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ORIGINAL PAPER

# Towards a liberalised European high speed railway sector: Analysis and modelling of competition using Game Theory

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**Abstract**
*Introduction* The liberalisation of the Railways imposed by European Directives introduces competition in a sector traditionally organised largely through national monopolies. As a result, the analysis of the competition particularly on a given route is very recent.
*Approach* The approach and methodologies so far developed to analyse the competition between European rail operators have resulted in interesting but isolated efforts. Developments based on game theory and analysis of strategic decision as part of the organisational economics theory have proven to be the most appropriate. This paper introduces an improvement on these methodologies by using the principles of consumer behaviour theory and the analysis capabilities of game theory to develop a dedicated purpose-built modelling tool for the analysis of intermodal competition within the operator's revenue function. To validate the model, a forecast analysis on the Madrid-Barcelona high speed corridor has been performed.
*Conclusions* The resulting model allows quantifying the minimum requirements for a new operator to stay in the market as well as the equilibrium price and level of investment required.

**Keywords** Railways · High-speed · Competition · Liberalisation · Game theory

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## 1 Introduction

During the 1990s the progressive decline of the railway market share in Europe prompted the European Commission to start a deep and fundamental process of transformation. A number of legislative measures grouped into what is known as Railway Packages aimed at gradually creating a competitive single European Railway System were introduced. One of the primary implications of this process is the introduction of competition through the liberalisation of transport service operations.

One these recent Directives is focused on the liberalisation of international passenger services [19]. This is a critical step as effectively opened up the passenger market from 2010. This legislation, supported by additional documents such as the Transport White Paper [18] that led to the 2011 version has transformed the European railway system introducing the legal requirement of full legal and commercial separation between infrastructure ownership and service providers. These requirements are the catalysts of a deep restructuring of all national railway companies as well as the newly formed operators willing to enter the market.

The level of competition introduced and the pace in which such process is taking place varies between European member States depending on the way and time scales the Directives have been incorporated into the national laws. In some cases, there have been considerable delays in its adoption. In other cases, national monopolies have been drastically reduced or have even disappeared, as is for the now extinct British Rail.

The introduction of these European Directives has effectively created two types of structures, namely:

- Independent organisations running the infrastructure and the operations as is the case in countries such as France, UK, Portugal, Sweden, Denmark, Finland, the Netherlands, Spain;
- Holding organisations integrating both the infrastructure managers and the former state-owned railway operator

(passenger and freight). Examples include Germany, Belgium and Italy;

The differences in adopting these Directives have prompted the need to quantify the level of implementation of the liberalisation process in order to be able to do an accurate comparison. Kirchner [26–29] introduced on behalf of Deutsche Bahn AG[1] the Rail Liberalisation Index (LIB Index) widely acknowledged as the reference method to perform such comparison. The LIB Index assesses on a regular basis the level of openness of the rail transport markets within the European Union member States plus Norway and Switzerland. It uses a system of three different indexes based on legal and practical barriers for newcomers (LEX, ACCESS, COM) and four categories (pending departure, delayed, on schedule, advanced) to rank on a scale from 100 to 1,000 points the level of liberalisation. In its more recent edition, only the UK, Germany, Sweden, Denmark, Austria and The Netherlands achieve advanced ranking (800–1,000 points). This means that only these six countries out of twenty-seven have completely incorporated the European Directives and legislation. New railway undertakings willing to access these markets have no significant barriers to do so.

However, the LibIndex has its limitations as it only assesses the level of implementation of the existing regulation, referring to it generally as competition level. Knorr and Eichinger [30] performed a critical appraisal of the Lib Index highlighting its key limitations.

To analyse the level of competition between operators, economic theory and industrial organisation indicators are widely accepted and acknowledged. In particular, the concentration index and industrial profitability which measure in detail the rates of profit and the market share [48].

To guarantee the future of the railway sector, the analysis of the competition and in particular the access of new operators is required [18]. Therefore, understanding the conditions that allow stable access of new railway operators under the upcoming liberalisation framework is at the core of the analysis carried out and presented in this paper. More specifically, the analysis focuses on the following:

- The strategic decisions that incumbent and newcomer operators need to take;
- The need for maximising profits;
- The operational costs incurred;
- The allocation of ticket prices and frequency of services as variables directly influencing competition;

Policy and political decisions are not part of the work as they are related to welfare analysis.

The model described in this paper aims to illustrate in a simple but effective way the complex web of strategic decisions a company needs to take in order to survive in a given sector of the economy. In this case the model focuses on the intramodal competition between an incumbent operator and a new operator trying to enter the market. The competition is based on basic variables such as ticket prices, frequency of service, core investment and operational costs. The competition between modes (high speed rail and air mainly) will also be considered in the Madrid-Barcelona case study.

The liberalisation process was officially adopted in Spain with the introduction of a national law at this effect [32] entering into force on 01 January 2005 for passenger services and a year later for freight operators.

In this context, the latest set of data available from 2009 [6] shows that there are currently eleven operating licences allocated in Spain, six of which have already their safety case approved. The data also shows that there are two distinctive profiles of new operators entering the market [33]. Those wholly owned by companies from the construction industry operating freight services and bus operators whose ultimate objective is to run rail passenger services but who apply for freight licences. Construction companies have identified clear synergies between their container operations at ports and the movement of construction materials for their buildings. For bus operators, the running of rail freight services is seen as a key step to acquire necessary knowledge and skills about the rail market and running of rail operations.

This paper describes the analysis of railway competition using a traditional modelling approach (section 2) but to which we propose an alternative by introducing potential analysis of intermodal competition in the revenue function through the use of a logistic or logit function showing the market share of each operator and the competing transport modes on the same corridor (section 3). The particular case of the Madrid-Barcelona corridor is described and used to validate the model (section 4) leading to a set of conclusions (section 5).

## 2 Literature review: Evolution of the railways liberalisation process analysis

### 2.1 Methods using econometrics approach for various transport modes

The analysis of liberalisation processes is relatively recent, particularly applied to the transport sector. Traditionally research in this area has been focused on competitiveness, productivity and technology efficiency [12] using cost analysis [8, 51]. Financial studies related to railways were already carried out at the time [4, 25] as it has been studies regarding network externalities [14] and the analysis of the influence of infrastructure investment on social aspects and wellbeing [37].

These studies into the financial situation of railways prompted the need to analyse the behaviour of passengers.

[1] German National railway

To address these new needs, discreet choice techniques were developed [5, 17, 34, 49]. Discreet choice models are now widely used, having been applied to not only to passenger transport but also freight and maritime transport [16]. The European Commission's Transport White Paper [19] specifically highlights the continuous and systematic misalignment of supply and demand as one of the most significant problems facing the railway sector.

The liberalisation of the air and railway transport sectors instigated expanding the scope of the studies in to areas such as structures for contestable markets, competitiveness and regulation [3]. Potential increases in the capacity of the transport networks and efficient ways to realise them were also covered by these studies [13, 47].

The combined analysis applied to the railway sector of all the previous (productivity and technology efficiency, discreet modal choice and contestable markets) has provided interesting results. Preston et al. [38] made a first attempt to apply these theories to the railway sector, by analysing the potential impact of introducing new rail operators competing on an existing passenger corridor. Whelan and Johnson [52, 53] developed a model based on demand and costs functions analysing the potential outcomes of introducing competition in the railway sector. These included potential offers that could be made if an auction system was to be used to allocate operation licences over specific routes as well as the use and running of stations.

These first attempts resulted in the development of two modelling tools, namely PRAISE [52] and MOIRA [1, 50]. PRAISE rail operations model analyses the interaction between supply and demand coupled with issues such as temporary reduced capacity of the network. Similar approach is taken by MOIRA, developed by AEA Technology Rail (Currently DeltaRail).

### 2.2 Improvements on econometrics approach

The econometrics approach can be improved by introducing two elements, namely:

- Discrete choice models, improving the estimation of demand functions to reflect more accurately the process whereby the passenger decides which transport mode to choose;
- Game theory to better reflect the strategies adopted by each of the operators involved.

Current practice in analysing the behaviour of the different stakeholders involved in a particular sector of the industry uses a combination of industrial management theory, game theory and discrete choice theory. For instance, these have been successfully applied to the analysis of intramodal competition in the aviation sector since its liberalisation process started in the early 1990s. Berry [7] developed a model for estimating the access conditions of new operators to the air passenger sector.

Ivaldi and Vives [24] analyse competition in the railway sector applying Game Theory, using a demand function based on a nested logit. Alder et al. [2] focused on studying the social benefits attached to the competition between high speed rail and air transport in Europe using a two stages model based on Game Theory.

Current additional tendencies analyse the infrastructure and access charges that best suit potential competitors as well as policies aimed at regulating access charges to congested sections of the railway network [15] or the air sector [11].

### 2.3 Applicability remarks

As a result of all the previous work, the models developed can be clustered into two main groups applicable to the railway case depending if there are based on econometric tools or tools using strategies analysis and game theory:

A first group includes models that focus on solving a partial equilibrium algorithm, ignoring the analysis of strategies and the interaction of the decisions made by different operators. Examples of this include the intermodal analysis modelling by Marc Ivaldy and Catherine Vibes [23, 24], the demand and cost function based models developed by Preston et al. [38], Wheelan and Johnson [52] and Glass [20] as well as the early models applied to transport analysing the strategic behaviour and price equilibrium situations by Brander and Zhang [9] and Oum et al. [36]. All these models provide results limiting the analysis of potential future situations;

A second group is formed by models that use the capabilities of microeconomics analysis based on game theory and the definition of strategies based on organisational theory. In addition such models tend to also include testbed experimental data. Within this group there is a particular type of model that focuses on the analysis of access to the network which is essential to the liberalisation assessment. At the core of these models is the allocation of capacity slots allowing the detailed analysis of the relationship between infrastructure managers and railway operators using an auctions approach based on experiments. Cox et al. [15] used this approach to analyse competition involving allocation of rights to use station and time-slot routes by price bids in a combinatorial auction with competition involving allocation of rights to regional monopolies by fare-structure bids for supplying a pre-specified minimum schedule. Brewer and Plott [10] developed a mechanism based on combinational auctions to assess the decentralised allocation of access rights to the Swedish rail network. Other models focus exclusively on the allocation of slots such as those developed by Nilsson [35] and Isacsson and Nilsson [22]. Also part of this group are models assessing the choice between frequency and the type of vehicle and their implications in terms of costs [39].

## 3 Spanish context

The liberalisation process was officially adopted in Spain by passing a Law (ley 39/2003) which came into force on 1$^{st}$ January 2005 for passenger-related services and a year later for freight services.

This paper applies the model to the conditions in the Spanish rail passenger market, with one operator having a dominant position. In particular, the high speed rail corridor between Madrid and Barcelona, which has been subject of a number of economic [46] and air-rail competition studies [21]. In addition, de Rus and Inglada [43] and de Rus and Nombela [45] have performed comprehensive cost-benefit analyses of the high speed rail case for Spain.

In this context, the latest set of data available [6] shows that there are eleven operating licences allocated in the country, of which six of them have their safety cases already approved. The data also shows that there are two distinctive profiles of new operators entering the market [33]. Those wholly owned by companies from the construction industry operating freight services and bus operators whose ultimate objective is to run rail passenger services but who apply for freight licences. Construction companies have identified clear synergies between their container operations at ports and the movement of construction materials for their buildings. For bus operators, the running of rail freight services is seen as a key step to acquire necessary knowledge and skills about the rail market and running of rail operations.

## 4 The model

The model described in this paper considers the work described in section 2, particularly in reference to the use of cost and revenue functions although it has significant differences in the way the three theories are combined. It allows the competition simulation of the railway market behaviour using a specific demand and costs structure in the second stage of the model (see section 3), introducing techniques used in capital investment analysis. This analysis includes the considerations of Berry [7] regarding market share. A logit function has been used for this purpose. The methodology basis of this widely used technique assumes that the cost reduction is already achieved and therefore the focus must be directed at increasing revenue by expanding the market share. The model complies with the Nash equilibrium point mathematical conditions establishing that in order to be unique it must be the absolute maximum (necessary and sufficient conditions). The model also complies with pay-off functions in relation to the definition of the reaction functions. Pay-off functions identify the response of a particular player (railway operator in this case) to the choices of the rest of the players (competing operators).

The outcome of the model as a result of the application of mathematical tools defined by the Game Theory complies with economic theory, allowing the valid interpretation of such results. This is considered when defining the demand, cost and benefit functions as well as the key conditions establishing the costs and charges (ticket prices), allowing a more inclusive view of the competition environment.

The application of the concepts described above make possible the modelling of competition in the railway sector. This provides the entry conditions that a new operator must adopt in a competing market.

The model has the potential to be further developed to include additional railway stakeholders introducing the infrastructure manager and the decisions related to the value and level of access charges [31]. However this would jeopardise the accuracy and scope of the results as it would not allow the in-depth analysis of the competition relationship between operators which are considered as essential to the success of the liberalisation process.

The potential social benefits deriving from the introduction of competing rail passenger services are out of the scope of the model here presented. Also out of scope is the effects introduced by an operator running network services as opposed to A to B services and/or in combination with other transport modes (an air transport style “hub and spoke” approach). Instead, the work focuses on the strategic decisions that the operators must take to enter a competing market. The methodology developed by the authors is based on a simple analytical model describing the competition between two railway operators and between these and other modes (Low-cost airlines mainly) in a Bertrand two stage game. The model and its methodology here presented offer a clear analysis of overall passenger demand management from all possible transport modes on the given corridor using a market share approach. Critically, it also provides with a clear assessment of how the competition measures introduced for the railway services liberalisation affect the overall market share of rail, which is one of the main objectives of the European policy for the sector.

The model developed is a two-stage game model as shown in the diagram in Fig. 1 (Fig. 1).

On the first stage the new operators decide whether they enter or not the market based on the available information. On the second stage the new operators has entered the market and start competing with the established operator. The quantification of the fixed costs is included in the investment requirements calculation (see section 5.4). The competition in prices will define the survival of the operators in the market.

### 4.1 Profit, cost and demand function

This section describes the profit function of the rail operators competing in the corridor including intermodal competition.

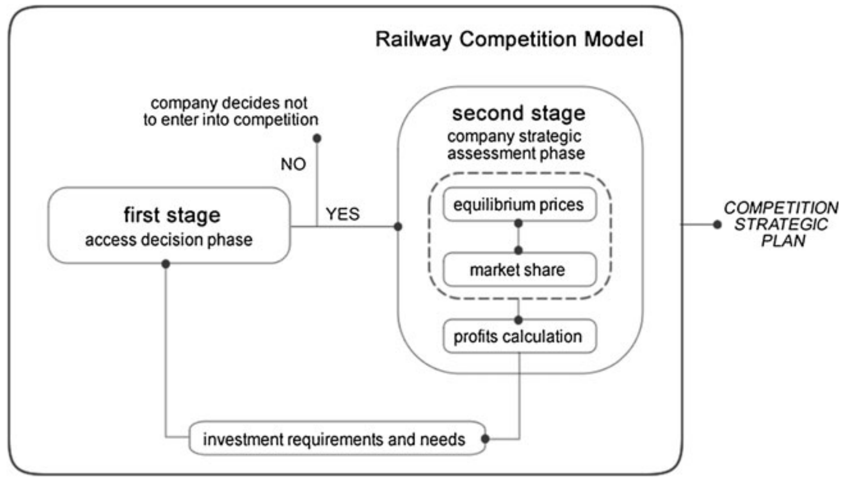


**Fig. 1** diagram of the Rail Competition Model

*Profit function* The profit function for each of the $i$ railways operators (1) is as follows:

$$\prod_i = I_i - C_i = p_i q_i = c_i q_i = q_i(p_i - c_i) = s_i Q_i(p_i - c_i) \quad (1)$$

Where $i$ is the operating company. $\Pi_i$ represents the profit made by operator $i$ (€), $I_i$ is its turnover (€) and $C_i$ (€) is the term representing its costs. $p_i$ represents the price (€) of a ticket and $q_i$ the demand (number of passengers) which is a function of the market share ($s_i$) of a given operator in relation to the total demand for the corridor (number of passengers). $Q_t$ is the total demand in the corridor. In this environment the operators use ticket price competition to achieve a market share as defined by Berry [7].

*Demand function* The demand ($d$) function (2) includes the prices and specific conditions for each operator. It critically improves current methods by focusing on the decision process introducing a logit Eq. (3).

$$d_i(p) = Q_t s_i \quad (2)$$

$$s_i = \frac{x_i}{x_{01} + x_{02} + x_r} \quad (3)$$

$$i = 01, 02, r$$

$$x_i = \exp(x_i)$$

$$x_{01} = \exp(\beta_{01} + \beta p_{01})$$

$$x_{02} = \exp(\beta_{02} + \beta p_{02})$$

$$x_r = \exp(\beta p_r)$$

Where $\beta_{01}$ and $\beta_{02}$ are specific constants representing all possible economic factors not related to prices (prices are included in $\beta$ which is related to the price functions of all operators and transport modes). Parameter $x$ represents conditional changes in the probability of choosing a specific transport mode related to infinitesimal variations in the specific constant and price. $\beta_{01}$ and $\beta_{02}$ encapsulate all factors affecting the competition such as regulation, policy, specific access conditions, entry barriers, constants representing elements of the competition for an established operator (01) and an operator willing to enter the market (02) not being covered by price. These include brand image, reputation, technical and operational practical knowledge of the corridor and network statement. Table 1 summarises the scope of $\beta_{01}$ and $\beta_{02}$ values.

The two rail operators considered in the analysis are noted as operator 01 ($E_{01}$) representing an established competitor (state-owned companies which used to have a monopoly in the sector) and operator 02 ($E_{02}$) representing a new competitor willing to enter the market. Operator r ($E_r$) represents the rest of operators other than railways competing in the same market/corridor. In the case of high speed rail competition for the Madrid-Barcelona corridor this means low-cost airlines.

The demand function uses a multinomial logit that calculates the probability of a passenger choosing a specific operator once he/she has decided to travel and by which transport mode.

The only limitation of the model is that the total demand for competing services (rail and air transport) is determined prior to running the model. The competition in ticket prices does

**Table 1** description of specific constant values

| *B* | Description |
|---|---|
| 0 | The reputation of the operator has no effect |
| 0.5 | Medium effect. The operator has certain level of trust and loyalty from its passengers giving a slight advantage. |
| 1 | Strong effect. The operator has full trust and loyalty from its passengers giving a clear competitive advantage. |

not include the upper and lower limits of the price range that could attract potential additional passengers from other transport modes such as coach travel or private cars [42].

*Cost function* This function includes only variable costs as fixed costs are already considered in the first stage when operators carry out an assessment process prior to deciding whether or not entering the market based on investment requirements.

Using the equilibrium point approach the model evaluates the competition and its viability in the long term.

### 4.2 Equilibrium point analysis

This section addresses the competition between two rail operators using the functions and restrictions already defined. The equilibrium is solved in the second stage (Fig. 1) using backward induction.

*First stage*: the railway operators establish their investment and fixed costs to decide whether or not to enter in competition;

*Second stage:* the operators that do enter the market start a price competition to obtain a market share that guarantees their permanence;

The optimum response (4) of the established operator $E_{01}$ to a ticket price ($p_{02}$) set by the new operator $E_{02}$ it is represented by a reaction function $R_{01}(p_{02})$ obtain from maximising the profits function (1).

$$\frac{\partial \prod_{01}}{\partial p_{01}} = q_{01} + (p_{01} - c_{01})\frac{\partial q_{01}}{\partial p_{01}} = 0 \tag{4}$$

$$\frac{\partial \prod_{01}}{\partial p_{01}} = s_{01}Q_t + (p_{01} - c_{01})\frac{\partial s_{01}Q_t}{\partial p_{01}} = 0$$

Where:

$$\frac{\partial s_{01}Q_t}{\partial p_{01}} = \frac{\beta \exp(\beta_{01}+\beta p_{01})s-(\beta \exp(\beta_{01}+\beta p_{01}))(\exp(\beta_{01}+\beta p_{01}))}{s^2}Q_t =$$

$$= \left[\beta s - \frac{(\beta s_{01})(\exp(\beta_{01}+\beta p_{01})}{s}\right]Q_t = Q_t\beta s_{01}(1 - s_{01})$$

$$s_{01} = \frac{\exp(\beta_{01}+\beta p_{01})}{\exp(\beta_{01}+\beta p_{01})+\exp(\beta_{02}+\beta p_{02})+\exp(\beta p_r)} = \frac{\exp(\beta_{01}+\beta p_{01})}{s}; s_{01}$$

$$= \exp(\beta_{01} + \beta p_{01})$$

$$\frac{\partial \prod_{01}}{\partial P_{01}} = Q_t s_{01} + (p_{01} - c_{01})(\beta(1 - s_{01}))Q_t s_{01} = 0$$

For further detail of the results please see annex 01.

## 5 Application to the Madrid-Barcelona high speed corridor

The model has been designed to assess the competition in a European high speed rail corridor. The Madrid-Barcelona corridor has been chosen for its high density of passengers and profit margins being generated for the current operator (established) which makes it potential an attractive option for new operators willing to enter competition. In addition it also fulfils the characteristics already identified by De Rus et al. [44] suggesting that if true competition in the railway passenger sector does take place it would be in duopoly conditions with just two competing operators (established and newcomer) and only on high density corridors.

### 5.1 Equilibrium prices

The first effect of the prospect of an increase in competition is a reduction of the equilibrium prices as a result of the possibility that the new comer operator $E_{02}$ will reduce its costs. Annex 02 provides information about corridor demand and operating costs. The value of the access specific constant as defined in the model varies between *0*, *0.5* and *1* [42].

The operative costs reduction achieved by the new operator ($E_{02}$) allows introducing lower prices than those of operator $E_{01}$ leading to an increased market share on the basis of equal quality of service provided. For instance the model predicts that a 25 % operative costs reduction for operator $E_{02}$ would lead to an establishing equilibrium prices 15.4 % lower (10.6 % if the specific constant is 0.5) which would also reduce the effects of the access specific constant ($\beta_{02}$) by 20 % (21.7 % if the specific constant is 0.5).

### 5.2 Market share

To obtain the market share of the three competitors $E_{01}$, $E_{02}$, $E_r$, the multinomial logit function (5) is applied as follows:

$$\begin{aligned} s_{01} &= \frac{\exp(\beta p_{01}+\beta_{01})}{\exp(\beta p_{01}+\beta_{01})+\exp(\beta p_{02}+\beta_{02})+\exp(\beta p_r)} \\ s_{02} &= \frac{\exp(\beta p_{02}+\beta_{02})}{\exp(\beta p_{01}+\beta_{01})+\exp(\beta p_{02}+\beta_{02})+\exp(\beta p_r)} \\ s_r &= \frac{\exp(\beta p_r)}{\exp(\beta p_{01}+\beta_{01})+\exp(\beta p_{02}+\beta_{02})+\exp(\beta p_r)} \end{aligned} \tag{5}$$

Table 2 shows the market share results from the model.

The price reduction introduced by $E_{02}$ proves to be an effective measure. It permits $E_{02}$ to obtain a proportion of the established operator market share as well as the competitor r. An approximate price reduction of 10 % gives $E_{02}$ a 9 % market share. The weighting factor of the specific constant reduces this advantage in 1 % suggesting that the bigger the relevance of the historical aspects the bigger the cost reduction needed by $E_{02}$ to maintain its competitive position.

The analysis of the market share offers some insights into the intermodal competition. The price reduction and competition between operators $E_{01}$ and $E_{02}$ results in a constant reduction of the market share of the operator $E_r$. Therefore, even if the prices of the established operator $E_{01}$ have to rise due to the specific constant, the equilibrium prices always remain below the price of operator

**Table 2** market share results (source: Renfe Operadora 2005)

| Access Specific Constant ($\beta_{01}$, $\beta_{02}$) | Operational Costs ($C_{01}$, $C_{02}$) | Prices (€) | | Market share (%) | | |
|---|---|---|---|---|---|---|
| | | $p_{01}$ | $p_{02}$ | $s_{01}$ | $s_{02}$ | $s_r$ |
| 0 | $E_{02}=E_{01}$ | 59 | 59 | 42.7 | 42.7 | 14.7 |
| | $E_{02}<E_{01}$ | 58 | 54 | 37.1 | 52 | 10.9 |
| 0.5 | $E_{02}=E_{01}$ | 61 | 58 | 48.4 | 39.3 | 12.3 |
| | $E_{02}<E_{01}$ | 59 | 53 | 42.6 | 48.6 | 8.8 |
| 1 | $E_{02}=E_{01}$ | 63 | 58 | 53.7 | 36 | 10.3 |
| | $E_{02}<E_{01}$ | 61 | 52 | 47.9 | 45 | 7.2 |

$E_r$ (€70), attracting more passengers. These results are in line with field research studies conducted on the same corridor [40, 41].

### 5.3 Additional results from the model: Operators profits and yield calculation

Although the model can obtain the equilibrium prices and market share values directly, these can also be calculated by applying the profit function derived from the model itself. Table 3 summarises the profits as predicted by the model using Eq. (4).

By analysing these figures, the competitive advantage related to the access specific constant can be quantified. They show that competitive advantage in terms of costs obtained by the new operator $E_{02}$ can be sufficient to neutralise the effect of the access specific constant as this affects not only costs but also prices, reflecting in the market share of the operator. Only with higher values of the specific constant the established operator $E_{01}$ can obtain bigger profits than the newcomer operator $E_{02}$. This means that this can only be achieved if renfe operadora ($E_{01}$) can utilise its position as established operator in this corridor by transmitting more confidence than its competitors.

This is valid as long as the newcomer operator matches the established operator passenger loading factor (70 %) and its rolling stock has a capacity of at least 329 seats (estimated average per train using a 70 % loading factor)

*Investment requirements calculation* The results shown so far are related to the characteristics of the competition between two railway operators and a third operator from other transport mode. However the entry conditions for a new operator need to be considered by analysing its fixed costs and calculating investment requirements.

The process stars identifying the fixed costs of the new operator which are related to its investment needs. These costs are obtained calculating the number of vehicles required to achieve the market share obtained in the price competition (see section 5.1) In addition, the model analyses the capacity of the Madrid-Barcelona corridor.

It is estimated that the new operator would need to run an average of 6,500 trains per year representing 22 daily trains. These trains would require compositions of 4 to 6 vehicles as a minimum. Table 4 shows the investment requirement values for the different options of rolling stock operations. The cost of a typical high speed train is in the region of €22 million per composition or convoy plus an estimated €19 million for maintenance over its lifetime. This means that the initial capital investment for the new operator will be around €204 million.

Where $A$ is the costs associated to the acquisition of rolling stock and $B$ is the difference between benefits and annual access charges. A discount rate ($k$) of 5 % is applied. The results are summarised on Table 4

Where the net present value (NPV) is calculated as follows (6):

$$NPV = -A + \frac{B_{01}}{(1+k)} + \frac{B_{02}}{(1+k)^2} + \cdots\cdots + \frac{B_n}{(1+k)^n} = -A + \sum_{j=01}^{n} \frac{B_j}{(1+k)^j} \quad (6)$$

**Table 3** Profit calculation results (number of trains source: ADIF network statement)

| Access Specific Constant ($\beta_{01}$, $\beta_{02}$) | Operational Costs ($C_{01}$, $C_{02}$) | Number of passengers | | | Number of trains per year | | | profit (€) | |
|---|---|---|---|---|---|---|---|---|---|
| | | $E_{01}$ | $E_{02}$ | $E_r$ | $E_{01}$ | $E_{02}$ | Total | $E_{01}$ | $E_{02}$ |
| 0 | $E_{02}=E_{01}$ | 1,493,368 | 1,493,368 | 513,264 | 6,484 | 6,484 | 12,969 | 26,048,059 | 26,048,059 |
| | $E_{02}<E_{01}$ | 1,296,788 | 1,821,737 | 381,475 | 5,631 | 7,910 | 13,541 | 20,601,407 | 37,990,126 |
| 0,5 | $E_{02}=E_{01}$ | 1,694,761 | 1,375,878 | 429,361 | 7,359 | 5,974 | 13,333 | 32,865,643 | 22,670,325 |
| | $E_{02}<E_{01}$ | 1,490,024 | 1,700,449 | 309,528 | 6,470 | 7,384 | 13,854 | 25,937,573 | 33,076,591 |
| 1 | $E_{02}=E_{01}$ | 1,880,196 | 1,259,073 | 360,731 | 8,164 | 5,467 | 13,631 | 40,635,716 | 19,669,860 |
| | $E_{02}<E_{01}$ | 1,674,856 | 1,573,382 | 251,762 | 7,272 | 6,832 | 14,104 | 32,111,166 | 28,576,842 |

**Table 4** Investment requirements results

| Access Specific Constant ($\beta_{01}$, $\beta_{02}$) | Operational Costs ($C_{01}$, $C_{02}$) | Prices (€) | | Profit (€) | | Average number of trains needed | Net Present Value-NPV (€ mil.) |
|---|---|---|---|---|---|---|---|
| | | $p_{01}$ | $p_{02}$ | $E_{01}$ | $E_{02}$ | $E_{02}$ | $E_{02}$ |
| 0 | $E_{02}=E_{01}$ | 59 | 59 | 26,048,059 | 26,048,059 | 8 | 13.7 |
| | $E_{02}<E_{01}$ | 58 | 54 | 20,601,407 | 37,990,126 | 9 | 113.6 |
| 0,5 | $E_{02}=E_{01}$ | 61 | 58 | 32,865,643 | 22,670,325 | 7 | −9.4 |
| | $E_{02}<E_{01}$ | 59 | 53 | 25,937,573 | 33,076,591 | 9 | 69.6 |
| 1 | $E_{02}=E_{01}$ | 63 | 58 | 40,635,716 | 19,669,860 | 6 | −27.4 |
| | $E_{02}<E_{01}$ | 61 | 52 | 32,111,166 | 28,576,842 | 8 | 32.7 |

The model's calculation of the fixed costs only considers rolling stock that could improve the financial situation of the new operator. Nevertheless, this new operator will be able to enter the passenger high speed rail services on the Madrid-Barcelona corridor if it can maximise its competitive advantage in terms of costs. The established operator $E_{01}$ will be able to retain its leading position in the market if it can maintain its core characteristic as the recognised company.

The model can establish the minimum market share that the operators are competing for, that is the minimum market share to be able to successfully enter the market. In the particular case of the high speed corridor between Madrid and Barcelona, this minimum market share is in the region of 25–30 %.

## 6 Conclusions

The analysis of the potential competition for passenger railway services is essential at a time where liberalisation is being introduced in Europe and when a debate about this process is still open. The objectives of this liberalisation process range from financial and market share related to a more efficient use of existing and future infrastructure addressing also key sustainability aspects.

The European Commission is proposing to measure competition by setting a number of performance indicators. These indicators, although able to provide useful comparable information do not give an insight on the cause-effect relation that leads the decision making process by operating companies.

This paper briefly reviews the existing knowledge and models that facilitate this cause-effect analysis to propose a specific model that would allow the assessment of the strategic decisions made by rail operating companies. This model contributes to knowledge by improving existing approaches to include a logit as part of the revenue function for the operators which provides the market share gains as a direct result of the decisions made in a multimodal environment where decision have an interaction between different operators.

The market share aspects of the model allow a clear analysis of overall passenger demand management for a whole corridor, independent of the transport mode. It also allows the assessment of how the measures introduced in terms of competition affect the total market share of railways which is a primary objective of European policy for the sector.

A key characteristic of this model is the ability of successfully analyse competition between railway operating companies in a simulated environment. The relation between economic theory, game theory and the analysis of strategic decisions and models for analysis of demand in traffic engineering improve the correlation of new operators to real operating conditions.

This two-stage model has been applied to the Madrid-Barcelona corridor to assess the strategic interactions that could take place. As can be seen from the results included in Table 4, there is competitive advantage in what is referred to as historical fact or reputation of the incumbent operator; the greater the value of the access specific constant the greater the profits obtained. In equilibrium the entrant accesses the market if the share is between 25 and 30 %. This is the bracket that ensures its permanence in the market.

Another key outcome of the results shown in Table 4 is that measures should be drawn by the new operator to ensure mitigation of the reputation effect of the incumbent operator. By keeping the value of the access specific constant as low as possible (0 to 0.5) the new operator will have a better chance of making profits and maintain its position in the market.

The analysis has introduce the importance of the effect that the reputation of a given operating company has and how a new operator might need to counterbalance this by establishing a price competition strategy based on reduced operating costs. The results of the Madrid-Barcelona case suggest that this is a valid strategy.

The analysis can be completed with the calculation of rolling stock needs (external data model) as shown in Table 3.

The inputs required for the model are kept simple and manageable. This, together with the application of the Economic Theory and the latest developments in demand function and costs estimation facilitate a good correlation between its results and reality. Application to other case studies can be done in a straightforward and useful manner, providing the necessary knowledge for analysis prior to the introduction of competition. Further improvements to the model can be made through experimental design to analyse in a more complex and continuous manner all aspects related to the liberalisation of railways on a corridor to corridor basis.



## Annex 01

The following table (Table 5) summarises the results obtained solving the Nash-Bertrand equilibrium (equilibrium price and market share) and the reaction functions $R_1$ and $R_2$ determining the strategies between the operators.

**Table 5** Summary of results arising from solving the Nash-Bertrand equilibrium and the reaction functions

| | | |
|---|---|---|
| Price | Maximum profits results | |
| | *E01*<br>$p_{01} = c_{01} - \frac{1}{\beta(s_{02}+s_r)}$ | *E02*<br>$p_{02} = c_{02} - \frac{1}{\beta(s_{01}+s_r)}$ |
| | Equilibrium prices | |
| | *E01* | |
| | $p^*_{01} = c_{01} - \frac{1}{\beta(1-s_{01})} == c_{01} - \frac{1}{\beta\left(\frac{\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}{\exp(\beta_{01}+\beta p_{01})+\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}\right)}$ | |
| | *E02* | |
| | $p^*_{02} = c_{02} - \frac{1}{\beta(1-s_{02})} = c_{02} - \frac{1}{\beta\left(\frac{\exp(\beta_{01}+\beta p^*_{01})+\exp(\beta p^*_r)}{\exp(\beta_{02}+\beta p_{02})+\exp(\beta_{01}+\beta p^*_{01})+\exp(\beta p^*_r)}\right)}$ | |
| Reaction function | *E01*<br>$R_{01}(p_{02}) = c_{01} - \frac{1}{\beta(s_{02}+s_r)}$ | *E02*<br>$R_{02}(p_{01}) = c_{02} - \frac{1}{\beta(s_{01}+s_r)}$ |
| Equilibrium solution | $S^{EN} = \{p^*_{01}, p^*_{02}\} = \left\{ \left(p^*_{01} = c_{01} - \frac{1}{\beta\left(\frac{\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}{\exp(\beta_{01}+\beta p_{01})+\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}\right)}\right), \left(p^*_{02} = c_{02} - \frac{1}{\beta\left(\frac{\exp(\beta_{01}+\beta p^*_{01})+\exp(\beta p^*_r)}{\exp(\beta_{01}+\beta p_{01})+\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}\right)}\right) \right\}$ | |
| Equilibrium demand | *E01*<br>$q^*_{01} = s_{01}Q_t = \frac{\exp\left(\beta\left(c_{01}-\frac{1}{\beta(s_{02}+s_r)}\right)\right)}{\exp\left(\beta\left(c_{01}-\frac{1}{\beta(s_{02}+s_r)}\right)\right)+\exp(\beta_{02}+\beta p^*_{02})+\exp(\beta p^*_r)}Q_t$ | |
| | *E02*<br>$q^*_{02} = s_{02}Q_t = \frac{\exp\left(\beta\left(c_{02}-\frac{1}{\beta(s_{01}+s_r)}\right)\right)}{\exp\left(\beta\left(c_{02}-\frac{1}{\beta(s_{01}+s_r)}\right)\right)+\exp(\beta_{01}+\beta p^*_{01})+\exp(\beta p^*_r)}Q_t$ | |

## Annex 02

*Demand and operating costs in Madrid-Barcelona high speed rail corridor*

Table 6 summarises the demand data (passenger per year) for the corridor based on a combine historic data and demand forecast analysis.

**Table 6** Demand data summary for the corridor (source: Renfe Operadora, 2007)

| Sections | Km | 2008 | 2010 | 2011 | 2015 | 2025 |
|---|---|---|---|---|---|---|
| Madrid-Barcelona | 631,0 | 2.447.130 | 3.016.021 | 3.105.647 | 3.491.586 | 4.052.128 |
| Madrid-Zaragoza | 306,7 | 1.177.995 | 1.376.421 | 1.421.892 | 1.619.305 | 1.879.269 |
| Zaragoza-Barcelona | 324,3 | 988.032 | 1.112.902 | 1.146.829 | 1.293.201 | 1.500.812 |
| Madrid-Lleida | 442,1 | 228.240 | 249.351 | 257.685 | 293.899 | 341.081 |
| Madrid-Tarragona | 522,8 | 233.957 | 304.199 | 316.199 | 369.122 | 428.381 |
| Zaragoza-Lleida | 135,4 | 146.432 | 160.691 | 166.163 | 189.977 | 220.476 |
| Zaragoza-Tarragona | 216,1 | 235.552 | 313.234 | 324.897 | 376.055 | 436.427 |

Table 7 summarises the characteristics and costs for the exploitation of the corridor.

**Table 7** Summary of characteristics and costs on both directions (source: renfe operadora)

| | Madrid-Barcelona | Barcelona-Madrid |
|---|---|---|
| Average running time (min) | 171.2 | 171.8 |
| Average running distance (km) | 610.4 | 626.3 |
| Variable costs per train (€) | 2,950.4 | 2,887.1 |
| Fixed costs per train (€) | 11,490.8 | 11,483.8 |
| Total cost per train (€) | 14,441,2 | 14,370.9 |

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