated in **Figure 6.1**, where – for a given transport corridor – the horizontal axis represents the modal distribution of the total number of users each year (x_t) in two alternative transport modes. Road traffic is measured from left to right (and x^0 is the number of road car users 'without-the-project'), whereas from right to left, $\overline{x} - x^0$ is the initial number of rail users. When the traffic flow is lower than the free flow capacity, vehicles' speed is not affected by their mutual interaction, and the average cost of a typical road user (AC_{road}) is constant.

However, once the capacity limit is reached, congestion appears and each additional user imposes additional time to all the remaining road users; as a consequence, the marginal cost is above the average cost, and both are increasing ($MC_{road} > AC_{road}$). On the other hand, there is no congestion for rail users, whose average cost ('without-the-project', AC^0_{rail}) remains constant and equal to the rail marginal cost. The modal equilibrium is initially reached in x^0, where the users' unit costs are equal for both modes.

Figure 6.1. Measurement of changes in road congestion costs



Consider now the implementation of a suburban project (e.g. a new link that shortens travel time), reducing travel time (and all the rail user's unit costs) from AC^0_{rail} to AC^1_{rail}. The new modal equilibrium is now defined by x^1, where $x^1 - x^0$ represents road users deviated to the train. Let us discuss the gains due to the rail project.

The indirect effect of the reduction of road congestion for the remaining users of the road is the time saving benefits relative to the initial situation (**area A** in the figure).[24] These benefits are equivalent to the reduction of the externality represented by **area E**.

[24] Note that congestion costs are calculated in **Figure 6.1** by comparing two equilibria, none of which is an optimal situation. Furthermore, we assume for illustration purposes a fix matrix approach where the total number of users (x_t) does not change with the reduction of the generalized costs. Otherwise, the rule of a half applies for the new users of the road.

6.2. Wider economic benefits and suburban rail projects[25]

The conventional CBA of transport improvements, based on the measurement of the user benefits in the primary market, is enough under the assumption of perfect competition in the rest of the economy, but it is inadequate when prices are not equal to marginal costs in secondary markets.

The inclusion of indirect effects in secondary markets linked to the primary market by relations of complementarity or substitutability should be included in the evaluation whenever there are distortions in the secondary markets and the cross elasticities are not zero. The final effect on the net present value of the projects could be positive or negative, and in practice the majority of the national and international CBA overlook the indirect effects or recommend to concentrate in those secondary market with a higher connection with the primary market, as long as price is significantly different from marginal cost.

In the case of suburban transport projects, there are other effects (not necessarily absent in intercity services) related to the change in proximity. They are the so-called WEB and they could be significant in some contexts. There are two types of WEB, both of them related to the spatial context of transport projects. The first one is connected to the value of proximity (WEB I) and the second one is related to the value of induced private investment and land-use change (WEB II).

The evaluation of WEB for rail transport projects first appeared in the research of Anthony Venables and Dan Graham within the economic assessment of the *Crossrail* project.[26] In a recent CBA workshop on the assessment of large-cross border transport projects organized by the Innovation and Networks Executive Agency (INEA) of the European Commission, Prof. Venables presented the main ideas about the rationale of the WEB:[27]

A perception exists that for some specific projects (Crossrail was one the most prominent cases) there is a large gap between the strategic case and the results of the

[25] This section draws on Graham (2007), de Rus (2010), and the presentation by A. Venables at the *CBA Workshop on the Assessment of Large-Cross Border Transport Projects* given at the Innovation and Networks Executive Agency (INEA), of the European Commission in Brussels, June 28th, 2019 (see ec.europa.eu/inea/. For a more detailed explanation of the WEB and their measurement see **PART I** (Section 7).

[26] *Crossrail* is a large investment program to reconfigure London suburban rail network running direct rail services between Reading and Heathrow Airport at the western ends of the railway, to Shenfield in Essex and Abbey Wood in south-east London at the eastern ends.

[27] This is the summary by INEA of the presentation of Anthony Venables in the CBA Workshop on the assessment of large-cross border transport projects, with a further explanation of the economies of agglomeration.

CBA, with a sort of empty intersection in-between; in such cases it is therefore difficult to reconcile the political or strategic narrative of a project and the numeric outcomes of the CBA.

CBA has been around for years, especially for transport, and it is based on a well-established methodology, which is largely based on the concept of economic equilibrium (general or partial). However, transport is related to spatial and land use distribution, and it is known that spatial equilibria are not efficient, and this may not be fully reflected in standard CBAs; this opens the case for using empirical evidences and research results in the field of spatial economy/geography.

According to the approach adopted in the UK, in addition to the "User-benefits" (time and direct costs on trips undertaken or created – primary market), traditionally included in standard CBA practices, two types of WEB in secondary markets are considered, which both relates to the spatial context of the project: the "value of proximity" (WEB I) and the "value of induced private investment and land-use change" (WEB II).

These two types of impacts are strictly related to what may be call "spatial context":

- Economic activity is spatially uneven: the real economy is characterised by high spatial unevenness, such as the disparities between densely populated manufacturing areas and thinly populated farm regions, between congested cities and peripheral rural areas; this cannot be the result of inherent differences between locations but rather the outcome of some sort of cumulative processes, necessarily involving some form of increasing returns, whereby geographic concentration can be self-reinforcing. In this sense, it is the opposite of "backyard capitalism", in which each household or small group produces most items for itself;
- Proximity raises productivity, based on classical mechanism such as scale and specialisation; specialisation leads to productivity and specialisation is easier in large agglomerations. There is large evidence supporting this relationship, that really goes beyond simple correlation and rather points to causality. Elasticity of productivity with respect of measures of "economic mass" (GDP, population, employment) is in range 0.03 – 0.1. This means that productivity in a city of 5 million inhabitants is 25% higher than the ones associated with a city of 200,000 inhabitants;
- Market failures: spatial equilibrium is not efficient. Two issues are worth mentioning: 'technological externalities' (e.g. knowledge spillovers) and 'pecuniary externalities' (e.g. investors cannot capture all benefit of investment, because this goes to someone else);

- Coordination failure. Again, two issues are worth mentioning: 'First-mover problem' (nobody wants to invest in a place because nobody is investing there) and 'low level equilibrium trap' (low income levels do not allow for investments, and this results in turn in low economic growth).

Having in mind the above mechanisms related to the spatial context, the two type of WEB that may be generated by transport projects can be described as follow:

WEB I (Proximity and productivity): the key mechanism is that transport improvement raises access to economic mass and increased access to economic mass raises productivity. Productivity increase applies to everyone in the affected place and not just to the travellers. The assessment of WEB I is based on robust empirical evidences, and relatively standard methodology and parameters (not much context-specific), hence it is easy to implement, but it still needs imposing disciplined methodology: for instance, it applies only within a limited spatial range (related to labour market and commuting range), and the effects are different depending on the economic sectors (i.e. finance and hi-tech are more sensitive to proximity).

Agglomeration economies are in fact a positive externality that firms generate when they locate close to other firms. If productivity increases with the density of firms in an area, productivity depends on the location decision of each firm. A company, when deciding where to install the plant, takes into account its own benefits but not the increase in the profits of other firms.

The benefits of time savings of a transport project are valued by the firms, which now change the location and increase the density of firms in a city or an industrial park (as measured by the derived demand function), but would be lower than the increases in productivity enjoyed by all the firms. Following the same reasoning, the reduction in the density of firms in the area where the companies were initially located reduces productivity and therefore it is a negative effect that must be accounted for.

There are several reasons explaining why firms in areas with a higher firm density are more productive, and why firms choose these locations despite the higher labour and land costs among other drawbacks. These reasons include access to wider markets, the availability of a more specialized labour market that matches the needs of firms, and the access to technologies and the production processes of firms in the area.

A project that reduces transport costs may also induce an increase in the concentration of jobs in an area where there are economies of agglomeration by reducing the cost of commuting for workers who, with the project, are now more willing to move to the city or the industrial park. However, the opposite might also occur if the reduction in transport costs encourages the dispersion of economic activity. For an urban project that reduces the costs of travel within the city it is more likely that the positive effect will dominate, while for an intercity transport project the possibility that the dispersion will increase cannot be ruled out, depending on a set of local factors such as land prices, wage differences between areas, and so on (see Duranton and Puga, 2004; Graham, 2007; Venables, 2007).

Productivity gains arising from economies of agglomeration result because productivity is non-constant with respect to city size and this means that the increase in labour density in the city thanks to the transport improvement increases the average productivity in the city. The new equilibrium with more workers moving to the city to work after the transport improvement is a consequence of the additional gains for the workers. It is worth mentioning, that those gains are net of taxes and hence the tax revenues are also productivity gains and have to be included in the economic evaluation of the project.

WEB II (Induced private investment and land-use change): The second category of WEB relates to welfare changes due to land use-changes. Assessing this second category of benefits is more complex than for WEB I. It is necessary to refer to the two basic steps required for the assessment of any benefits in a CBA: What are the quantity changes? What is their social value?

- Valuation. Assigning the social value requires understanding the underlying impacts of changes induced by increased accessibility: a) further proximity and productivity effects (if transport enables clustering of economic activities); b) interaction with other labour market distortions (for instance, enabling commuting to more productive jobs – in this case the benefit is not the entire additional wage; c) interaction with distortions created by non-marginal changes (if an induced private investment changes prices or wages that are not captured by the investors himself);
- Quantity. There is an inherent difficulty in establishing quantity changes. This strongly depends on context (easy for Crossrail, very hard for HS2), as there are issues in econometric evidence, which might require specific modelling tools (LUTI – Land Use and Transport Integrated Models and/or SCGE - Spatial Computational Equilibrium models). The evaluation of WEB II also need to avoid issues related to displacement: if there is no change in the supply of labour at the national level, increased employment in one firm, locality or region will be at the expense of others, and net effect might arise only due to increase in productivity.

Some of the key lessons-learned from the experience in the UK are that the WEB approach provides a good attempt for capturing important aspects of reality based on a rigorous approach. However, the experience also shows that this approach has sometimes been used too mechanically, without substantiating it with a convincing justification: to be relevant, the approach needs to be supported by a convincing narrative.

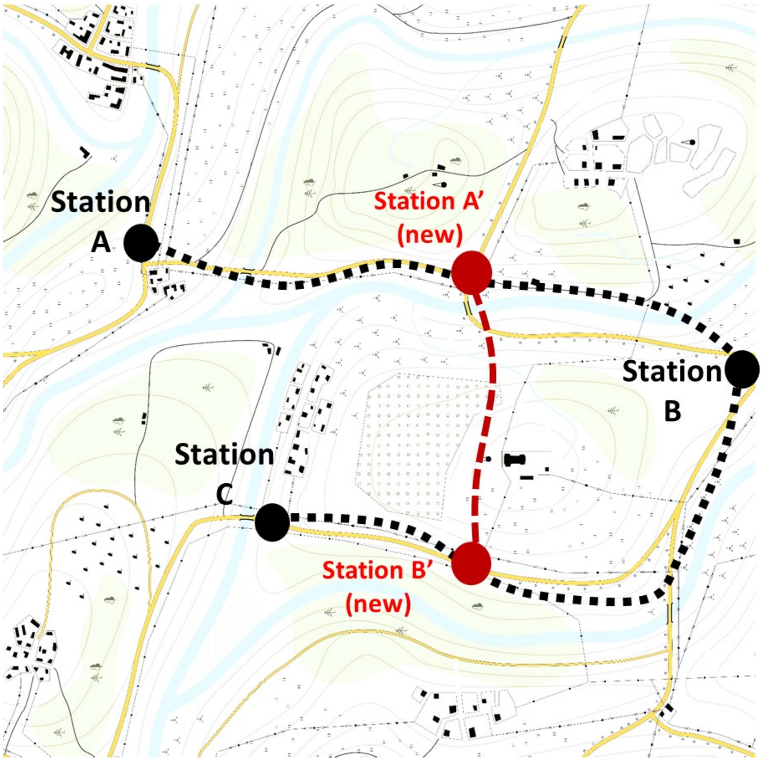
Several general principles for incorporating the assessment of WEB in the framework of a territorial/place-based policy:

- Narrative: There should be a clear narrative of the main problem(s) that policy is intended to address and the key market failure(s) that motivate the project/initiative;
- Transparency: The mechanisms underpinning both the quantity changes and their social value should be clear and explained in a manner that enables the key magnitudes to be understood from straightforward back-of-the-envelope calculation;
- Sensitivity: There should be analysis of the dependence of the quantity effects and their valuation on key assumptions about the economic environment. Scenarios outlining the quantitative importance of failure of these assumptions should be outlined;
- Complementary policies: There should be a thorough consideration of complementary measures that are needed for a successful implementation of a project;
- Alternatives: Any project should make a strong case that provides the most cost-effective way to solve the main problem(s) described in the narrative.

6.3. The cost-benefit analysis of a suburban rail project in practice

In this section we finally provide a practical illustration of some of the main issues discussed with respect to the CBA of suburban rail projects. Again, we will use a very stylized example and focus only on the critical elements when assessing these rail projects.

Figure 6.2. Project description: a new rail link (stations and distances)



Distances (in kms)	By train	By road
A – B	50	60
B – C	40	60
A – C *	**90**	**120**
A – A’	30	35
A’ – B	20	25
B – B’	25	35
B’ – C	15	25
A’ – B’	10	60
A – B’	40	95
A’ – C	10	60
A – C **	**55**	**120**

* without-the project ** with-the project

In particular, as depicted in **Figure 6.2**, consider a metropolitan region which is currently served by a non-saturated rail network that includes (among others) three stations **A**, **B** and **C**. The only mobility alternative in this area is road transport (by private cars) and the project under assessment consists in constructing and connecting two new stations (depicted as **A’** and **B’** in the figure) which reduces access/egress time for nearby residents, simultaneously increasing frequencies (by reducing average waiting times due to the ‘Mohring effect’) and shortening the travel path between **A** and **B** (which in turn reduces in-vehicle travel time), without affecting monetary prices. One of the major objectives of this project is to deviate users from the road network to alleviate existing congestion problems. The counterfactual alternative is a ‘do-nothing’ scenario (where congestion would increase when traffic increases over time, due to the increase in economic activity).

We will perform the *ex-ante* social CBA of this project following the change in resources and willingness to pay methodology and assuming – to simplify calculations – that all prices reflect their social opportunity costs (except in the road alternative) and that freight transport is not affected by the project. We will consider that the total investment on infrastructure (including planning and constructing the new stations and tracks, auxiliary buildings and all the signalling and communications systems) is €110 million in 2019 monetary values, distributed over two years (2020-2021), and the new services will start operating at the beginning of 2022. The evaluation horizon will be 50 years (from 2020 to 2069) and the residual value of the infrastructure is zero. We will also assume that there is a single public rail operator and only incremental costs – both in terms of the acquisition of new trains and the operation and maintenance of the new infrastructure and rolling stock – will be relevant from the point of view of the socioeconomic assessment of this project.

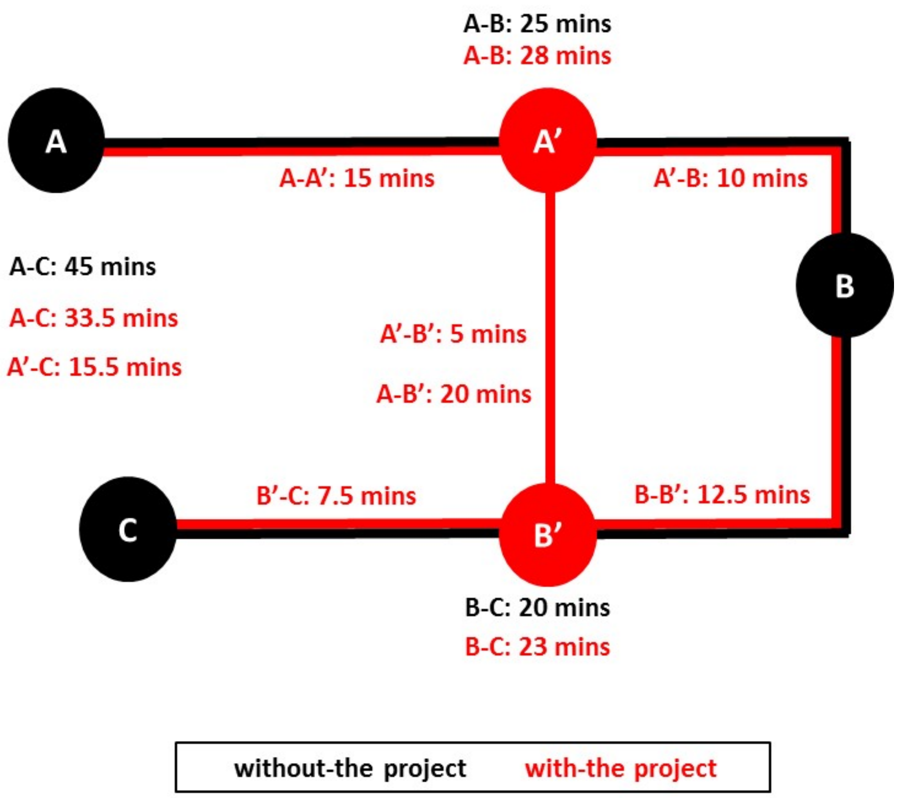
From the demand side, in this example we consider that a complete demand forecasting model is available for the decision-maker. In particular, and departing from available data on existing rail users and current road traffic counts, the model allows us to estimate the number of new rail users after the project (*generated demand*) and those that will switch from road to railways due to the project in each of the sections of the network (*deviated demand*). This modal distribution will be estimated for the first year of the operation of the new infrastructure (2022) and it will be assumed to grow according the GDP projections. The demand analysis can be performed by distinguishing, for each year, five demand groups: *existing rail users* (those in sections **A–B**, **B–C** and **A–C** that were initially travelling by rail): *existing road users*, new or *generated* (*rail*) *demand, (rail) demand deviated from road* and *final road users* (which will be important to determine the effects associated to congestion reduction). Our calculations will be particularly based on an initial figure of 2.000.000 rail passenger-trips at the starting year of operations, and 150.000 daily vehicles in the entire road network of this metropolitan region.[28]

With regard to travel time, we have assumed an average commercial speed of 120 kms/h in the case of railways, and the corresponding in-vehicle times (including time at intermediate stops) for all the suburban routes are summarized in **Figure 6.3**. Notice that we should add to the in-vehicle time the time spent at intermediate stops (3 minutes) when applicable, and consider that – on average – access/egress time to existing rail stations is 0.3 hours (18 minutes), but it reduces to 0.2 hours for the new stations (**A'**, **B'**), due to increased accessibility. For an average rail user, the waiting time at the rail station before boarding his train is 0.10 hours (6 minutes) 'without-the-project', but it is shortened by 50% after 2022. This will be due to the 'Mohring effect',

[28] We exogenously consider that 10% of the initial rail users travel from stations **A** to **C**, 60% between **A** and **B**, and the remaining 30%, between **B** and **C**. The road traffic distribution is also exogenous, although in a real case, the demand for each section should be specifically estimated. Generated demand is estimated as a 3% of existing traffic, whereas deviated demand is calculated using a 10% coefficient. These particular values will be later discussed in the risk analysis.

since an (expected) increase in demand will make the rail services provider increase the frequency, thus reducing the waiting time.[29]

Figure 6.3. In-vehicle travel time (including time at intermediate stops) by rail in all suburban routes



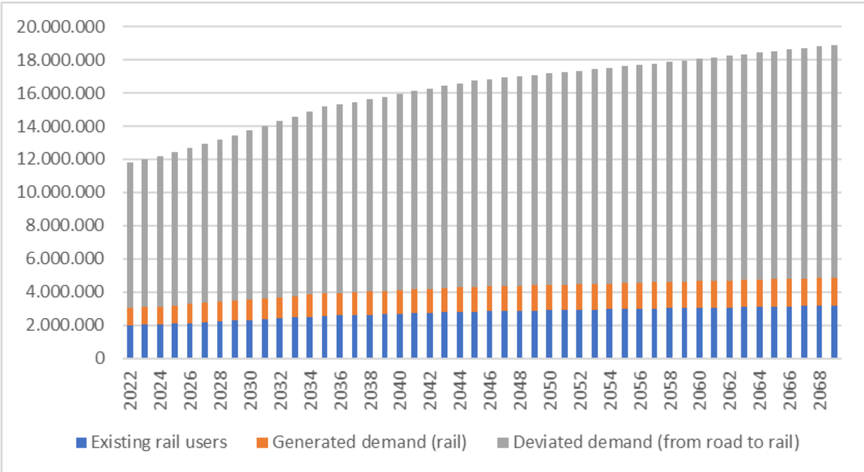
On the other hand, calculating travel time for road users is not so straightforward, since it requires explicitly modelling the effects of congestion (reduction). As discussed above, congestion appears when the number of users progressively increase beyond the infrastructure 'capacity level'. The factors that determine this upper limit depend on the basic design of the infrastructure, its physical characteristics and the traffic composition. In this example we will simplify the practical definition of congestion in the following way: there will be no congestion if the total daily demand in the road network is below 135,000 vehicles/day; there will be 'some congestion' if the demand is between 135,000 and 150,000 vehicles/day, and there will be 'severe congestion' above that threshold. The corresponding average speed for each case will be 80 km/h, 70 km/h and 60 km/h,

[29] We assume that for sections **A–B** and **B–C** total travel time does not change with the project: savings in waiting time are compensated by the increase in 'in-vehicle' time (due to the addition of a new stop at the intermediate station). However, note that the value of time applied to these changes may differ.

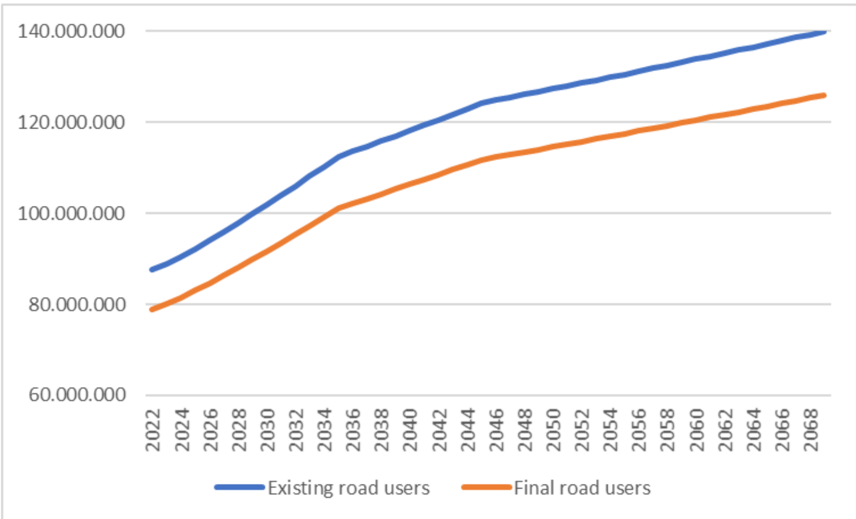
respectively. **Figure 6.4** summarizes the evolution and distribution of the rail and road demand estimates between 2022 and 2069.

Figure 6.4. Demand estimates for the suburban rail project by sections

Rail demand



Road demand



From the cost side, apart from the described investment costs, we have calculated the incremental operating and maintenance costs for infrastructures and services by departing from the initial values of 7.0 and 8.0 euros per train-km, respectively, and assuming that the number of trains that need to be purchased are calculated from the number of additional required services 'with' and 'without' the project.[30]

Taking into account all these elements, and using a similar approach as that described in **Section 5.2**, it is immediate to identify the main social benefits and costs from this project as the following ones:

1. For *existing rail users* in sections **A–B**, **B–C** and **A–C**, the value of their travel time savings each year is given by

$$ {}^{access}v_R({}^{access}t_R^0 - {}^{access}t_R^1)x_R^0 + {}^{wait}v_R({}^{wait}t_R^0 - {}^{wait}t_R^1)x_R^0 + {}^{in}v({}^{in}t_R^0 - {}^{in}t_R^1)x_R^0, \qquad \textbf{(6.1)} $$

where the first summand is equal to zero because there are no changes in access/egress time, the second summand is positive ('Mohring effect') and the third is negative (due to an additional stop).[31]

2. For *generated rail users* in all sections and each year, their willingness to pay can be calculated as discussed in **Figure 5.1**, as:

$$ \left[\frac{1}{2}(g_R^0 + g_R^1) - v_R t_R^1\right](x_R^1 - x_R^0), \qquad \textbf{(6.2)} $$

where g is the corresponding generalized price, $(x_R^1 - x_R^0)$ represents the generated demand, and the term $v_R t_R^1$ can be disaggregated as in **(6.1)**.

3. For *rail users deviated from road*, their travel time savings have been calculated for each section and year using the same approach discussed in **Figure 5.2**.[32] The benefits from deviated demand comes from time savings of those deviated users from the road transport (**areas A' + D'**) and resources saved from this mode (**area E'**). Therefore, for the deviated demand of the road transport, we have that the increase in social welfare (disregarding the rail operating costs of this deviated demand, that will be considered latter on) is given by:

$$ \Delta W_d = \frac{1}{2}(g_m^0 + g_m^1)x_d^m - v_m t^1 x_d^m, \qquad \textbf{(6.3)} $$

[30] The (incremental) number of trains has been calculated following the same steps described in **Section 5.2**, assuming a unit acquisition cost of €10.000.000 for a 360-seats train. An average load factor of 80% has been assumed.

[31] All values of time are expressed in euros 2019, and have been updated from HEATCO (2006), assuming similar values to those used in **Section 5.2**.

[32] In section A'B' we consider that users were travelling by road from A' to B' via B, before the project.

where the subscript m corresponds to the road transport.

4. For *users remaining at the road after the project*, the value of their travel time savings is associated with congestion reduction when road traffic flow decreases, which can be simply calculated as:

$$v_m(t_m^0 - t_m^1)x_m^1\,, \tag{6.4}$$

where the subscript m corresponds to the road transport, x_m^1 denotes the remaining road users, and v_m is the average value of travel time for road users.

5. From the point of view of the provision of the new infrastructure and services, the incremental costs associated to this project include the *investment costs* (I), the *acquisition costs* of the new trains (C_a), and the incremental *changes in maintenance and operating costs*, as defined by:

$$-I - C_a - (C_R^0 - C_R^1)\,. \tag{6.5}$$

By adding expressions **(6.1)** to **(6.5)** it is finally possible to obtain the total change in social welfare (ΔW_h) associated with this project for each of the years included in the evaluation horizon. The NPV_S is then given by

$$NPV_S = \sum_{h=2019}^{2069} \frac{\Delta W_h}{(1+r)^{2020-h}}\,,$$

and the corresponding result is positive as summarized in **Table 6.1**. In this example, all the values of time savings are large enough to compensate the social costs of the new infrastructure and services, and – therefore – the project should be carried out from the point of view of its net contribution to social welfare.

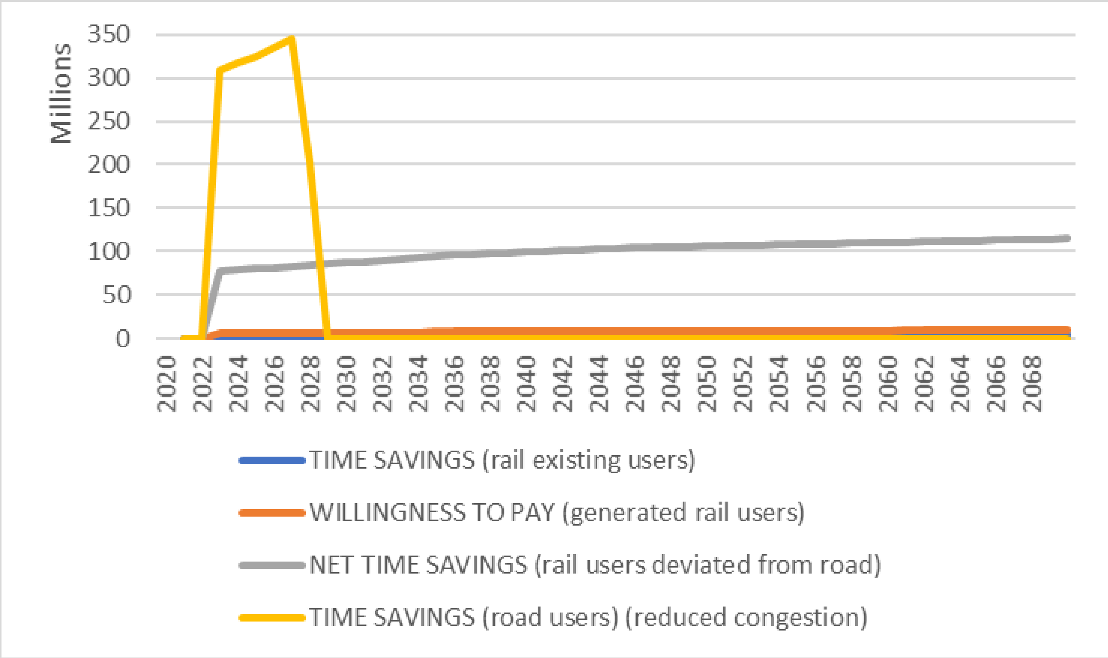
Table 6.1. Economic evaluation of the suburban rail project

	Actual values in euros 2019
Time savings (existing rail users)	**74,326,056.84 €**
Willingness to pay (generated rail users)	**177,740,026.85 €**
Time savings (rail users deviated from road)	**-3,015,060,410.90 €**
Avoided costs (rail users deviated from road)	**5,314,451,507.11 €**
Time savings (road users, due to lower congestion)	**1,565,125,398.66 €**
Investment cost	**-105,212,555.38 €**
Rolling stock acquisition costs	**-79,488,806.81 €**
Infrastructure operation and maintenance costs	**-707,321,021.11 €**
Services operation and maintenance costs	**-808,366,881.27 €**
NPV_S	**2,416,193,313 €**

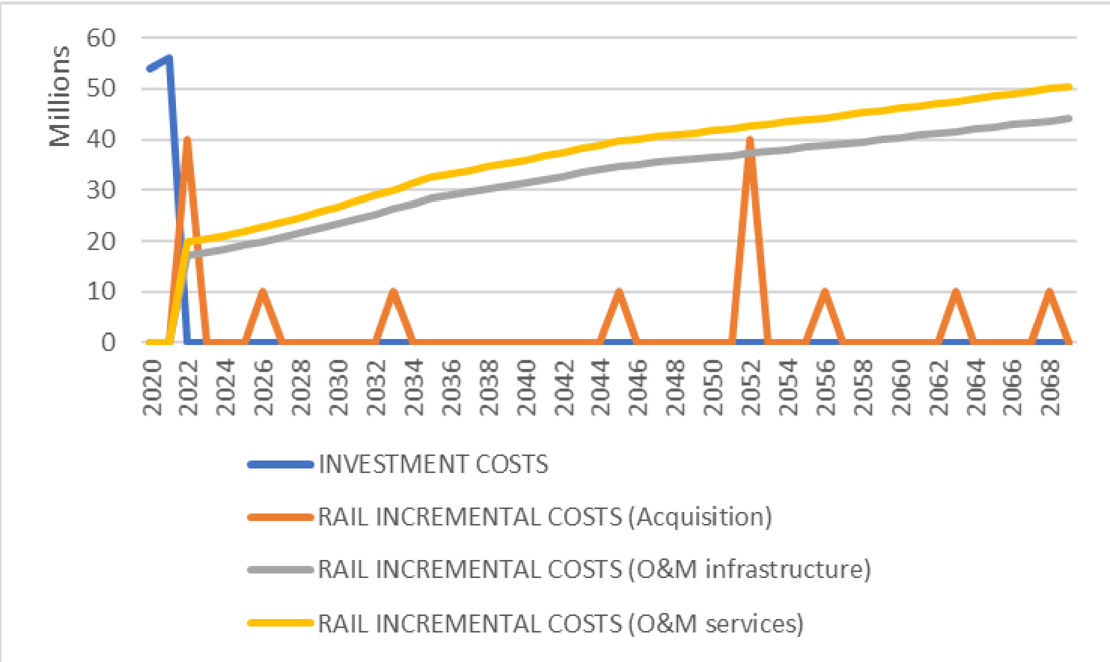
It is immediate to note, as showed in **Table 6.1,** that most of the benefits of this projects are obtained from the avoided costs and net value of time savings of deviated users (in particular those in section **A–A’** and **A–B**, although not separately represented) and the gains from reduced congestion are also important. Interestingly, these gains concentrate in the first years of operation of the project since, as the traffic increases over time, congestion is also increased again. With regard to the costs, the largest shares correspond to operation and maintenance, which increase with the number of train-km. Other external costs (apart from congestion), have not been included in this example.

Figure 6.5. Evolution of social benefits and costs

Benefits



Costs



We have neither considered an explicit analysis of WEB in this example, although their discussion should follow the patterns described in **Section 6.2**. However, to conclude the evaluation, we can perform a brief risk analysis by identifying and modelling the key variables whose associated uncertainty may affect most the *NPVs* results. In particular, following the procedures described in detail in **PART I**, we may assume that the sensitivity analysis in this case allows us to identify at least five key parameters related to cost and demand risks:

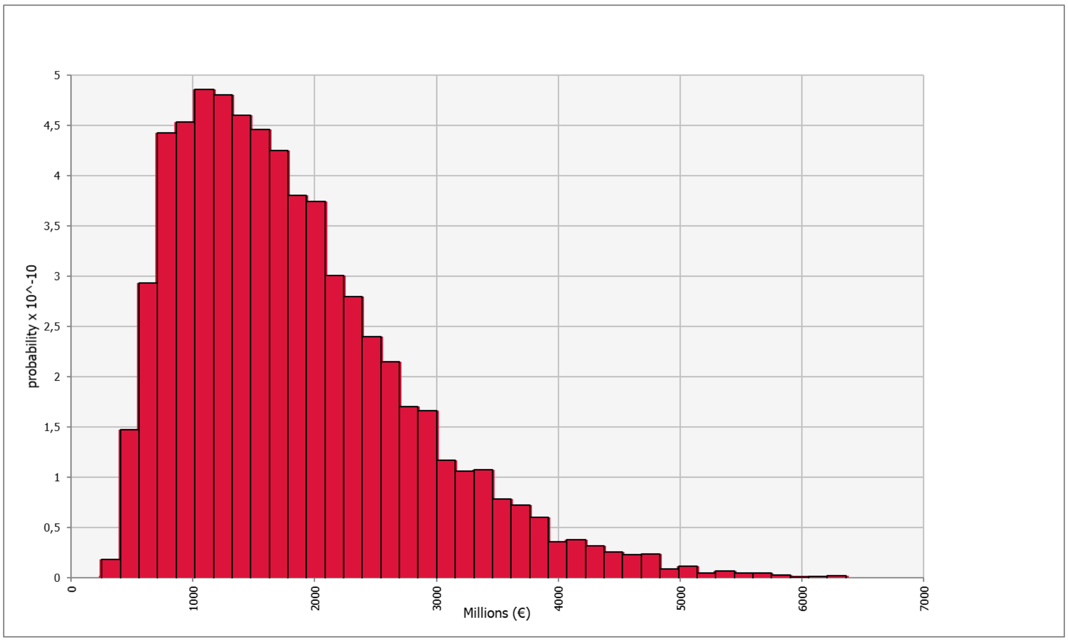
- the possibility of *overruns* on the investment costs,[33] will be modelled using a uniform distribution between 0% and 30%,
- the possibility of overruns on the unit operating and maintenance costs, also modelled with a similar distribution,
- the possible existence of a demand forecast overestimation factor, modelled through a triangular distribution between -30% and +5% (with a most likely value of 0%)
- the percentage of generated demand, will be represented by a triangular distribution between 2% and 10% (with 3% as the most likely value), and
- the percentage of deviated traffic, a triangular distribution between 5% and 15% (with 10% as the most likely value).[34]

Under these assumptions, the quantitative risk analysis was performed with a specialised software for 10,000 simulations. The technique used was a Monte Carlo simulation which involved a random sampling method of each different probability distribution selected for the present model. The variables are considered independent of each other, so each 'extraction' takes a random value for each variable to compute the corresponding *NPVs*, whose probability distribution is finally presented in **Figure 6.6**. As it can be observed, the probability of obtaining a negative *NPVs* is 0%, showing that a positive decision about this project can be made even without considering other additional benefits, including WEB.

[33] See Flyvbjerg *et al*. (2003), for example.

[34] It will be also assumed that these two final distributions are positively correlated.

Figure 6.6. Risk analysis: probability distribution of the *NPVs*



Simulation Summary Information	
Workbook Name	SUBURBAN RAIL EXAMPLE
Number of Simulations	1
Number of Iterations	10000
Number of Inputs	5
Number of Outputs	1
Sampling Type	Latin Hypercube
Simulation Start Time	1/8/20 13:41:10
Simulation Duration	00:02:48
Random # Generator	Mersenne Twister
Random Seed	1828292871

Summary Statistics for SOCIAL NPV			
Statistics		Percentile	
Minimum	252.891.532	5%	648.627.867
Maximum	6.360.537.378	10%	782.051.113
Mean	1.826.808.818	15%	893.430.755
Std Dev	948.261.038	20%	1.000.012.735
Variance	8,99199E+17	25%	1.102.055.050
Skewness	1	30%	1.205.436.246
Kurtosis	4	35%	1.312.028.739
Median	1.643.295.188	40%	1.421.377.922
Mode	1.032.217.391	45%	1.528.561.570
Left X	648.627.867	50%	1.643.295.188
Left P	0	55%	1.762.046.220
Right X	3.676.281.660	60%	1.889.757.140
Right P	1	65%	2.022.079.661
Diff X	3.027.653.793	70%	2.168.436.527
Diff P	90%	75%	2.345.357.988
#Errors	0	80%	2.548.407.611
Filter Min	Off	85%	2.804.005.756
Filter Max	Off	90%	3.149.408.659
#Filtered	0	95%	3.676.281.660

ANNEX A. REVIEW OF MANUALS AND GUIDELINES ON COST-BENEFIT ANALYSIS OF RAIL PROJECTS

This annex briefly reviews two of the most recent official guidelines related with the methodology for the economic evaluation of rail transport projects. As discussed in the **PART I** document, there are several more general CBA manuals that sometimes include a section or an example on transport projects and in some cases, they refer to rail investments.

For example, the European guide to cost-benefit analysis of investment projects (EC, 2015), includes an interesting case study of a railways project consisting in the upgrading of a double-track (conventional) railway section, part of the TEN-T Priority axis.[35] The project objective is to improve the level of railway service on an important corridor, in particular by reducing travel times, increasing capacity and improving safety, thereby contributing to the overall attractiveness of the rail transport mode within the country and also at trans-European level. The main benefits of this project are quantified as travel time savings for the existing rail users, reduced operating costs for service providers, and gains for diverted traffic from road to rail through a reduction of congestion costs and accidents. The case study provides a detailed financial and economic assessment performed using a 30-year reference period with respective discount rates of 4% and 5%. From a methodological point of view, the analysis is carried out using the change in surpluses approach, by calculating consumers' surplus, producers' surplus and changes in external costs. No reference is included to taxpayers' or workers' surplus. The internal rate of return is 10.6 %, and the NPV_S is €880 million. The evaluation is completed with a sensitivity analysis (to determine the 'critical' variables whose variations, positive or negative, have the greatest impact upon the project's economic results), after which their switching values (those that make NPV_S = 0) are calculated. A risk assessment is also included, considering and modelling the specific risk associated with construction, land acquisition, maintenance costs and demand forecasts.

The European Investment Bank guidelines (EIB, 2013) also include a general discussion of the elements that define the appraisal of a rail project and a specific case study on interurban railways consisting in the improvement of a single track line that is operating close to capacity and provides passenger and freight services. The "do-minimum" scenario is defined as investing enough resources in the existing track to maintain its good operation conditions, whereas the "do-something" scenario includes

[35] The guide also includes an urban transport project involving a building and operating a tram line jointly with other public transport and accessibility policies.

the installation of an additional track to increase capacity, although no increase in the design speed is foreseen. The time horizon for the analysis is 35 years, which coincides with the weighted average economic life of the project. The financial analysis is disaggregated for the infrastructure manager and the service operator and is negative in both cases. However, the economic analysis, shows that the project generates enough benefits to society to justify the costs. The internal rate of return is 7.2% and the *NPVs* is above €163 million. Sensitivity and risk analysis are not provided.

Tables A.1 to **A.2** provide a more detailed analysis of the structure and contents of two specific CBA manuals for rail projects. The first one is Turró (2004), known as RAILPAG (*Railway Project Appraisal Guidelines*), prepared for the European Commission and the European Investment Bank. RAILPAG respond to the need for EU-harmonised procedures for the socio-economic and financial appraisal of rail projects following the latest developments in the sector, especially where supra-national financing is under consideration. Indeed, the methods used in the various member states are often tied to the domestic vision of rail transport characterised by integration of infrastructure and service operators, strong public intervention and lack of competition, and tend to obey to short-term political purposes rather than long-term socioeconomic objectives. In some cases, the evaluation manuals have not been updated for many years, and there was a common agreement that available appraisal guidelines were not sufficiently adapted to the new context of liberalisation, separation of infrastructure and operations, increased accountability and EU-wide integration of railways.

The second one is the Spanish ADIF Manual (ADIF, 2018), which can be viewed as a more technical approach to the economic assessment of rail projects, when they are defined from a national perspective. This manual updates previous versions and includes several technical annexes with specific features for different types of rail projects, from track improvements to the construction of new stations or terminals.

Table A.1. Some official guidelines for the assessment of rail transport projects (I)

Short name	RAILPAG (2007)
Full name	*RAILPAG* *RAILWAY PROJECT APPRAISAL GUIDELINES*
Organization	European Commission European Investment Bank
Publishing date	2007
Language	English
Brief description	The RAILPAG (Railway Project Appraisal Guidelines) aim at providing a common framework for the appraisal of railway projects across the EU. It starts by discussing the relationship among the various stakeholders in the rail sector and then describing the processes leading to decisions about these projects. The following chapters give indications on how to carry out a CBA adapted to the particular conditions of rail projects, providing some guidance regarding both the more general aspects, such as the preparatory work and the economic analysis. It focuses on those elements that are most relevant for rail projects and on the criteria and parameters to be used in the economic analysis, which should be correctly specified and harmonised at the European level. RAILPAG considers that for complex or/and larger projects, the distributional effects of an investment are an important component for decision makers and therefore illustrates how the results of the CBA can be presented in a way that facilitates the understanding of the consequences of the project, based on a stakeholders-effects matrix. The text is relatively self-contained and does not require a specific background in project assessment. After the introduction, its main body can be structured into four main topics: *1. Appraisal procedures*, defining the place of the various stakeholders in the process. *2. General elements*, including project definition, alternatives and demand forecasts. *3. Financial and economic analysis*, where the main benefits and costs are discussed, including some particular aspects relevant to rail projects such as capacity issues, appraisal period and discount rates. *4. Applied issues* related to the practical implementation of the methodology and the presentation of results. The document also includes two annexes with tables providing indicators and values that are considered particularly relevant. Annex C consists of general comments followed by a set of fiches on key matrix cells. Annex D shows 10 case studies, reflecting a whole range of rail investments, which can be used to illustrate their practicality. Finally, Annex E provides some references, mostly referring to specific EU documents or research projects.
Source	www.eib.org/en/publications/railpag-railway-project-appraisal-guidelines

Table A.2. Some official guidelines for the assessment of rail transport projects (II)

Short name	**ADIF (2018)**
Full name	*GUÍA PARA LA EVALUACIÓN DE INVERSIONES DE FERROCARRIL.*
Organization	Dirección General ADIF. *Subdirección de estudios de demanda y planificación de inversiones*
Publishing date	2018 (previous versions from 2008 to 2016)
Language	Spanish
Brief description	This document (in two volumes) provides a complete set of guidelines for the economic analysis of transport projects defined from a national perspective. Volume I analyses the new socioeconomic context of the rail industry in Spain and Europe and discusses the overall methodology for defining a rail project, including an analysis of the role played by different stakeholders. It then provides specific guidance for the financial analysis, distinguishing the infrastructure manager perspective (ADIF) and the viewpoint of the firms providing rail services. For the economic analysis, there is a detailed discussion of shadow prices and how should be they applied. Volume I also includes a methodology for a (non-compulsory) qualitative assessment as well as a description of the procedures for the sensibility and risk analyses. There are several annexes with detailed information on ADIF unit revenues and costs, unit prices for investments, prices and costs for other transport modes, parameters on the evaluation horizon and the economic life of the relevant assets, value of time, discount rates and external costs. Volume II includes a more disaggregated description of the different types of projects that can be evaluated and their main specificities by type of line and technology. It also discusses different methods for demand estimation, based either in the four-stage model or in the projection of mobility ratios. The manual includes some previous references and, interestingly, some parameters values about the cost of acquisition and maintenance of rolling stock according to architectures and sizes, as well as other operational costs for them. In sum, this a manual that does not provide a detailed methodological analysis of the CBA procedures, but contains very useful reference information for most of the parameters requires in the economic assessment of rail projects.
Source	Not available online

ANNEX B. VARIABLES AND INFORMATION SOURCES FOR THE COST-BENEFIT ANALYSIS OF RAIL PROJECTS

The tables in this annex provide a final checklist of the main input data necessary to perform a cost-benefit analysis of a rail project according to the methodology discussed in this document. They are grouped into three categories (*general parameters*, *costs parameters* and *demand parameters*) and include a brief explanation of their relevance and characteristics as well as a reference to potential data sources from where they can be obtained. These tables are in line with the overall recommendations from the EC (2015) guide to cost-benefit analysis of investment projects and EC (2019) on the external costs of transport, although other guidelines and manuals, as those reviewed in **Annex A**, may be also of interest.[36]

[36] As discussed in the previous section, the infrastructure manager in Spain (ADIF) has, for example, its own guidelines. As the planning authority, the Ministry of Transport, Mobility and Urban Agenda also publishes regularly updates on several technical parameters such as the value of time the external costs of accidents and other related values.

Table B.1. General parameters

	Comments and sources
PROJECT DEFINITION	The economic assessment of a transport project should always include a brief description of the alternative(s) to be evaluated and the counterfactual (baseline case) with respect to which the incremental measurement of benefits and costs will be performed. This information can be obtained from the technical documents/planning studies associated with the project.
EVALUATION HORIZON	The period (year) of initial reference for the economic evaluation is a subjective decision, although in *ex-ante* CBA it is typically considered the year when the decision is going to be made. The duration of the evaluation horizon should be associated with the economic life of the assets involved in the project, although EC (2015) recommends 30 years.
DISCOUNT RATE	The economic interpretation of the discount rate in CBA is related to the intertemporal rate of consumption substitution for users and the opportunity cost of capital. As a general reference, EC (2015) recommends a 5% rate for major projects in Cohesion countries and 3% for the other Member States. Financial discount rates may be higher.
SHADOW PRICES	Shadow prices are used to convert market prices into prices that reflect the true opportunity costs. Sources of distortions include market inefficiencies, existence of regulated prices, taxes and subsidies. Fiscal corrections and conversion from market to shadow prices should be addressed by taking into account the *tax rates* levied on each input (VAT, customs, income taxes) and using appropriate tables of *conversion factors*. The value of these conversion factors, however, may vary across different sources (EC, 2015; EIB 2013, for example). For shadow wages, the source market of the labour inputs used in the project should be properly identified in order to define the corresponding opportunity costs. A comparison of shadow wages across different EU regions is found, for example, in **Florio *et al.* (2011)**.

Table B.2. Cost parameters checklist

	Comments and sources
Investment costs	Investment costs are closely related to the project definition. They should include all the payments associated with the inputs required by the project, including planning and evaluation studies, terrain acquisition and preparation, engineering works, materials, labour and other inputs. These costs items should be disaggregated as much as possible, and properly attributed to the period in which they take place. The main source of information for these costs are the technical documents/planning studies associated with the project and other sources from the public or private institution(s) in charge of undertaking it. In some cases – when the information is not fully available – standard unit values (as those suggested in ADIF, 2018, or in the relevant economic literature) may be used as references. It is important to take into account the possibility of cost overruns, which may increase construction costs or delay the construction period. With respect to the residual value of the assets, they should be in line with their economic lifespan and the evaluation horizon. General recommendations on these issues are generally available in the manuals and guidelines reviewed at **Annex A**.
Operation and maintenance costs (rail)	Operation & maintenance costs, both for infrastructure. rolling stock and other associated assets (stations) and inputs (spare parts and labour costs), are critical variables for the assessment process, but not always easy to obtain. Some of these cost items may be independent of traffic volumes (scheduled maintenance, for example), while other elements vary in accordance with the intensity of use (in terms of train-km) or demand (in number of passengers-km or ton-kms). The main sources for these costs are the infrastructure manager and the operating companies, although reference values may be obtained from general guidelines and related literature, as above. These costs items should be also disaggregated as much as possible and attributed to the period in which they take place.
Rolling stock acquisition costs (rail)	For *ex-ante* CBA, the fleet size has to be estimated in accordance to the expected demand, the frequency and capacity of the services that will be provided. The useful lifespan of the rolling stock (according to their usage and maintenance levels) should be also consider for renewal orders. Estimates on the unit acquisition costs largely vary with many characteristics of these assets, and it is to difficult to provide general references. In any case, project-specific characteristics should be taken into account when making rolling stock acquisition decisions
Other costs (other modes)	The (avoided) costs in alternative transport modes are relevant for the CBA of rail projects. This information should be obtained from public or private operators in each sector, statistical offices or relevant related literature. Users' operating costs associate to private vehicles (cars, vans, lorries, etc.) should be estimated taking into account the different components of these costs (petrol, repairs, insurance, etc.) and their changes with and without the project. Additional references and values can be also found at Betancor *et al*. (2009).
External costs	The main and most updated reference for external costs related to rail transport can be found at EC (2019). When project-specific impacts cannot be estimated, this document includes detailed parameter values for estimating accident costs, congestions costs and environmental externalities related to noise, habitat damage, effects on the landscape, air pollution, climate change and others.

Table B.3. Demand parameters checklist

	Comments and sources
Existing demand (rail and other modes)	The existing demand (in terms of the number of passenger-trips and/or freight transported) can be obtained from the transport operators in the corridor, both for rail and other modes of transport. It is very important to disaggregate the different sections under study, as well as the main origins and destinations served by each operator. When relevant, data should also include the usage of stations and other infrastructures (airports, bus stations, etc.). The data should include monetary prices and travel times (frequencies), as well as the possible existence of peak or valley periods throughout the year. Relevant taxes and subsidies should be also be explained.
Modal distribution (with the project)	For the *ex-ante* evaluation of rail investment projects, it is necessary to have an adequate prediction of the (passenger and freight) demand by transport modes for each of the years of the evaluation horizon, both 'with-the-project' and 'without-the-project'. This prediction of the modal distribution can be performed through different statistical techniques, both quantitative and qualitative, whose quality largely determines the reliability of the evaluation. In ex post analyses, actual data from transport operators can be use instead.
Revenues, prices and users' costs	Since information on the price paid by each passenger is not always available, it is common to use average revenue data per passenger-trip as an approximation. It is important, however, to take into account the different types of monetary prices (some of them, variable), as well as the existence of special discounts or subsidies for certain groups. In the case of user costs associated with private cars, unit prices should be calculated on the basis of the main cost items involved (fuel, repairs, insurance, etc.), bearing in mind that some of these vary with the distance travelled. The main source for these data is the operators or sectoral statistical agencies, although several exogenous assumptions can sometimes be made about the future evolution of these values based on expectations about each sector (e.g. introduction of competition, privatisation, etc.)
Travel time and value of time	Travel time values should be project specific, or estimated from distance and average commercial speed, distinguishing – at least – in-vehicle time, access and egress time to origin and destination and average waiting time per passenger-trip/unit of cargo. In the case of networks, the existence of 'Mohring effects' associated with changes in frequency should be also taken into account. Travel time savings are usually the main source of benefits for many transportation projects and should be carefully measured. The value of time should also be disaggregated, penalizing, if necessary, those that generate greater disutility. General parameters per country can be used (see HEATCO, 2006, or EC, 2019) taking into account the mode of transport and the distribution of travel motives.

REFERENCES

ADIF (2018): *Guía para la evaluación de inversiones de ferrocarril*. Dirección General. Subdirección de Estudios de Demanda y Planificación de Inversiones. ADIF. Madrid.

Betancor, O., Moral., E and J. Campos (2009): Producer and user costs estimation in transport projects evaluation. CEDEX Working Paper, available at www.evaluaciondeproyectos.es/

Betancor, O. and G. Llobet (2015): *Contabilidad Financiera y Social de la Alta Velocidad en España*, FEDEA 2015/08. Madrid.

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

Campos, J., de Rus, G., and I. Barron (2009): 'The cost of building and operating a new high speed rail line', in de Rus, G. (ed.) *Economic Analysis of High Speed Rail in Europe*, BBVA Foundation.

de Rus, G. (2010): *Introduction to Cost-benefit Analysis: Looking for Reasonable Shortcuts*. Edward Elgar Publishing, Cheltenham, UK.

de Rus, G., Campos, J., Graham, D. and M.P. Socorro (2019): *Guidelines for the economic assessment of transport projects with applications to investment in rail infrastructure and transfers to increase mobility. Part I: A general methodology for cost-benefit analysis in transport.*, University of Las Palmas de Gran Canaria, mimeo.

Duranton, G. and D. Puga (2004): 'Micro-foundations of urban agglomeration economies', in J.V. Henderson and J.-F. Thisse (eds), *Handbook of Urban and Regional Economics*, Vol. 4: Cities and Geography, North Holland: Elsevier, 2063–117.

EC: European Commission (2015): *Guide to cost-benefit analysis of investment projects. Economic Appraisal tool for Cohesion Policy 2014-2020*. Brussels

EC: European Commission (2019): *Handbook on the external costs of transport*, Brussels.

ECA: European Court of Auditors (2018): *A European high-speed rail network: not a reality but an ineffective patchwork*. Special Report. Luxembourg. Available at www.eca.europa.eu/.

EIB: European Investment Bank (2013): *The economic appraisal of investment projects at the EIB*. Available at www.eib.org/en/publications/economic-appraisal-of-investment-projects.

Florio, M., Fiorio, C. and C. del Bo (2011): 'Shadow Wages for the EU Regions', *Fiscal Studies*, 32(1): 1-40. Università degli Studi di Milano Working Paper No. 2009-42.

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003): *Megaprojects and Risk: An Anatomy of Ambition*, Cambridge (UK): Cambridge University Press.

García-Álvarez, A. (2016): *Explotación de los servicios de transporte de viajeros. La demanda en el transporte de viajeros. Generación, evolución y reparto modal*. Fundación de los Ferrocarriles Españoles.

González Franco, I. (2015): 'Metodología para la estimación de la combinación de velocidades máximas que permiten alcanzar el tiempo de viaje comercialmente requerido en una infraestructura ferroviaria'. PhD Thesis, Universidad Politécnica de Catalunya.

Graham, D.J. (2007): 'Agglomeration, Productivity and Transport Investment', *Journal of Transport Economics and Policy* 41(3): 317–343

HEATCO (2006): Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO). Deliverable D5: Proposal for harmonised guidelines, Stuttgart: IER University of Stuttgart.

Laurino, A., Ramella, F., and P. Beria (2015): 'The economic regulation of railway networks: a worldwide survey', *Transportation Research. Part A* 77: 202–212.

Martín Cañizares, M.P. (2015): 'Contribución al diseño eficiente de la configuración en planta de líneas de alta velocidad'. Tesis Doctoral, Universidad Politécnica de Catalunya.

Ministerio de Fomento (2017): *Revisión de los servicios ferroviarios de viajeros declarados como Obligación de Servicio Público*. Gobierno de España. Madrid.

Nash, C.A. (2014): 'Appraisal in the rail sector: General issues and British experience in dealing with them', *Research in Transportation Economics* 47: 19-26.

Nash, C.A., Nilsson, J.E. and H. Link (2013): 'Comparing three models for introduction of competition into railways', *Journal of Transport Economics and Policy* 47 (2): 191–206.

Preston, J. (2013): *The Economics of Investment in High-Speed Rail*. Brussels. OECD.

Turró, M. (2004): RAILPAG. *Railway Project Appraisal Guidelines*, European Commission and European Investment Bank. Available at www.eib.org/en/publications/railpag-railway-project-appraisal-guidelines

UIC (2018): *High speed rail: fast track to sustainable mobility*. International Railways Union. Paris. Available at www.uic.org

Vassallo, J.M., Ortuño, A. and O. Betancor (2017): *Las cuentas del transporte en España, Estudios sobre la Economía Española*. Fundación de Estudios de Economía Aplicada, FEDEA.

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