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Access pricing, infrastructure investment and intermodal competition

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ABSTRACT

This paper considers the existence of a given transport infrastructure and analyzes the optimal conditions for investing in a complementary or rival new infrastructure. The model allows us to identify some key variables to be considered in cost–benefit analysis and highlights the importance of socially optimal access pricing in relation to investment decisions. The socially optimal conditions for investment depend on, among others, the cross-effects between different modes of transport, the volume of demand, the construction cost of the new infrastructure, and the restrictions faced by the regulator.

1. Introduction

This paper considers the existence of a given transport infrastructure and analyzes the optimal conditions for investing in a complementary or substitute new infrastructure. In particular, we focus on transport modes that are characterized by an unbundled vertical structure, in which transport infrastructure is owned by an entity (public or private) that allows downstream firms to use it in order to provide transport services to final consumers. This is the case, for example, of airports or railways.

Public investments in high-speed rail (HSR) infrastructure and airports serve as an excellent case for the analysis of access pricing,[1] investment and intermodal competition. Intermodal competition refers to the provision of transport services by alternative modes. However, for the sake of generality, in this paper, we consider both the case of substitutability and complementarity in the services provided by the different modes of transport.

On the one hand, airlines and HSR may be considered as substitutes in short and medium length routes. Even though several authors set different thresholds on the distance for which the HSR loses its advantage over aircraft (Pavaux, 1994; Buchanan and Partners, 1995; Janic, 2003; De Rus and Nombela, 2007; Vickerman, 2009), most authors agree that the HSR is no longer competitive for distances above 800 km in length (Commission for Integrated Transport, 2004; Givoni and Banister, 2007).

On the other hand, some authors argue that airlines and HSR may be also considered as complements (Givoni, 2005; Givoni and Banister, 2006; Socorro and Viecens, 2013). In this context, Socorro and Viecens (2013) find some intermodal

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[1] Access pricing are charges levied for the use of the transport infrastructure.

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agreements between airlines and railways in Europe. Among all cases, AIRail – the joint venture between Lufthansa, Deutsche Bahn and Fraport – is considered the most advanced intermodal product available to travelers in Europe (Steer Davies Gleave, 2006). AIRail connects Frankfurt airport with Stuttgart and with Cologne. Passengers purchase a single ticket for the entire trip by plane and HSR, and they pick up their luggage at the final destination.

In all cases, either substitutes or complements, access pricing for the use of each infrastructure is crucial. In this paper, we analyze the socially optimal access prices to be charged for the use of airports and the HSR infrastructure with and without budget constraint. This corresponds to either public or regulated private transport infrastructures.

Access pricing for the use of a particular public transport infrastructure is often, in Europe, performed by independent agencies that analyze the specific characteristics of such an infrastructure and take access pricing decisions independently. The Office of Rail Regulation, for example, is the independent safety and economic regulator for Britain's railways and the Civil Aviation Authority has as its prime focus to ensure that the airports at Heathrow, Gatwick and Stansted do not exploit their potential market power. There is no relation between the decisions of both agencies.

Moreover, ECMT (2005) brings evidence on what rail access pricing policy is actually followed by different European countries. In response to a questionnaire, European countries described themselves as following either social marginal cost pricing (with state compensation for the difference between the corresponding revenue and total financial cost), an access pricing policy consisting of collecting the full financial cost minus subsidies, or an access pricing policy consisting of mark-ups to social marginal cost. According to Sánchez-Borràs et al. (2010), France and Spain apply mark ups to social marginal cost, while Germany, Italy and Belgium follow an access pricing policy consisting of collecting the full financial cost minus subsidies.

Rail access pricing in all these countries is set taking into account the specific costs of the rail infrastructure and disregarding the existence of other transport infrastructures. In this paper, we show that if consumers consider that the services provided by the different transport modes are either substitutes or complements, the socially optimal access price for the use of each public infrastructure cannot be set independently. Moreover, we illustrate with an empirical example the consequences of disregarding the degree of complementarity and substitutability between transport modes on optimal access pricing and investment decisions.

There are several papers in the literature analyzing access pricing and capacity investment in facilities with vertical structure.[2] In particular, some recent papers have applied this setting in the analysis of airports, including the analysis of a non-competing airport (Brueckner, 2002; Fu et al., 2006; Zhang and Zhang, 2006), complementary airports (Pels and Verhoef, 2004; Brueckner, 2005; Basso, 2008; Mantin, 2012), or an airport competing with other airports or transport facilities (Basso and Zhang, 2007). Thus, access pricing has been already analyzed either in the case of substitutes or complementary transport facilities.[3]

However, in this paper we consider a model that allows for both, imperfect substitutability or complementarity. In particular, we consider a representative consumer that maximizes a quadratic and strictly concave utility function as proposed by Dixit (1979) and Singh and Vives (1984). This approach allows us to obtain linear demand functions for transport service operators in each transport infrastructure.[4] To our knowledge, this is the first paper that uses this approach to analyze socially optimal access pricing and investment in a context of several transport infrastructures. In particular, we analyze how socially optimal access pricing is affected by the degree of complementarity or substitutability between modes, or even more important, the conditions under which a new complementary or rival facility should be constructed. This paper uses an industrial organization approach, providing a methodology to identify some key elements to be considered in cost–benefit analysis, and empirically illustrating the importance and sensitivity of the results to the parameters and restrictions faced by the regulator.

We consider a dynamic model in which different agents sequentially choose their actions. In the first period, a benevolent regulator must decide whether or not to construct a new transport infrastructure, taking into account that there already exists a substitute or complementary transport infrastructure. In the second period, the regulator must decide the access price to be charged to private operators for the use of public infrastructures. We distinguish between a welfare-maximizing regulator (first best approach) and a budget-constrained welfare-maximizing regulator, that is, a regulator that maximizes social welfare but must achieve financial breakeven (second best approach). Given the access prices, in the next period private operators set ticket prices. Finally, given the ticket prices, consumers decide how often they will use each transport mode, where the modes are considered as imperfect substitutes or complements.

Transport infrastructure usually involves significant amounts of public funds and the investment is, essentially, irreversible. The decision of constructing a new infrastructure not only requires the project to have a positive net present value compared with an alternative in which optimal access pricing is not applied, but also to increase the social welfare compared to the situation in which the infrastructure is not constructed and socially optimal access pricing is used. In this sense, if the regulator is not subject to any budget constraint we show that the new infrastructure is more likely to be constructed

[2] For a general review on access pricing see, for example, Laffont and Tirole (1994), Vickers (1995), or Armstrong (2002). For a general review on the relationship between access pricing and private incentives to invest see, for example, Gans and Williams (1999), Gans (2001), or Valletti (2003).

[3] See also Van der Weijde et al. (2013) for a model of perfect substitutes between rail and road or De Borger et al. (2008) for a model of toll and capacity choices on transport networks with either parallel competition (substitutes) or serial competition (complements).

[4] This approach has been extensively used in the transport literature (see, for example, Lin (2004), Oum and Fu (2007), Flores-Fillol and Moner-Colonques (2007), Clark et al. (2009), Socorro and Betancor (2010), or Clark et al., 2011). Socorro and Viecens (2013) also use this approach to analyze the potentials of airline and HSR integration. Fu et al. (2006) use it to analyze how access pricing in an airport affects downstream airline competition. However, they just consider one infrastructure and they do not focus on optimal access pricing.

the higher the private revenues, the lower the demand elasticity and the lower the social cost of the investment. Given these values, a key parameter is the population. High individual willingness to pay, low opportunity cost of capital and low construction costs are not enough unless we have a reasonable level of demand, which is proportional to the number of users.

This paper supports and qualifies some of the results found in the cost–benefit analysis literature. Firstly, this literature highlights the role of the number of passengers when evaluating the construction of a new transport infrastructure. Thus, Vickerman (1997), de Rus and Román (2006), de Rus and Nash (2007), de Rus and Nombela (2007) and de Rus (2012) conclude that high-speed rail investment requires a minimum first year demand threshold within the range of 10–30 million passenger-trips for a line of 500–600 km, which is unlikely to be satisfied in many transport corridors in Europe. Secondly, economists have devoted high effort in estimating the social discount rate (Burgess and Zerbe, 2013; Moore et al., 2013) and the investment cost of transport infrastructures (HEATCO, 2006; Campos and de Rus, 2009). The economic model developed in this paper supports the need of estimating all these variables in order to decide whether or not to construct a new infrastructure. Moreover, it also shares the cost–benefit analysis idea that the investment decision may vary dramatically depending on whether the government only charges variable costs or aims for full cost recovery (De Rus, 2011).

Governments and supranational agencies argue that one of the main benefits of rail infrastructure investment is the reduction of environmental externalities. In general, aviation is considered a mode of transport more environmentally friendly than HSR, especially regarding its impact on climate change (Eurocontrol, 2004; Schreyer et al., 2004; Givoni, 2007). However, the use of capacity must be high enough to offset the pollution associated with the production of electric power consumed by high speed trains (and in the construction period), as well as noise pollution (Kageson, 2009). Given the intense debate in the literature about the environmental costs of rail and air transport, we have included such impacts in our model. However, we have not included other indirect effects. The reason is that in undistorted competitive markets, the net benefit of a marginal change in secondary markets is zero: welfare remains constant as long as the price changes are small. As Greenwald and Stiglitz (1986) points out: "… if firms are maximizing profits and individuals are maximizing utility, both facing prices that correctly reflect opportunity costs, then standard envelope theorem arguments imply that changes in profits or utility induced by changes in allocations (resulting from any small change in prices) are negligible".

The rest of the paper is organized as follows. Section 2 is dedicated to present the main features of the model. The model is solved backwards. Thus, Section 3 analyzes the operators' maximization programs. In Section 4 we discuss the socially optimal access pricing and investment, both in a first best and second best approach. In Section 5 we illustrate the importance and sensitivity of our results with an empirical example. Finally, Section 6 concludes.

2. The model

Following Dixit (1979) and Singh and Vives (1984), we consider an economy composed of an oligopolistic transport sector and a competitive (*numeraire*) sector summarizing the rest of the economy. The transport sector contains two public transport infrastructures (a rail infrastructure and an airport) that are used by private operators.[5] In particular, the rail infrastructure is used by a private rail operator while two private airlines operate in the airport. In this context, a benevolent regulator must decide the access prices to be charged to private operators for the use of public infrastructures in order to maximize the social welfare of the overall economy.

Denote by q_1, q_2, q_t the quantity offered by airline 1, airline 2 and the rail operator, respectively. Consumers are all identical with a utility function separable and linear in the *numeraire* good, m: $U(q_1, q_2, q_t) + m$. Therefore, there are no income effects on the transport sector, and we can perform partial equilibrium analysis.

$U(q_1, q_2, q_t)$ is assumed to be quadratic and strictly concave:

$$U(q_1, q_2, q_t) = u_a q_1 + u_a q_2 + u_t q_t - \frac{1}{2}\left(q_1^2 + q_2^2 + q_t^2 + 2\gamma q_1 q_2 + 2\delta q_1 q_t + 2\delta q_2 q_t\right), \tag{1}$$

where u_a and u_t are positive parameters, γ represents the degree of product differentiation between airlines, and δ represents the degree of product differentiation between airlines and the railway. We assume that passengers consider that airlines are substitutes but exhibit brand loyalty to particular carriers, that is, airlines sell differentiated products.[6] Therefore, $\gamma \in [0, 1)$. When the parameter γ is zero, airlines are independent. As γ tends to one, airlines are considered better substitutes. On the contrary, passengers may consider railways and airlines either as substitutes or complements. Therefore, we assume that $\delta \in (-1, 1)$. If δ is negative, airlines and rail are complements. If δ is positive, airlines and rail are substitutes. Thus, as δ tends to minus one, rail and airlines are considered better complements, while as δ tends to one, rail and airlines are considered better substitutes. The parameter δ is equal to zero when passengers consider rail and airlines as independent goods. Notice that we are always in a context of imperfect substitutability or complementarity. Moreover, we assume that $\gamma > \delta$, which always holds if airlines and rail are complements. If airlines and rail are substitutes, the previous condition implies that passengers consider that the degree of substitutability between one airline and the train is lower than the degree of substitutability between one airline and the other one. Finally, in order to have the model well defined, we also assume that $\gamma > \delta^2$.

[5] Other transport modes can be included in the *numeraire* sector.

[6] Product differentiation between airlines may be due to different reasons such as brand loyalty, the existence of frequent flier programs, etc. (see, for example, Brueckner and Whalen, 2000, or Flores-Fillol and Moner-Colonques, 2007).

Passengers' generalized cost is defined as the sum of the ticket price, p_i with $i = 1, 2, t$, and the monetary value of time and/or any disutility component associated with the specific transport mode, t_a and t_t, which includes access, egress, waiting and in-vehicle time, discomfort, etc. Thus, the representative consumer solves:

$$\underset{q_1,q_2,q_t}{\text{Max}}\ U(q_1, q_2, q_t) - (p_1 + t_a)q_1 - (p_2 + t_a)q_2 - (p_t + t_t)q_t, \tag{2}$$

where t_a and t_t denote all costs associated with the specific transport mode except the ticket price.

The above maximization program can be rewritten as:

$$\underset{q_1,q_2,q_t}{\text{Max}}\ \alpha q_1 + \alpha q_2 + \beta q_t - \frac{1}{2}\left(q_1^2 + q_2^2 + q_t^2 + 2\gamma q_1 q_2 + 2\delta q_1 q_t + 2\delta q_2 q_t\right) - p_1 q_1 - p_2 q_2 - p_t q_t, \tag{3}$$

where $\alpha = u_a - t_a$ and $\beta = u_t - t_t$ denote the maximum (net of all except ticket price) willingness to pay for travelling by air or by rail, respectively.

The utility function described above gives rise to a linear demand structure for the representative consumer, and direct demands can be written as:

$$\begin{aligned} q_1 &= a_a - b_a p_1 + d_a p_2 + d_t p_t, \\ q_2 &= a_a - b_a p_2 + d_a p_1 + d_t p_t, \\ q_t &= a_t - b_t p_t + d_t p_1 + d_t p_2, \end{aligned} \tag{4}$$

where:

$$a_a = \frac{(\alpha - \beta\delta)}{1 + \gamma - 2\delta^2}, \quad b_a = \frac{(1 - \delta^2)}{(1 - \gamma)(1 + \gamma - 2\delta^2)}, \quad d_a = \frac{(\gamma - \delta^2)}{(1 - \gamma)(1 + \gamma - 2\delta^2)}$$

$$a_t = \frac{\beta(1 + \gamma) - 2\alpha\delta}{1 + \gamma - 2\delta^2}, \quad b_t = \frac{1 + \gamma}{1 + \gamma - 2\delta^2}, \quad d_t = \frac{\delta}{1 + \gamma - 2\delta^2}.$$

We assume that $\alpha - \beta\delta > 0$, and $\beta(1 + \gamma) - 2\alpha\delta > 0$. Notice that, given our assumptions, a_a, b_a, d_a, a_t, and b_t are strictly positive, while d_t may be positive or negative depending on whether airlines and the railway are substitutes or complements, respectively.

We assume that operating airlines and the rail operator produce an environmental damage. Let us denote by A the environmental damage that airlines produce per passenger and by T the environmental damage per passenger produced by the rail operator.[7]

The timing of the game is as follows: In the first period, a benevolent regulator must decide whether or not to construct a new rail infrastructure, taking into account that there already exists an airport and that consumers perceive the airlines services either as substitutes or complements to the railway services. In the second period, the regulator must decide the access price to be charged to private operators for the use of public infrastructures. We distinguish between a welfare-maximizing regulator and a budget-constrained welfare-maximizing regulator, that is, a regulator that maximizes social welfare but must achieve financial breakeven. In the last period and given the access prices, private operators compete in prices with differentiated products. The game is solved by backward induction.

3. Third period: private operators' maximization programs

In the third period, private operators consider access prices as given. Let us denote by μ_a the access price charged to private airlines for the use of the public airport, and by μ_t the access price charged to the rail operator for the use of the public rail infrastructure. Let us denote by c_a and c_t the constant marginal operating cost for airlines and rail, respectively.

Each airline i maximizes its own profits and, thus, airline i solves the following maximization program:

$$\underset{p_i}{\text{Max}}\ \pi_\text{i} = (p_i - c_a - \mu_a)q_i, \tag{5}$$

where q_i is given by expression (4), with $i = 1, 2$.

The rail operator solves the following maximization program:

$$\underset{p_t}{\text{Max}}\ \pi_\text{t} = (p_t - c_t - \mu_t)q_t, \tag{6}$$

where q_t is given by expression (4).

First order conditions for airline 1, airline 2 and the rail operator's maximization program are given by:

[7] For the sake of simplicity, we just consider operating environmental costs, ignoring all fixed environmental costs that might arise during the construction of the public infrastructures.

$$\frac{\partial \pi_1}{\partial p_1} = a_a + \mu_a b_a - 2p_1 b_a + p_2 d_a + b_a c_a + d_t p_t = 0,$$
$$\frac{\partial \pi_2}{\partial p_2} = a_a + \mu_a b_a - 2p_2 b_a + p_1 d_a + b_a c_a + d_t p_t = 0, \quad (7)$$
$$\frac{\partial \pi_t}{\partial p_t} = a_t + \mu_t b_t + p_1 d_t + p_2 d_t + b_t c_t - 2b_t p_t = 0.$$

Privately optimal ticket prices are then given by:

$$p_1^* = p_2^* = \frac{1}{4b_a b_t - 2d_t^2 - 2d_a b_t}(2a_a b_t + a_t d_t + 2\mu_a b_a b_t + \mu_t b_t d_t + 2b_a c_a b_t + b_t c_t d_t)$$
$$p_t^* = \frac{1}{4b_a b_t - 2d_t^2 - 2d_a b_t}(2b_a a_t + 2a_a d_t - d_a a_t + 2\mu_a b_a d_t + 2\mu_t b_a b_t - \mu_t d_a b_t + 2b_a c_a d_t + 2b_a b_t c_t - d_a b_t c_t). \quad (8)$$

Let us now analyze how optimal ticket prices change when both the access price for the use of the own public infrastructure and the access price for the use of the other public infrastructure are increased. Both results are summarized in the following lemmas.

Lemma 1. *The higher the access price for the use of the public airport μ_a, the higher the ticket price to be charged to consumers by airlines. The higher the access price for the use of the rail infrastructure μ_t, the higher the ticket price to be charged to consumers by the rail operator.*

Proof. See the Appendix A. ■

Lemma 2. *If airlines and the railway are substitutes (complements), the higher the access price for the use of the public airport μ_a, the higher (the lower) the ticket price to be charged to consumers by the rail operator. If airlines and the railway are substitutes (complements), the higher the access price for the use of the rail infrastructure μ_t, the higher (the lower) the ticket price to be charged to consumers by airlines.*

Proof. See the Appendix A. ■

4. Socially optimal access pricing and investment

In the second period, anticipating how private operators react to access prices, a benevolent regulator must decide the socially optimal access prices to be charged for the use of public infrastructures. Let us denote by C_a and C_t the marginal operating and maintenance cost of each public infrastructure.

Social willingness to pay for capacity per individual ($SWTP^{capacity}$) is defined as the sum of the individual consumer surplus (CS), private operators surplus per individual and the infrastructure operator surplus per individual, minus environmental costs per individual. Formally:

$$SWTP^{capacity} = CS + \pi_1 + \pi_2 + \pi_t + (\mu_a - C_a)(q_1 + q_2) + (\mu_t - C_t)q_t - A(q_1 + q_2) - Tq_t, \quad (9)$$

where $CS = U(q_1, q_2, q_t) - (p_1 + t_a)q_1 - (p_2 + t_a)q_2 - (p_t + t_t)q_t$.

Thus, social willingness to pay for capacity per individual is given by:

$$SWTP^{capacity} = \alpha q_1 + \alpha q_2 + \beta q_t - \frac{1}{2}(q_1^2 + q_2^2 + q_t^2 + 2\gamma q_1 q_2 + 2\delta q_1 q_t + 2\delta q_2 q_t) - (A + C_a + c_a)(q_1 + q_2) - (T + C_t + c_t)q_t. \quad (10)$$

Suppose that there are N identical consumers in the society and that K_t denotes the investment required to construct the rail infrastructure, K_a the investment in airport capacity and r is the opportunity cost of capital. Then, social welfare (SW) is defined as the difference between the total social willingness to pay for capacity and the social cost of capacity:

$$SW = N\ SWTP^{capacity} - rK_a - rK_t, \quad (11)$$

that is:

$$SW = N\left[\alpha q_1 + \alpha q_2 + \beta q_t - \frac{1}{2}(q_1^2 + q_2^2 + q_t^2 + 2\gamma q_1 q_2 + 2\delta q_1 q_t + 2\delta q_2 q_t) - (A + C_a + c_a)(q_1 + q_2) - (T + C_t + c_t)q_t\right] - rK_a - rK_t. \quad (12)$$

Notice that short-run social marginal costs for the use of public infrastructures are given by the sum of the marginal environmental cost, the marginal operating and maintenance cost of the public infrastructure and the marginal operating costs for private operators, that is:

$$\begin{aligned} SMC_a &= A + C_a + c_a, \\ SMC_t &= T + C_t + c_t, \end{aligned} \qquad (13)$$

where SMC_a and SMC_t denotes the short-run social marginal cost for the use of the airport and the short-run social marginal cost for the use of the rail infrastructure, respectively.

We assume that the maximum (net of all except price) willingness to pay for travelling by air or by rail is higher than the short-run social marginal cost for the use of the airport or the rail infrastructure, respectively, that is, $\alpha > SMC_a$ and $\beta > SMC_t$. Moreover, in order to have the model well defined (positive quantities) we need to assume that $\beta - SMC_t > \frac{2\delta}{1+\gamma}(\alpha - SMC_a) > \frac{2\delta^2}{1+\gamma}(\beta - SMC_t)$.

We will consider two possibilities: a regulator that maximizes social welfare and a regulator that maximizes social welfare but must achieve financial breakeven.

4.1. First best approach: a welfare-maximizing regulator

4.1.1. Optimal access prices for a welfare-maximizing regulator

A welfare-maximizing regulator chooses the access prices for the use of the airport and the rail infrastructure, μ_a and μ_t, in order to maximize the social welfare given by expression (12). First, we have to take into account that privately optimal ticket prices, $p_1^* = p_2^*$ and p_t^*, are given by expression (8), and that optimal quantities, $q_1^* = q_2^*$ and q_t^*, are obtained from expressions (4) and (8). Second, we substitute optimal quantities in the social welfare function given by expression (12). Finally, we derive the resulting social welfare function with respect to μ_a and μ_t. Thus, first order conditions are given by: $\frac{\partial SW}{\partial \mu_a} = 0$ and $\frac{\partial SW}{\partial \mu_t} = 0$.

Solving the system given by the above two first order conditions, we obtain the following socially first best optimal access prices:

$$\begin{aligned} \mu_a^* &= A + C_a + \frac{1-\gamma}{1-\delta^2}[\delta(\beta - SMC_t) - (\alpha - SMC_a)] \\ \mu_t^* &= T + C_t + \frac{1}{1+\gamma}[2\delta(\alpha - SMC_a) - (1+\gamma)(\beta - SMC_t)]. \end{aligned} \qquad (14)$$

Proposition 1. *If consumers do not consider airlines and rail as independent goods ($\delta \neq 0$) the socially optimal access price for the use of each public infrastructure cannot be set independently.*

The socially first best optimal access price for the use of a particular infrastructure is decreasing in the maximum willingness to pay for travelling in that transport mode and increasing in the social marginal costs of that infrastructure. However, Proposition 1 implies that if airlines and rail are not considered as independent goods the decisions on how much to charge for the use of a particular infrastructure must be taken by considering the willingness to pay and social costs not only of that particular good but also those of the other good. The higher the degree of complementarity or substitutability between transport modes, that is, the value of δ in absolute terms, the more important is to consider the cross-effects between facilities when deciding the optimal access pricing.

If goods are substitutes, the socially first best optimal access price for the use of a particular infrastructure is increasing in the maximum willingness to pay for travelling in the other transport mode and decreasing in the social marginal costs of the other infrastructure. On the contrary, if goods are complements, the socially first best optimal access price for the use of a particular infrastructure is decreasing in the maximum willingness to pay for travelling in the other transport mode and increasing in the social marginal costs of the other infrastructure. All these results are summarized in the following proposition.

Proposition 2. *The socially first best optimal access price for the use of a particular public infrastructure is higher:*

- *the lower is the maximum willingness to pay for travelling in that transport mode* $\partial\mu_a/\partial\alpha < 0$, $\partial\mu_t/\partial\beta < 0$;
- *the higher are the social marginal costs of that particular infrastructure* $\partial\mu_a/\partial A > 0$, $\partial\mu_a/\partial C_a > 0$, $\partial\mu_a/\partial c_a > 0$, $\partial\mu_t/\partial T > 0$, $\partial\mu_t/\partial C_t > 0$, $\partial\mu_t/\partial c_t > 0$;

Moreover, if consumers consider airlines and rail as substitutes (complements) the socially first best optimal access price for the use of a particular public infrastructure is higher:

- *the higher (lower) is the maximum willingness to pay for travelling in the other transport mode* $\partial\mu_a/\partial\beta > (<)0$, $\partial\mu_t/\partial\alpha > (<)0$;
- *the lower (higher) are the social marginal costs of the other infrastructure* $\partial\mu_a/\partial T < (>)0$, $\partial\mu_a/\partial C_t < (>)0$, $\partial\mu_a/\partial c_t < (>)0$, $\partial\mu_t/\partial A < (>)0$, $\partial\mu_t/\partial C_a < (>)0$, $\partial\mu_t/\partial c_a < (>)0$.

Proof. See the Appendix A. ■

Let us look at the socially optimal ticket prices and quantities per individual that are induced by the regulator. Socially optimal ticket prices are obtained by substituting the socially first best optimal access prices given by expression (14) into the privately optimal tickets prices given by expression (8). It is straightforward to show that $p_1^* = p_2^* = A + C_a + c_a$ and $p_t^* = T + C_t + c_t$. This is a well-known result in the access pricing literature.

Socially optimal quantities are obtained by substituting the socially optimal ticket prices obtained above into the demand functions given by expression (4). Thus, socially optimal quantities for airlines and the rail operator are given by:

$$q_1^* = q_2^* = \frac{1}{1+\gamma-2\delta^2}[\alpha - SMC_a - \delta(\beta - SMC_t)]$$
$$q_t^* = \frac{1}{1+\gamma-2\delta^2}[(1+\gamma)(\beta - SMC_t) - 2\delta(\alpha - SMC_a)] \tag{15}$$

The maximum social willingness to pay for capacity per individual $SWTP^{capacity^*}$ is obtained by substituting the socially optimal quantities given by expression (15) into the function given by expression (10). The maximum social welfare SW^* is obtained by substituting the socially optimal quantities given by expression (15) into the function given by expression (12).

Taking into account expressions (14) and (15), first best optimal access prices can be rewritten as:

$$\mu_a^* = A + C_a - \frac{1}{b_a}q_1^*,$$
$$\mu_t^* = T + C_t - \frac{1}{b_t}q_t^*. \tag{16}$$

Let us define by ε_1^* the demand elasticity of airline 1 or 2 with respect to his own price evaluated in the social optimum, that is, $\varepsilon_1^* = -b_a\frac{p_1^*}{q_1^*}$. Let us also denote by ε_t^* the demand elasticity of the rail operator with respect to his own price evaluated in the social optimum, that is, $\varepsilon_t^* = -b_t\frac{p_t^*}{q_t^*}$. Then, first best optimal access prices can be also written as:

$$\mu_a^* = A + C_a - \frac{p_1^*}{|\varepsilon_1^*|},$$
$$\mu_t^* = T + C_t - \frac{p_t^*}{|\varepsilon_t^*|}. \tag{17}$$

Eq. (17) indicates that the difference between the socially optimal access price charged for the use of a particular transport infrastructure and its marginal operating and maintenance costs is the difference between marginal environmental costs and a term that depends on market power. The higher the market power of private operators, the lower are access prices. Moreover, if the demand elasticity (in absolute value) is low enough socially optimal access prices may be even negative, that is, the regulator gives subsidies to private operators in order to induce them to charge a ticket price equal to short-run social marginal costs. This is a well-known result in the access pricing literature.

4.1.2. Rail infrastructure investment for a welfare-maximizing regulator

Suppose as a benchmark the case in which there is no rail infrastructure. Then, the representative consumer's utility function is given by:

$$U(q_1, q_2) = \alpha q_1 + \alpha q_2 - \frac{1}{2}(q_1^2 + q_2^2 + 2\gamma q_1 q_2), \tag{18}$$

where α denotes the maximum (net of all except price) willingness to pay for travelling by air.

The utility function described above gives rise to a linear demand structure, and direct demands can be written as:

$$q_1 = a - bp_1 + dp_2,$$
$$q_2 = a - bp_2 + dp_1, \tag{19}$$

where $a = \frac{\alpha(1-\gamma)}{1-\gamma^2}$, $b = \frac{1}{1-\gamma^2}$ and $d = \frac{\gamma}{1-\gamma^2}$. Notice that given our assumptions, the parameters a, b, and d are strictly positive.

In this context, a benevolent regulator must decide the access price $\overline{\mu}_a$ to be charged to private airlines for the use of the public airport. Given this access price, airlines compete in prices with differentiated products. Privately optimal ticket prices are then given by:

$$\overline{p}_1^* = \overline{p}_2^* = \frac{1}{2b-d}(a + b\mu_a + bc_a). \tag{20}$$

If there is no rail infrastructure, a benevolent regulator chooses the access price for the use of the public airport $\overline{\mu}_a$ in order to maximize social welfare. In this case, social welfare is defined as:

$$\overline{SW} = N\overline{SWTP}^{capacity} - rK_a, \tag{21}$$

with $\overline{SWTP}^{capacity} = \alpha q_1 + \alpha q_2 - \frac{1}{2}(q_1^2 + q_2^2 + 2\gamma q_1 q_2) - (A + C_a + c_a)(q_1 + q_2)$.

Thus, the socially first best optimal access price is given by:

$$\overline{\mu}_a^* = A + C_a - (1-\gamma)(\alpha - SMC_a). \tag{22}$$

In this social optimum, tickets prices and quantities are given by:

$$\overline{p}_1^* = \overline{p}_2^* = SMC_a, \qquad \overline{q}_1^* = \overline{q}_2^* = \frac{1}{1+\gamma}(\alpha - SMC_a). \tag{23}$$

Then, if there is no rail infrastructure the maximum social welfare that can be achieved is given by:

$$\overline{SW}^* = N\overline{SWTP}^{capacity^*} - rK_a, \tag{24}$$

where $\overline{SWTP}^{capacity*} = \frac{1}{1+\gamma}(\alpha - SMC_a)^2$ is the maximum social willingness to pay for capacity per individual.

Let us now compare the maximum social welfare that can be achieved if there is no rail infrastructure, $\overline{SW}^*$, with the maximum social welfare when there is a rail operator, SW^*. Let $SW^* - \overline{SW}^*$ represent the gain in social welfare due to the existence of a rail infrastructure, and let $SWTP^{capacity^*} - \overline{SWTP}^{capacity^*}$ denote the difference in the maximum social willingness to pay for capacity per individual due to the existence of a rail infrastructure. Then, the gain in social welfare due to the existence of a rail infrastructure is given by:

$$SW^* - \overline{SW}^* = N\left(SWTP^{capacity^*} - \overline{SWTP}^{capacity^*}\right) - rK_t, \tag{25}$$

where $SWTP^{capacity^*} - \overline{SWTP}^{capacity^*} = \frac{1}{2b_t}(q_t^*)^2$, and q_t^* is given by expression (15).

Denoting by ε_t^* the demand elasticity of the rail operator with respect to his own price evaluated in the social optimum, the difference in the maximum social willingness to pay for capacity per individual due to the existence of a rail infrastructure can be rewritten as:

$$SWTP^{capacity^*} - \overline{SWTP}^{capacity^*} = \frac{1}{2}\frac{p_t^* q_t^*}{|\varepsilon_t^*|}. \tag{26}$$

Notice that if the regulator is a welfare-maximizer, the difference in the maximum social willingness to pay for capacity per individual due to the existence of a rail infrastructure is always positive. However, this might not be enough. In order to construct the rail infrastructure we need the society to be willing to pay for the extra costs, that is, we need a gain in social welfare due to the existence of the rail infrastructure.

Proposition 3. If the regulator is a welfare-maximizer the rail infrastructure must be constructed if there is a gain in social welfare for the cases in which the new facility is and is not constructed and first best optimal access pricing is applied, that is, $SW^* - \overline{SW}^* > 0$. In other words, the rail infrastructure must be constructed if and only if:

$$\frac{1}{2}\frac{p_t^* q_t^*}{|\varepsilon_t^*|} > \frac{rK_t}{N}. \tag{27}$$

The social profitability of investing in the new infrastructure depends on the difference between the social willingness to pay for capacity in the case in which there is a rail infrastructure and the case where the rail infrastructure is not constructed, summarized by the left hand side fraction of condition (27), the cost of the infrastructure and the opportunity cost of capital. A key parameter is the population (N) served by the new infrastructure.[8] High social willingness to pay per individual, low opportunity cost of capital and low construction costs are not enough unless we have a reasonable level of demand,[9] and this critically depends on geographic and demographic conditions.

Notice that, in order to be optimal to construct the rail infrastructure we not only need to have a positive social welfare. What we need is the investment to be welfare enhancing, that is, induce a higher social welfare than in the case in which

[8] The size of infrastructure is considered to be fixed and independent from the traffic. Although the size of infrastructure cannot be always considered independent from the traffic volume, transport infrastructure presents a high level of indivisibility which is especially significant in the case of railways.

[9] From actual construction, rolling stock, maintenance and operating costs of European HSR lines, average values of time, a reasonable range of potential travel time savings, and a 5% discount rate, de Rus and Nombela (2007) find that HSR investment is difficult to justify when the expected first year demand is below 8–10 million passengers for a line of 500 km, an optimal length for HSR to compete with air transport. Similarly, de Rus and Román (2006), and de Rus (2012) conclude that high-speed rail investment requires a minimum first year demand threshold within the range of 10–30 million passenger-trips for a line of 500–600 km.

there is no rail infrastructure. Thus, $SW^* > 0$, is a necessary but not sufficient condition. In a first best world, the necessary and sufficient condition implies a positive difference in social welfare for the cases in which the rail is and is not constructed and first best optimal access pricing is applied, that is, $SW^* - \overline{SW}^* > 0$.

All the conditions found in this section imply the availability of public funds without restrictions. In particular, we have shown that for a welfare-maximizing regulator socially optimal access prices may be set below marginal operating and maintenance costs. However, the idea of a regulator subsidizing private operators for the use of public infrastructures may be inacceptable, unfeasible or even inefficient. Thus, in the next subsection we consider a benevolent regulator that maximizes social welfare but is subject to cost recovery.

4.2. Second best approach: a budget-constrained welfare-maximizing regulator

In this subsection we consider a benevolent regulator that maximizes social welfare but must guarantee that for each infrastructure revenues cover all costs, including both operating and maintenance, and investment costs. A regulator that maximizes social welfare but must achieve financial breakeven solves for each representative consumer the following maximization program:

$$\begin{aligned} &\underset{\mu_a,\mu_t}{Max}\ SW = \alpha q_1 + \alpha q_2 + \beta q_t - \frac{1}{2}\left(q_1^2 + q_2^2 + q_t^2 + 2\gamma q_1 q_2 + 2\delta q_1 q_t + 2\delta q_2 q_t\right) - (A + C_a + c_a)(q_1 + q_2) \\ &- (T + C_t + c_t)q_t - rK_a - rK_t \\ &s.t.\ (\mu_a - C_a)(q_1 + q_2) - (rK_a)/N \geqslant 0, \\ &(\mu_t - C_t)q_t - (rK_t)/N \geqslant 0. \end{aligned} \tag{28}$$

If the optimal solutions for a welfare-maximizing regulator satisfy the restrictions given by expression (28), that is:

$$(\mu_a^* - C_a)(q_1^* + q_2^*) - (rK_a)/N \geqslant 0, \tag{29}$$

$$(\mu_t^* - C_t)q_t^* - (rK_t)/N \geqslant 0, \tag{30}$$

then, the maximum social welfare SW^* obtained by a welfare-maximizing regulator coincides with the maximum social welfare obtained by a budget-constrained welfare-maximizing regulator.

Let us denote by sw^* the maximum social welfare achieved by a budget-constrained welfare-maximizing regulator when any of the conditions given by expressions (29) and (30) is not satisfied (second-best solution). Therefore, $sw^* < SW^*$.

Consider as a benchmark the case in which there is no rail infrastructure. If there is no rail infrastructure, a regulator that maximizes social welfare but must achieve financial breakeven solves the following maximization program:

$$\begin{aligned} &\underset{\mu_a,\mu_t}{Max}\ \overline{SW} = N\ \overline{SWTP}^{capacity} - rK_a \\ &s.t.\ N\left[(\mu_a - C_a)(q_1 + q_2)\right] - rK_a \geqslant 0. \end{aligned} \tag{31}$$

If the optimal solutions for a welfare-maximizing regulator in the benchmark case in which there is no rail infrastructure satisfy the condition given by expression (31), that is:

$$(\overline{\mu}_a^* - C_a)(\overline{q}_1^* + \overline{q}_2^*) - (rK_a)/N \geqslant 0, \tag{32}$$

then, the maximum social welfare $\overline{SW}^*$ obtained by a welfare-maximizing regulator if there is no rail infrastructure coincides with the maximum social welfare obtained by a budget-constrained welfare-maximizing regulator if there is no rail infrastructure .

Let us denote by $\overline{swtp}^{capacity^*}$ the maximum social willingness to pay for capacity per individual and by $\overline{sw}^*$ the maximum social welfare achieved by a budget-constrained welfare-maximizing regulator both if there is no rail infrastructure and the condition given by expression (32) is not satisfied (second best solutions). Then, we can conclude that $\overline{swtp}^{capacity^*} < \overline{SWTP}^{capacity^*}$ and, thus, $\overline{sw}^* < \overline{SW}^*$.

Let us now compare the maximum social willingness to pay for capacity per individual if there is no rail infrastructure with the maximum social willingness to pay for capacity per individual when there is a rail operator and the regulator is subject to cost recovery. We can distinguish the following cases:

Case 1: Conditions (29), (30) and (32) are satisfied. Then, the difference between the maximum social willingness to pay for capacity per individual when there is a rail operator and the maximum social willingness to pay for capacity per individual if there is no rail infrastructure and the regulator is subject to cost recovery is given by: $SWTP^{capacity^*} - \overline{SWTP}^{capacity^*} = \frac{1}{2}\frac{p_t^* q_t^*}{|\varepsilon_t^*|}$. In this case, the decision whether to construct or not the rail infrastructure coincides for a welfare-maximizing regulator and for a welfare-maximizing regulator subject to cost recovery.

Case 2: Condition (32) is satisfied but conditions (29) and/or (30) are not satisfied. Then, the difference between the maximum social willingness to pay for capacity per individual when there is a rail operator and the maximum social willingness to pay for capacity per individual if there is no rail infrastructure and the regulator is subject to cost recovery is given by: $swtp^{capacity^*} - \overline{SWTP}^{capacity^*} < SWTP^{capacity^*} - \overline{SWTP}^{capacity^*}$. Notice that in this case it might happen that a welfare-maximizing

Table 1
Minimum number of users required in the first year to construct the rail infrastructure.

Main results	First best approach	Second best approach
Optimal access price for railways	$\mu_t = -24.44$	$\mu_t = 49.17$
Optimal access price for airports	$\mu_a = 2.55$	$\mu_a = 12.12$
Individual demand quantity for rail	$q_t = 97.56$	$q_t = 29.83$
Individual demand quantity for each airline	$q_1 = q_2 = 23.17$	$q_1 = q_2 = 41$
Minimum number of users in the first year (in thousands)	$N = 230.63$	$N = 574.57$
Minimum number of passenger-trips in the first year for rail (in millions)	$N * q_t = 22.5$	$N * q_t = 17.14$

regulator decides to construct the rail infrastructure but a budget-constrained welfare-maximizing regulator does not, that is: $sw^* - \overline{SW}^* < 0 < SW^* - \overline{SW}^*$.

Case 3: Conditions (29) and (30) are satisfied but condition (32) is not satisfied. Then, the difference between the maximum social willingness to pay for capacity per individual when there is a rail operator and the maximum social willingness to pay for capacity per individual if there is no rail infrastructure and the regulator is subject to cost recovery is given by: $SWTP^{capacity^*} - \overline{swtp}^{capacity^*} > SWTP^{capacity^*} - \overline{SWTP}^{capacity^*} > 0$.

Thus, it might be the case that a budget-constrained welfare-maximizing regulator decides to construct the rail infrastructure but a welfare-maximizing regulator does not, that is: $SW^* - \overline{sw}^* > 0 > SW^* - \overline{SW}^*$.

Case 4: Condition (32) and at least one of the conditions (29) and (30) is not satisfied. Then, the difference between the maximum social willingness to pay for capacity per individual when there is a rail operator and the maximum social willingness to pay for capacity per individual if there is no rail infrastructure and the regulator is subject to cost recovery is given by: $swtp^{capacity^*} - \overline{swtp}^{capacity^*}$. In this case, two situations may occur. On the one hand, it might be the case that a budget-constrained welfare-maximizing regulator decides to construct the rail infrastructure but a welfare-maximizing regulator does not, that is: $sw^* - \overline{sw}^* > 0 > SW^* - \overline{SW}^*$. However, it might be also the case that a welfare-maximizing regulator decides to construct the rail infrastructure but a budget-constrained welfare-maximizing regulator does not, that is: $sw^* - \overline{sw}^* < 0 < SW^* - \overline{SW}^*$.

Theoretically all cases can arise. Investment costs are usually very high compared to social marginal costs and, thus, Case 4 is the common situation in self-financed projects. All other cases also correspond to real world situations in which the transport infrastructure is co-financed and, thus, the investment cost considered by the regulator is just part of the full investment cost.

5. Empirical illustration

In order to illustrate the implications of our results when deciding whether to construct or not a new transport infrastructure, we will consider the following case. Suppose a route within the range of 500–650 km length, for example, the route Madrid-Barcelona (Spain). For such a route we will consider two possible transport modes: air transport and high-speed rail. The total investment cost (land costs and stations excluded) for the 621 km of high-speed rail infrastructure joining Madrid and Barcelona was €9.5 billion of 2008 (see Sánchez-Borràs, 2010; de Rus, 2012). Thus, in our example, we will consider that the investment required to construct the rail infrastructure is K_t = €10 billion. On the other hand, the investment in airport capacity is assumed to be €1 billion.[10] However, since for operating the route two airports are needed, we assume that $K_a = €2$ billion. The opportunity cost of capital is assumed to be 5%, that is, $r = 0.05$.

Marginal operating costs are assumed to be covered by the ticket price. Looking at the web in the route Madrid-Barcelona we observe that ticket prices are above €50 for full-service airlines and above €32 for high-speed rail.[11] Thus, in our example, we consider that the marginal operating cost for airlines and rail is $c_a = €40$ and $c_t = €30$, respectively. Moreover, we assume that marginal operating and maintenance costs for each infrastructure are and $C_t = €20$, respectively.

Regarding the consumers, we initially assume that they consider airlines and the high-speed rail as good substitutes, that is, $\delta = 0.7$. The degree of product differentiation between airlines is also assumed to be low, that is, $\gamma = 0.8$. Finally, we assume that the maximum (net of all except ticket price) willingness to pay for travelling by air or by rail is $\alpha = 160$ and $\beta = 180$.

For the sake of simplicity, we will not consider environmental costs, that is, $A = 0$ and $T = 0$, so conditions (29), (30) and (32) are not satisfied (Case 4) and in the optimum all restrictions are binding.

As already shown in this paper, the rail infrastructure must be constructed if the gain in total social willingness to pay for capacity is higher than the cost of the investment, that is, if there is a positive gain in social welfare due to the existence of a rail infrastructure. In order to illustrate the differences between a welfare-maximizing regulator and a regulator subject to cost recovery, let us now obtain the minimum number of users N required in the first year to guarantee that the construction of the rail infrastructure is welfare enhancing, considering both the first best and second best approach. Table 1 summarizes the main results.

[10] The Ciudad Real's Central airport located in Spain (opened in 2008 and closed in 2011) cost €1.1 billion (see http://business.financialpost.com/2013/12/11/spain-ghost-airport-ciudad-real/?__lsa=3d1d-6f5e).

[11] Data from edreams in July 2014 for a round trip ticket in the route Madrid-Barcelona, bought with two months in advance.

Table 2
Sensitivity of first best results with respect to changes in the investment cost of rail infrastructure.

First best approach: a welfare-maximizing regulator			
Investment required to construct the rail infrastructure (in billions of euros)	$K_t = 10$	$K_t = 15$	$K_t = 20$
Optimal access price for railways	$\mu_t = -24.44$	$\mu_t = -24.44$	$\mu_t = -24.44$
Optimal access price for airports	$\mu_a = 2.55$	$\mu_a = 2.55$	$\mu_a = 2.55$
Individual demand quantity for rail	$q_t = 97.56$	$q_t = 97.56$	$q_t = 97.56$
Individual demand quantity for each airline	$q_1 = q_2 = 23.17$	$q_1 = q_2 = 23.17$	$q_1 = q_2 = 23.17$
Minimum number of users in the first year (in thousands)	$N = 230.63$	$N = 345.94$	$N = 461.25$
Minimum number of passenger-trips in the first year for rail (in millions)	$N * q_t = 22.5$	$N * q_t = 33.75$	$N * q_t = 45$

Table 3
Sensitivity of second best results with respect to changes in the investment cost of rail infrastructure.

Second best approach: a budget-constrained welfare-maximizing regulator			
Investment required to construct the rail infrastructure (in billions of euros)	$K_t = 10$	$K_t = 15$	$K_t = 20$
Optimal access price for railways	$\mu_t = 49.17$	$\mu_t = 48.9$	$\mu_t = 48.9$
Optimal access price for airports	$\mu_a = 12.12$	$\mu_a = 11.38$	$\mu_a = 11.02$
Individual demand quantity for rail	$q_t = 29.83$	$q_t = 29.55$	$q_t = 29.36$
Individual demand quantity for each airline	$q_1 = q_2 = 41$	$q_1 = q_2 = 41.45$	$q_1 = q_2 = 41.68$
Minimum number of users in the first year (in thousands)	$N = 574.57$	$N = 876.45$	$N = 1178.09$
Minimum number of passenger-trips in the first year for rail (in millions)	$N * q_t = 17.14$	$N * q_t = 25{,}9$	$N * q_t = 34.59$

Table 4
Sensitivity of first best results with respect to changes in the degree of differentiation between airlines and rail.

First best approach: a welfare-maximizing regulator			
Degree of product differentiation between airlines and railways	$\delta = 0.7$	$\delta = 0$	$\delta = -0.1$
Optimal access price for railways	$\mu_t = -24.44$	$\mu_t = -110$	$\mu_t = -122.22$
Optimal access price for airports	$\mu_a = 2.55$	$\mu_a = -12$	$\mu_a = -14.84$
Individual demand quantity for rail	$q_t = 97.56$	$q_t = 130$	$q_t = 143.82$
Individual demand quantity for each airline	$q_1 = q_2 = 23.17$	$q_1 = q_2 = 61.11$	$q_1 = q_2 = 69.1$
Minimum number of users in the first year (in thousands)	$N = 230.63$	$N = 59.17$	$N = 48.89$
Minimum number of passenger-trips in the first year for rail (in millions)	$N * q_t = 22.5$	$N * q_t = 7.7$	$N * q_t = 7.03$

Table 1 illustrates some of the results obtained in the previous sections of the paper. On the one hand, in absence of environmental costs first best socially optimal access prices are lower than the marginal operating and maintenance cost of the infrastructure and, as shown in Table 1, they can even be negative. On the contrary, if the regulator must achieve financial breakeven, second best socially optimal access prices are always above marginal operating and maintenance costs. Since in a second best optimum access prices are higher, consumers' travel demand decreases, and more users are needed to guarantee a gain in social welfare when the rail infrastructure is constructed. Thus, if we have, for example, 300,000 users in the first year the rail infrastructure should be constructed in a first best world but not if the regulator is budget-constrained. In this case, notice that with our data the number of passenger-trips in the first year[12] for rail is lower in the second best approach since, though more users are needed, they travel less.

Let us now analyze how sensitive are our results to changes in two key parameters of the model: the investment cost required to construct the rail infrastructure and the degree of product differentiation between airlines and the high-speed rail. Let us start with the former. Focusing on the Spanish case, we have initially consider an investment cost for the rail infrastructure of €10 billion. However, this figure may be much higher in other countries. For these reason, we analyze how our results change when we increase the investment cost to €15 billion and €20 billion.

Tables 2 and 3 summarize the main results for the first best and second best approach, respectively. In both cases, a higher investment cost requires a higher number of users and a higher number of passenger-trips in the first year. However, while first best access prices are set independently of the investment cost, second best access prices must guarantee full cost recovery. Hence, as shown in Table 3, second best rail access prices and quantities slightly decrease with the investment cost in rail infrastructure. In the second best approach the minimum number of users increases faster with the investment cost than in the first best approach, requiring a minimum of 1.178 million users for an investment cost of €20 billion.

Tables 4 and 5 analyze the sensitivity of first best and second best results with respect to changes in the degree of product differentiation between airlines and rail. Initially we have assumed that consumers consider airlines and the high-speed rail as good substitutes, that is, $\delta = 0.7$. However, they may also consider both modes of transport as complements. Thus, we will

[12] The minimum number of passenger-trips in the first year is computed assuming that every user travels the whole route length.

Table 5
Sensitivity of second best results with respect to changes in the degree of differentiation between airlines and rail.

Second best approach: a budget-constrained welfare-maximizing regulator			
Degree of product differentiation between airlines and railways	$\delta = 0.7$	$\delta = 0$	$\delta = -0.1$
Optimal access price for railways	$\mu_t = 49.17$	$\mu_t = 84.75$	$\mu_t = 89.52$
Optimal access price for airports	$\mu_a = 12.12$	$\mu_a = 14.32$	$\mu_a = 14.9$
Individual demand quantity for rail	$q_t = 29.83$	$q_t = 32.63$	$q_t = 35.47$
Individual demand quantity for each airline	$q_1 = q_2 = 41$	$q_1 = q_2 = 48.93$	$q_1 = q_2 = 50.31$
Minimum number of users in the first year (in thousands)	$N = 574.57$	$N = 236.69$	$N = 202.78$
Minimum number of passenger-trips in the first year for rail (in millions)	$N * q_t = 17.14$	$N * q_t = 7.72$	$N * q_t = 7.19$

check how our results change if we consider certain degree of complementarity between modes, with $\delta = -0.1$. More interestingly, we can also check how the optimal access pricing and optimal decision on whether or not to construct the rail infrastructure vary if we assume that consumers consider both airlines and high-speed rail services as independent products.

As shown in Tables 4 and 5, both the optimal access price and the minimum number of users required in the first year to construct the rail infrastructure are quite sensitive to changes in the degree of product differentiation. As the degree of substitutability between airlines and the high-speed rail decreases, the minimum number of users and the minimum number of passenger-trips also decreases, both in the first and second best approach.

Optimal access prices differ depending on the degree of substitutability between transport modes, and thus, the decision on the socially optimal access price to be charged for the use of a particular infrastructure must be taken by considering the existence of substitutions or complementarities between facilities. If the regulator does not take the degree of product differentiation into account and just assumes that δ is equal to zero, he might end up setting the wrong access prices and wrong investment decisions.

6. Conclusions

Transport infrastructure investment is essential for economic activity. The provision of additional capacity accommodates the growth of traffic overtime without affecting (or reducing the impact on) the generalized costs of transport, which indeed affects practically all goods and services in the economy. Although transport infrastructure investment is crucial for the operation of a modern economy, it requires significant amounts of public funds. In this context, a sound cost–benefit analysis is fundamental in order to guarantee that only projects that increase social welfare will be finally carried out.

The contribution of this paper to the literature is twofold. On the one hand, it supports and qualifies some of the empirical results found in the cost–benefit analysis literature. In particular, it shows the key variables to be taken into account when deciding whether or not to construct a new infrastructure. On the other hand, it highlights the importance of socially optimal access pricing in relation to investment decisions. Access charges strongly affect operators' profits and consumer surplus and, hence, prices and quantities. Thus, access charges must be considered in any cost–benefit analysis.

The model shows that even in the case in which society's willingness to pay for the construction and operation of a new infrastructure is higher than the investment cost, investing might not be the best option. If the base case implies no socially optimal access pricing, the positive net present value of the investment is not a sufficient condition for implementing the project. In a first best world the necessary and sufficient condition implies a positive difference in social welfare between the cases in which the new infrastructure is and is not constructed, with socially optimal access pricing being applied in both cases. This is not a result derived from the presence of uncertainty and irreversibility but from the interaction of access pricing and investment decisions and the need to consider as a benchmark the case in which social welfare is maximized, that is, the case in which the infrastructure is not constructed and socially optimal access pricing is considered.

Besides supporting and qualifying some empirical models in the literature, the proposed framework has some other important real world applications. On the one hand, one of the main conclusions of this paper is that the decision on the socially optimal access price to be charged for the use of a particular infrastructure must be taken by considering the existence of substitutions or complementarities between facilities. This result has important implication in terms of the institutional design of public agencies such as the ministry of transport in many countries, where the division of management units is usually based on technological characteristics (road, air or rail) with decisions taken in isolation and without considering the overall picture and the important cross-effects between different modes of transport. As shown in this paper, such a real world policy is not optimal.

On the other hand, in this paper we consider projects for which passengers' willingness to pay are higher than short-run social marginal costs, obtaining the optimal conditions for access pricing and investment in a first best framework (welfare-maximizing regulator). Although, first best analysis allows us to identify the key variables to be taken into account in cost–benefit analysis, real world usually requires a second best approach. For this reason, and in order to apply the main results of our model to real life settings, we also consider a budget-constrained welfare-maximizing regulator. As shown in this paper, access pricing strongly affects the results of a transport infrastructure project and, thus, projects that are socially desirable with first best access pricing may not be longer desirable in a budget-constrained world (and vice versa). In general, the second best approach implies higher access prices and, thus, lower travel demand. For this reason, more users are needed to guarantee that the construction of the new transport infrastructure is welfare enhancing.

Although this paper considers some simplifying assumptions (quadratic utility function, symmetric airlines, constant marginal costs, etc.), our model allows the identification of the key variables to be taken into account regarding socially optimal access pricing and investment. All these results are general. However, for the sake of simplicity, we do not consider the cost of public funds.

There are four possible extensions to our model. Firstly, to include in the model the cost of public funds. Secondly, to analyze the optimal timing of the project, considering the possibility of postponing the project one period instead of investing today. Thirdly, to consider networks instead of just transport infrastructures. Finally, to estimate the inefficiencies associated with real world access pricing instead of socially optimal access pricing, both in terms of quantities and prices, and investment decisions.

Finally, we would like to highlight that, though we use the case of airports and rail infrastructure as an example, the main conclusions regarding access prices and investment can be also applied to other public infrastructures (such as ports or toll-roads) with differentiated products considered either as substitutes or complements by users.

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Appendix A

Proof of Lemma 1. We need to check the sign of the following partial derivatives:

$$\frac{\partial p_1^*}{\partial \mu_a} = \frac{\partial p_2^*}{\partial \mu_a} = -b_a \frac{b_t}{d_t^2 - 2b_a b_t + d_a b_t}, \quad \frac{\partial p_t^*}{\partial \mu_t} = \frac{1}{2} \frac{d_a b_t - 2b_a b_t}{d_t^2 - 2b_a b_t + d_a b_t}.$$

We know that b_a and b_t are strictly positive. Given the definitions of b_a, d_a, b_t, and d_t, we have that: $d_t^2 - 2b_a b_t + d_a b_t = -\frac{1}{(1-\gamma)(1+\gamma-2\delta^2)^2}(2+\gamma-\gamma^2-2\delta^2)$, which given our assumptions is clearly negative; $d_a b_t - 2b_a b_t = \frac{1+\gamma}{(1-\gamma)(1+\gamma-2\delta^2)^2}(\delta^2+\gamma-2)$, which given our assumptions is clearly negative. Thus, $\frac{\partial p_1^*}{\partial \mu_a} = \frac{\partial p_2^*}{\partial \mu_a} > 0$ and $\frac{\partial p_t^*}{\partial \mu_t} > 0$, as we wanted to prove. ■

Proof of Lemma 2. We need to check the sign of the following partial derivatives:

$$\frac{\partial p_1^*}{\partial \mu_t} = \frac{\partial p_2^*}{\partial \mu_t} = -\frac{1}{2} b_t \frac{d_t}{d_t^2 - 2b_a b_t + d_a b_t}, \quad \frac{\partial p_t^*}{\partial \mu_a} = -b_a \frac{d_t}{d_t^2 - 2b_a b_t + d_a b_t}.$$

We know that b_a and b_t are strictly positive while d_t may be positive or negative depending on whether airlines and the railway are substitutes or complements, respectively. Given the definitions of b_a, d_a, b_t, and d_t, we have that: $d_t^2 - 2b_a b_t + d_a b_t = -\frac{1}{(1-\gamma)(1+\gamma-2\delta^2)^2}(2+\gamma-\gamma^2-2\delta^2)$, which given our assumptions is clearly negative. Thus, $\frac{\partial p_1^*}{\partial \mu_t} = \frac{\partial p_2^*}{\partial \mu_t} > 0$ and $\frac{\partial p_t^*}{\partial \mu_a} > 0$ if airlines and the railway are substitutes, while $\frac{\partial p_1^*}{\partial \mu_t} = \frac{\partial p_2^*}{\partial \mu_t} < 0$ and $\frac{\partial p_t^*}{\partial \mu_a} < 0$ if airlines and the railway are complements. This completes the proof. ■

Proof of Proposition 2. We need to check the sign of the following derivatives:

$$\frac{\partial \mu_a}{\partial \alpha} = -\frac{1-\gamma}{1-\delta^2} < 0; \quad \frac{\partial \mu_t}{\partial \beta} = -1 < 0; \quad \frac{\partial \mu_a}{\partial A} = \frac{\partial \mu_a}{\partial C_a} = \frac{2-\gamma-\delta^2}{1-\delta^2} > 0; \quad \frac{\partial \mu_a}{\partial c_a} = \frac{1-\gamma}{1-\delta^2} > 0; \quad \frac{\partial \mu_t}{\partial T} = \frac{\partial \mu_t}{\partial C_t} = 2 > 0;$$

$$\frac{\partial \mu_t}{\partial c_t} = 1 > 0; \quad \frac{\partial \mu_a}{\partial \beta} = \delta \frac{1-\gamma}{1-\delta^2} > (<) 0 \text{ if } \delta > (<) 0; \quad \frac{\partial \mu_t}{\partial \alpha} = 2\frac{\delta}{1+\gamma} > (<) 0 \text{ if } \delta > (<) 0;$$

$$\frac{\partial \mu_a}{\partial T} = \frac{\partial \mu_a}{\partial C_t} = \frac{\partial \mu_a}{\partial c_t} = -\delta \frac{1-\gamma}{1-\delta^2} < (>) 0 \text{ if } \delta > (<) 0; \quad \frac{\partial \mu_t}{\partial A} = \frac{\partial \mu_t}{\partial C_a} = \frac{\partial \mu_t}{\partial c_a} = -2\frac{\delta}{1+\gamma} < (>) 0 \text{ if } \delta > (<) 0.$$

This completes the proof. ■

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