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Pricing and investment in alternative transport infrastructures

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ABSTRACT

Pricing and investment decisions are not independent; causality in the relationship cuts both ways. Optimal prices, once the investment has been made and is irreversible, are quite different compared with the situation contemplated in the *ex-ante* evaluation of the project, when no cost is already sunk, and various capacity options are still open. This paper deals with this critical aspect of the relationship in the planning process, when deciding on alternative transport infrastructures. Pricing affects demand and, hence, social welfare. The social profitability of the project can vary significantly depending on the pricing policy. Therefore, before deciding whether it is socially worthwhile to invest in a project, the government needs to be clear about the charging scheme that will be applied. In this paper we show that, when comparing different transport alternatives, a particular charging scheme may favor the creation of a particular transport infrastructure network, leading to irreversible long-term equilibria that would not be optimal under other charging schemes.

Keywords: pricing, investment, social welfare.

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1.INTRODUCTION

In this paper, we use a game-theory model to analyze the effects of alternative charging schemes on transport infrastructure investments. The social profitability of a project can be quite different depending on the pricing policy (see Hotelling, 1938; Dupuit, 1844; Small *et al*., 1989; Oum and Zhang, 1990; Zhang and Zhang, 2010 or Tirole and Weyl, 2012). Therefore, before deciding whether it is socially worthwhile to invest in a project, the government needs to clearly define the charging scheme that will be applied for the use of such infrastructure.

Different charging schemes may be applied in practice. Although optimal access prices for the use of a particular transport infrastructure should include variables related to other substitute transport modes (de Rus and Socorro, 2015), access pricing in Europe is often performed by independent agencies that analyze the specific characteristics of one transport infrastructure and take access pricing decisions independently, without considering the overall picture and the important cross-effects between different modes of transport (Engel *et al*., 2014).

If access prices are only set considering the specific characteristics of the transport mode, two possibilities arise. The first possibility consists of charging according to short-run marginal costs. The second consists of charging mark-ups over short-run marginal costs to cover full costs (i.e. both operating and construction costs). The latter charging scheme may be employed for three reasons (Laffont and Tirole, 1993): 1) the existence of a shadow cost of public funds due to distortionary taxation to finance the deficit; 2) the marginal cost pricing structure does not reveal whether users are willing to pay the fixed costs of capacity and 3) the absence of budget constraint will reduce the incentive for cost reduction. Equity could also be used as an argument for departing from marginal cost pricing (Feldstein, 1972). Finally, there might also be competition reasons: when users pay for the full cost of all transport modes, intramodal competition is not affected.

ECMT (2005) provides evidence on the rail access pricing policy 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.

Prices affect demand and, thus, the social surplus of the investment project. Therefore, before evaluating a transport infrastructure we need to know the associated charging scheme. This is the main argument of Dupuit (1844) when analyzing the social welfare of a toll-free bridge. If there is no charge for the use of the bridge and there are only fixed costs, the bridge should be constructed if (the maximum) user's surplus is higher than the construction cost. If the regulator charges a price for the use of the bridge, the user's surplus decreases, and this change in the charging scheme may reduce the social surplus, leading to a situation in which the socially optimal decision is now not to build the bridge.

Following Dupuit's argument, some academics have linked pricing and capacity investment for a particular transport mode (see, for example, Vickrey, 1969; Keeler and Small, 1977; Bennathan and Walters, 1979; Small *et al*., 1989; Oum and Zhang, 1990; Hansson and Nilsson, 1991; Yang and Meng, 2000; Zhang and Zhang, 2003; Szeto and Lo, 2006; De Borger *et al*., 2007; Martín and Socorro, 2009; Mun and Nakagawa, 2010; or Lindsey, 2012). However, to the best of our knowledge, this is the first paper that links pricing and investment when deciding between alternative transport modes. Pricing decisions variously affect the social welfare of alternative transport modes. Thus, when comparing different transport alternatives, a particular charging scheme may favor the creation of a particular transport infrastructure network, leading to long-term equilibria that would not be optimal under other charging schemes.

In this paper, we develop a game-theory model in which users demand services in two transport modes: air transport and railway. Given users' preferences, the regulator must decide whether to invest in air transport, railway; both transport modes; or postpone the investment; using two possible charging schemes: either charging according to short-run marginal costs or charging mark-ups over short-run marginal costs. In this context, we show that the regulator may favor the construction of the rail infrastructure by choosing a charging scheme based on short-run marginal costs.

This is the case of the high-speed rail (HSR) infrastructure in Spain, which is charged according to short-run marginal costs in the recent past. However, even with this favorable charging scheme, none of the HSR lines in Spain generates net social benefits (see de Rus and Inglada, 1993; Levinson *et al.*, 1997; de Rus and Roman, 2005; de Rus and Nombela, 2007; de Rus and Nash, 2007; de Rus, 2011; Albalate and Bel, 2015; and Betancor and Llobet, 2015). As shown in this paper, much higher levels of demand are needed to make HSR investments optimal.

The rest of the paper is organized as follows: in section 2 we explain the main assumptions of the model. The game consists of three stages and is solved by backward induction in section 3. Section 4 includes an empirical illustration. Finally, section 5 concludes.

2.THE MODEL

Following the general differentiated product model developed by Singh and Vives (1984), applied to the transport sector by de Rus and Socorro (2014), let us consider an economy composed of an oligopolistic transport sector and a competitive (*numeraire*) sector, which summarizes the rest of the economy. The transport sector contains two transport modes: rail and air transport.[1] Transport infrastructures are public and used by private operators. In particular, we assume that the rail infrastructure is used by a private operator while two private airlines operate in the airports.

Denote by q_1, q_2, q_t the quantity offered and demanded on a certain route by airline 1, airline 2 and the rail operator, respectively. On such a route, there exist N identical users 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 so we can perform partial equilibrium analysis.

The utility function of the representative user in the transport sector, $U(q_1, q_2, q_t)$, is assumed to be quadratic and strictly concave:

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

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

Where u_a and u_t are positive parameters that measure user's preferences for each transport mode, 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 airlines as substitutes but exhibit brand loyalty to particular carriers; that is, airlines compete with differentiated products.[2] Therefore, $\gamma \in [0,1)$. When the parameter γ is zero, airlines are independent. As γ tends to one, airlines are considered better substitutes.

Moreover, passengers consider the railway and airlines as substitutes. Therefore, we assume that $\delta \in [0,1)$. 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. However, we assume that $\gamma > \delta$, which 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.

The generalized price is composed of the ticket price and all other costs associated with the specific transport mode, such as the cost of time or discomfort. In particular, the generalized price is the weighted combination of its various components, where the weights are the different values of time (i.e. access, egress, waiting and in-vehicle time) and monetary value of any other disutility component associated with the specific transport mode. Thus, the representative user solves:

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

where p_i, with $i=1,2,t$, denotes the ticket price, and 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:

$$\underset{q_1,q_2,q_t}{Max}\ \alpha q_1+\alpha q_2+\beta q_t-\frac{1}{2}(q_1{}^2+q_2{}^2+q_t{}^2+2\gamma q_1q_2+2\delta q_1q_t+2\delta q_2q_t)-p_1q_1-p_2q_2-p_tq_t, \tag{3}$$

[2] Product differentiation between airlines may be due to several reasons such as brand loyalty, the existence of frequent flier programs, etc. (see, for example, Chen and Chang, 2008).

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.

Let us denote by μ_a and μ_t the access price charged to airlines and the railway operator, respectively, and by c_a and c_t the constant marginal operating costs of each transport operator. Denote by C_a and C_t transport infrastructure marginal maintenance and operating costs.

We consider two possible access charging policies commonly used in practice. The first consists of charging the use of transport infrastructures according to short-run marginal costs, that is, $\mu_a = C_a$ and $\mu_t = C_t$, respectively. The second consists of charging a mark-up over short-run marginal costs in order to cover part of the construction costs, that is: $\mu_a = C_a + A$ and $\mu_t = C_t + T$, where A and T represent mark-ups over short-run marginal costs. Let us denote by K_a and K_t the construction costs of an airport and the railway infrastructure respectively, with $K_a < K_t$, and by r the opportunity cost of public funds.

For every segment connecting two regions, the timing of the game has three stages. In the first stage, the regulator decides the access pricing scheme: either charging transport operators according to short-run marginal costs or, alternatively, charging a mark-up over short-run marginal costs. Next, given the charging scheme, the regulator decides whether to construct (or not) airports, the rail infrastructure or both transport infrastructures to connect regions. In the second stage, given the charging scheme and the transport infrastructures that were built, private operators pay access prices and decide the ticket price to be charged to final users. Finally- in the third stage- given the ticket price, each user demands a certain number of trips on those transport modes for which transport infrastructures were built. The game is solved by backward induction.

3.OPTIMAL TRANSPORT INFRASTRUCTURES

3.1. Stage 3: Users' demand

In the last stage of the game, given the ticket price, the representative user demands a certain number of trips on those transport modes for which transport infrastructures were built.

If only airports were constructed, the representative user demands air transport trips to airline 1 and airline 2. Let us denote by q_1^a and q_2^a the quantity demanded by the representative user to airline 1 and airline 2 if only airports were constructed. Then, the representative user solves:

$$\underset{q_1, q_2}{Max}\ \alpha q_1 + \alpha q_2 - \frac{1}{2}(q_1{}^2 + q_2{}^2 + 2\gamma q_1 q_2) - p_1 q_1 - p_2 q_2, \tag{4}$$

which leads to the following linear demand functions for airlines:

$$\begin{aligned} q_1^a &= a - bp_1 + dp_2, \\ q_2^a &= a - bp_2 + dp_1, \end{aligned} \tag{5}$$

where $a = \dfrac{\alpha(1-\gamma)}{1-\gamma^2}$, $b = \dfrac{1}{1-\gamma^2}$, $d = \dfrac{\gamma}{1-\gamma^2}$.

On the other hand, if only the rail infrastructure was constructed, the representative user demands rail transport trips to the rail operator. Let us denote by q_t^t the number of rail trips demanded by the representative user if only the rail infrastructure was constructed. Then, the representative user solves

$$\underset{q_t}{Max}\ \beta q_t - \frac{1}{2} q_t{}^2 - p_t q_t, \tag{6}$$

which leads to the following linear demand functions for the rail operator:

$$q_t^t = \beta - p_t. \tag{7}$$

Finally, when both airports and the rail infrastructure are constructed, the representative user demands both air transport and train journeys. Let us denote by q_1^{a+t}, q_2^{a+t}, q_t^{a+t} the quantity demanded by the representative user to airline 1, airline 2 and the rail operator when both airports and the rail infrastructure are constructed. In this case, the representative user solves the maximization program given by expression (3), leading to the following linear demand functions for airlines and the rail operator:

$$\begin{aligned} q_1^{a+t} &= a_a - b_a p_1 + d_a p_2 + d_t p_t, \\ q_2^{a+t} &= a_a - b_a p_2 + d_a p_1 + d_t p_t, \\ q_t^{a+t} &= a_t - b_t p_t + d_t p_1 + d_t p_2, \end{aligned} \tag{8}$$

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

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

We assume that $\alpha - \beta\delta > 0$, and $\beta(1+\gamma) - 2\alpha\delta > 0$. Given these assumptions, all the parameters (a_a, b_a, d_a, a_t, b_t, y d_t) are strictly positive.

3.2. Stage 2: Optimal ticket prices

In the second stage, given the charging scheme and the transport infrastructures that were built, private operators pay access prices (μ_a and/or μ_t) and decide the ticket price to be charged to final users.

If only airports are constructed, airlines compete with differentiated products, solving the following maximization program:

$$\underset{p_i}{Max}\ \pi_i^a = (p_i - c_a - \mu_a) q_i^a, \tag{9}$$

where π_i^a represents the profit for airline i and q_i^a represents user's demands given by expression (5), with $i = 1, 2$. Optimal ticket prices for airline 1 and airline 2 when only airports were constructed are then given by:

$$p_1^a = p_2^a = \frac{a + b\mu_a + bc_a}{2b-d}. \tag{10}$$

If only the rail infrastructure was constructed, the rail operator solves the following maximization program:

$$\underset{p_t}{Max}\ \pi_t^t = (p_t - c_t - \mu_t) q_t^t, \tag{11}$$

where π_t^t represents rail operator profits and q_t^t is the representative user's demand given by expression(7). Optimal ticket price for the rail service when only the rail infrastructure is constructed is given by:

$$p_t^t = \frac{\beta + \mu_t + c_t}{2}. \tag{12}$$

If both airports and the rail infrastructure are constructed, airlines and the rail operator compete in differentiated products. On the one hand, airline i solves:

$$\underset{p_i}{Max}\ \pi_i^{a+t} = (p_i - c_a - \mu_a) q_i^{a+t}, \tag{13}$$

where q_i^{a+t} is given by expression (8), with $i = 1, 2$.

On the other hand, the rail operator solves:

$$\underset{p_t}{Max}\ \pi_t^{a+t} = (p_t - c_t - \mu_t) q_t^{a+t}, \tag{14}$$

where q_t^{a+t} is given by expression (8).

Solving airlines and rail operator maximization programs, we obtain the following optimal ticket prices for air transport and rail trips when both airports and the rail infrastructure are constructed:

$$\begin{aligned} p_1^{a+t} = p_2^{a+t} &= \frac{1}{4b_a b_t - 2d_t^2 - 2d_a b_t}(2a_a b_t + a_t d_t + 2\mu_a b_a b_t + \mu_t b_t d_t + 2b_a c_a b_t + b_t c_t d_t) \\ p_t^{a+t} &= \frac{1}{4b_a b_t - 2d_t^2 - 2d_a b_t}(2b_a a_t + 2a_a d_t - d_a a_t + 2\mu_a b_a d_t + 2\mu_t b_a b_t - \mu_t d_a b_t \\ &\qquad + 2b_a c_a d_t + 2b_a b_t c_t - d_a b_t c_t). \end{aligned} \tag{15}$$

3.3. Stage 1: Optimal transport infrastructures

In the first stage, the regulator decides the access pricing scheme: either charging transport operators according to short-run marginal costs or, alternatively, charging a mark-up over short-run marginal costs. Then, given the charging scheme, the regulator decides whether (or not) to construct airports, the rail infrastructure or both transport infrastructures to connect regions.

In order to optimally choose which transport infrastructure should be constructed, the regulator should compare the social welfare associated with each possible alternative. Social welfare for each alternative is defined as the sum of users' surplus, transport operators' surplus, and profits due to the use of transport infrastructures, minus the opportunity cost of public funds. With this definition, positive social welfare has two possible interpretations. On the one hand, if demand and costs are constant every year, positive social welfare means that the net present value associated with an infinite-life infrastructure is positive. On the other hand, if demand and costs vary during the project life, positive social welfare means that it is optimal to construct the transport infrastructure today instead of postponing the investment for a period (see the Annex for a formal explanation of these two interpretations).

The regulator has four possible alternatives:

Alternative 0: To construct no infrastructure today and postpone the investment until the number of users in the economy, N, is higher.

Alternative 1: To only construct the air transport infrastructure. The social welfare associated with this alternative, SW_a, is given by:

$$SW_a = N[U(q_1^a, q_2^a) - (p_1^a + t_a)q_1^a - (p_2^a + t_a)q_2^a + \pi_1^a + \pi_2^a + (\mu_a - C_a)(q_1^a + q_2^a)] - rK_a, \quad (16)$$

which can be rewritten as:

$$SW_a = N[\alpha q_1^a + \alpha q_2^a - \frac{1}{2}[(q_1^a)^2 + (q_2^a)^2 + 2\gamma q_1^a q_2^a] - (C_a + c_a)(q_1^a + q_2^a)] - rK_a, \quad (17)$$

where q_1^a and q_2^a represent user's demands given by expression (5) when considering optimal ticket prices given by expression (10).

Alternative 2: To only construct the rail infrastructure. The social welfare associated with this alternative, SW_t, is given by:

$$SW_t = N[U(q_t^t) - (p_t^t + t_t)q_t^t + \pi_t^t + (\mu_t - C_t)q_t^t] - rK_t, \quad (18)$$

which can be rewritten as:

$$SW_t = N[\beta q_t^t - \frac{1}{2}(q_t^t)^2 - (C_t + c_t)q_t^t] - rK_t, \tag{19}$$

where q_t^t represents user's demand given by expression (7) when considering the optimal ticket price given by expression (12).

Alternative 3: To construct both the air and rail infrastructures. The social welfare associated with this alternative, SW_{a+t}, is given by:

$$\begin{aligned} SW_{a+t} = N[U(q_1^{a+t}, q_2^{a+t}, q_t^{a+t}) - (p_1^{a+t} + t_a)q_1^{a+t} - (p_2^{a+t} + t_a)q_2^{a+t} - (p_t^{a+t} + t_t)q_t^{a+t} + \pi_1^{a+t} + \pi_2^{a+t} + \pi_t^{a+t} \\ + (\mu_a - C_a)(q_1^{a+t} + q_2^{a+t}) + (\mu_t - C_t)q_t^{a+t}] - rK_a - rK_t, \end{aligned} \tag{20}$$

which can be rewritten as:

$$\begin{aligned} SW_{a+t} = N[\alpha q_1^{a+t} + \alpha q_2^{a+t} + \beta q_t^{a+t} - \frac{1}{2}[(q_1^{a+t})^2 + (q_2^{a+t})^2 + (q_t^{a+t})^2 + 2\gamma q_1^{a+t} q_2^{a+t} + 2\delta q_1^{a+t} q_t^{a+t} + 2\delta q_2^{a+t} q_t^{a+t}] \\ - (C_a + c_a)(q_1^{a+t} + q_2^{a+t}) - (C_t + c_t)q_t^{a+t}] - rK_a - rK_t, \end{aligned} \tag{21}$$

where q_1^{a+t}, q_2^{a+t}, and q_t^{a+t} represent user's demands given by expression (8) when considering optimal ticket prices given by expression (15).

Notice that the social welfare function associated with each alternative is linear and strictly increasing in N (the number of users). When $N = 0$, the social welfare associated with each alternative is simply the opportunity cost of public funds used to construct the transport infrastructure today. The slope of the social welfare function associated with each alternative depends on the parameters of the model and the charging scheme used by the regulator, μ_a and μ_t. The regulator may charge for the use of transport infrastructures according to short-run marginal costs, that is, $\mu_a = C_a$ and $\mu_t = C_t$; or charge a mark-up over short-run marginal costs, that is: $\mu_a = C_a + A$ and $\mu_t = C_t + T$, where A and T represent mark-ups.

Since the slope of the social welfare functions depends on the parameters of the model and the charging scheme chosen by the regulator, we may have different situations.

Figure 1 depicts a situation in which if the number of users in the economy is lower than N_1 the optimal alternative is ***alternative 0***, that is, construct no infrastructure today and wait until the number of users increases. However, if the number of users in the economy is between N_1 and N_2 the regulator should optimally choose ***alternative 1***, that is, to only construct the air transport infrastructure. When the number of users is between N_2 and N_3, the optimal decision is to choose ***alternative 2***, that is, to only construct the rail infrastructure. Finally, if the number of users is high enough, in particular, higher than N_3, the optimal alternative is ***alternative 3***, that is, to construct both the air and rail infrastructures.

Figure 1. Optimal alternative depending on the number of users in the economy: Example 1

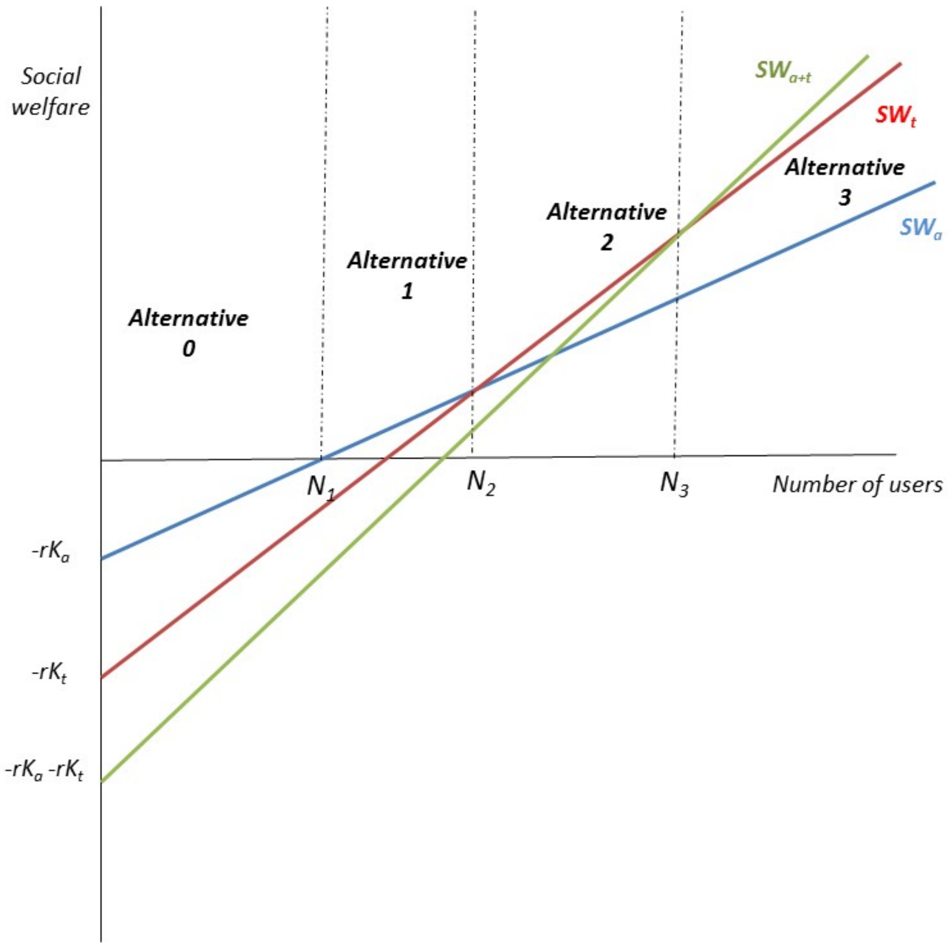


Figure 2 illustrates a situation in which, given the slope of the social welfare functions associated with each alternative, if the number of users in the economy is lower than N_1 the best alternative for the regulator is ***alternative 0***, that is, to construct no

infrastructure today and postpone the investment until the number of users is higher. However, if the number of users is between N_1 and N_2, the regulator should optimally choose ***alternative 1***; that is, to only construct the air infrastructure. If the number of users in the economy is high enough, in particular, higher than N_2, the optimal choice is ***alternative 3***; that is, to construct both the air and rail infrastructures. In this example, ***alternative 2*** (to only construct the rail infrastructure) is never optimal.

Figure 2. Optimal alternative depending on the number of users in the economy: Example 2

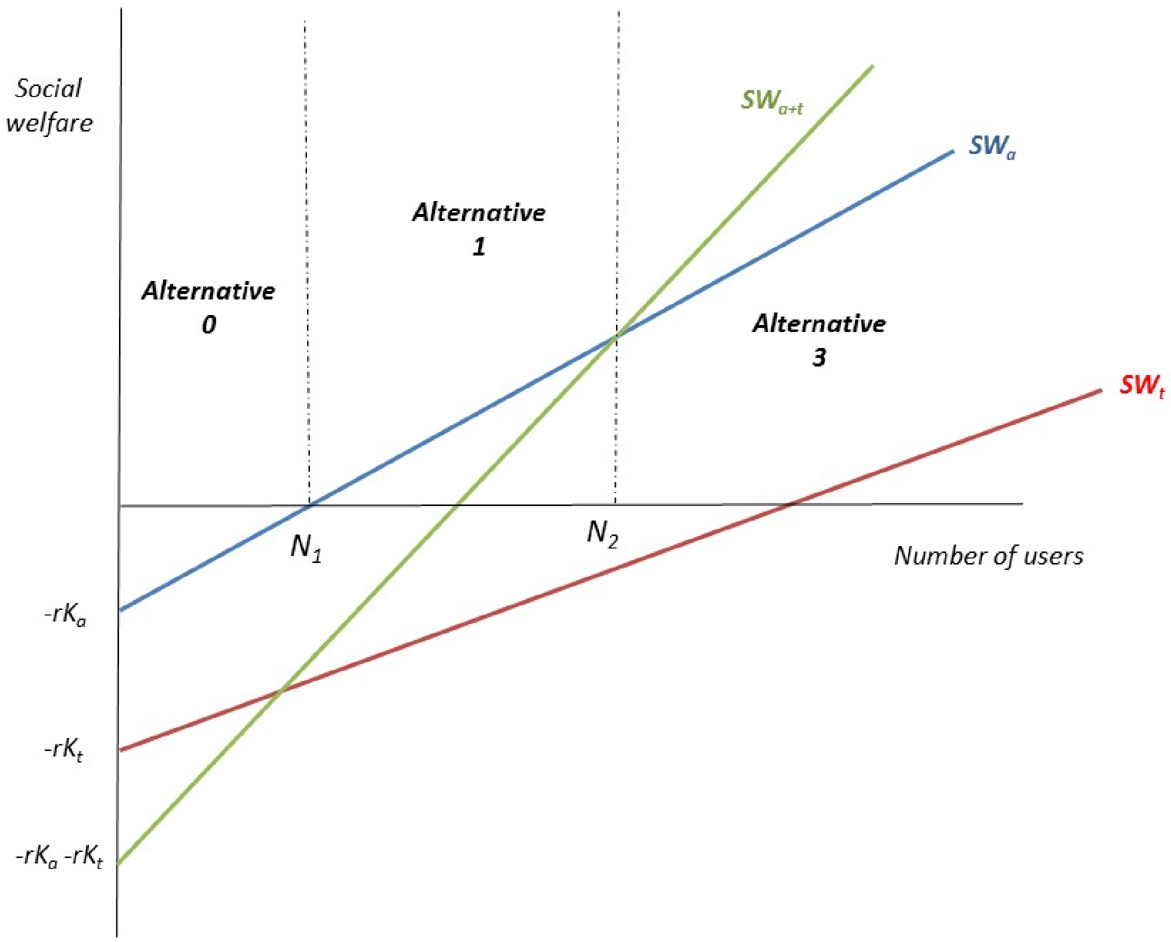
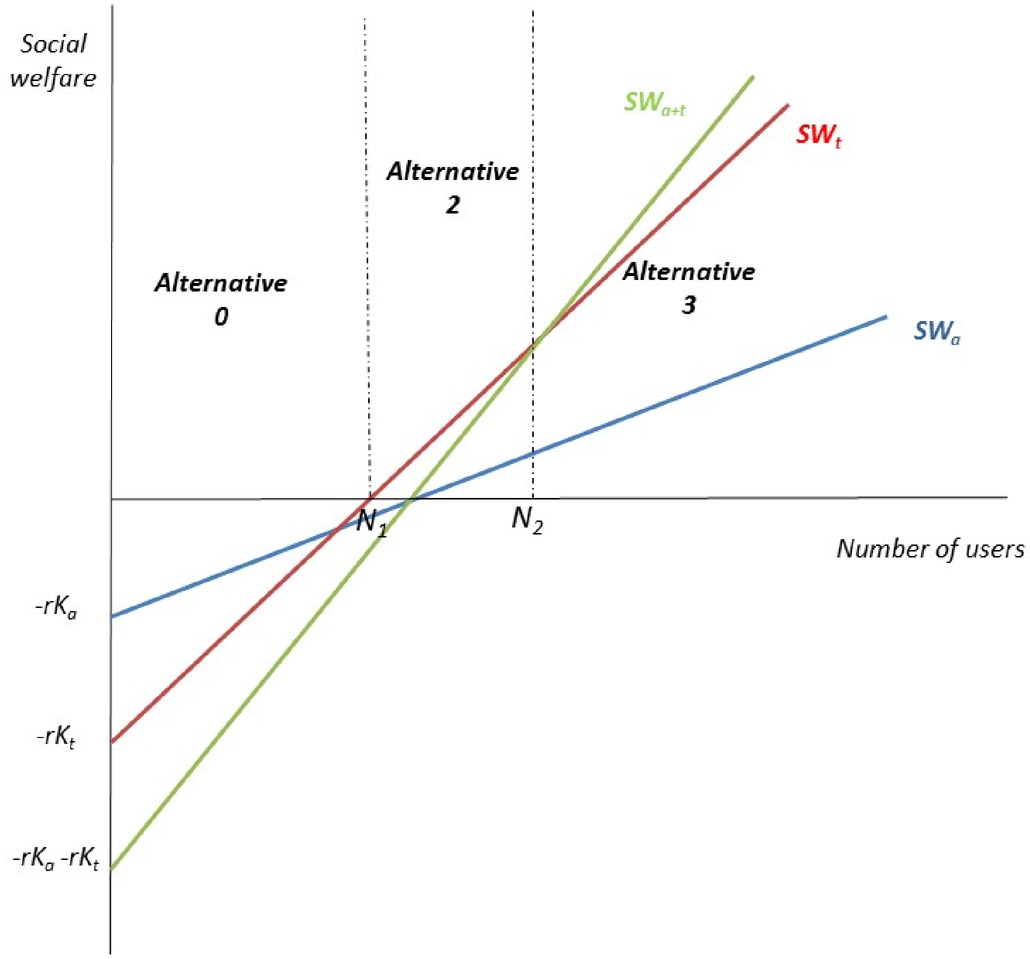


Figure 3 represents another situation in which, given the slope of the social welfare functions associated with each alternative, if the number of users in the economy is lower than N_1 the best alternative for the regulator is ***alternative 0***, that is, to construct no infrastructure today and postpone the investment until the number of users is higher. However, if the number of users is between N_1 and N_2, the regulator should optimally choose ***alternative 2***, that is, to only construct the rail infrastructure. If the number of

users in the economy is high enough, in particular, higher than N_2, the optimal choice is ***alternative 3***, that is, to construct both the air and rail infrastructures. In this example, ***alternative 1*** (to only construct the air infrastructure) is never optimal.

Figure 3. Optimal alternative depending on the number of users in the economy: Example 3



The slope of the social welfare function associated with each alternative depends on the charging scheme chosen by the regulator and the parameters of the model (such as user's preferences for each transport mode, the degree of product differentiation between airlines and between air and rail transport, marginal operating costs for transport operators, and marginal operating and maintenance costs of transport infrastructures). The regulator cannot influence the parameters of the model but can affect the slope of the social welfare function through the charging scheme. The higher the access prices, the flatter the social welfare function associated with each alternative. Thus, if the regulator moves from a charging scheme based on short-run marginal costs to a charging scheme based on mark-ups over short-run marginal costs, the social welfare function associated with each alternative becomes flatter. Since $K_a < K_t$ and mark-ups aim to cover part of the construction costs of each transport infrastructure, $A < T$, and the effect on the slope of the social welfare function when moving from one charging scheme to the other is higher in the case of the rail infrastructure. This is illustrated in **Figure 4,** where dashed lines represent social welfare functions when using a charging scheme founded on short-run marginal costs and solid lines represent social welfare functions when moving to a charging scheme based on mark-ups over short-run marginal costs.

Figure 4. Optimal alternative depending on the charging scheme

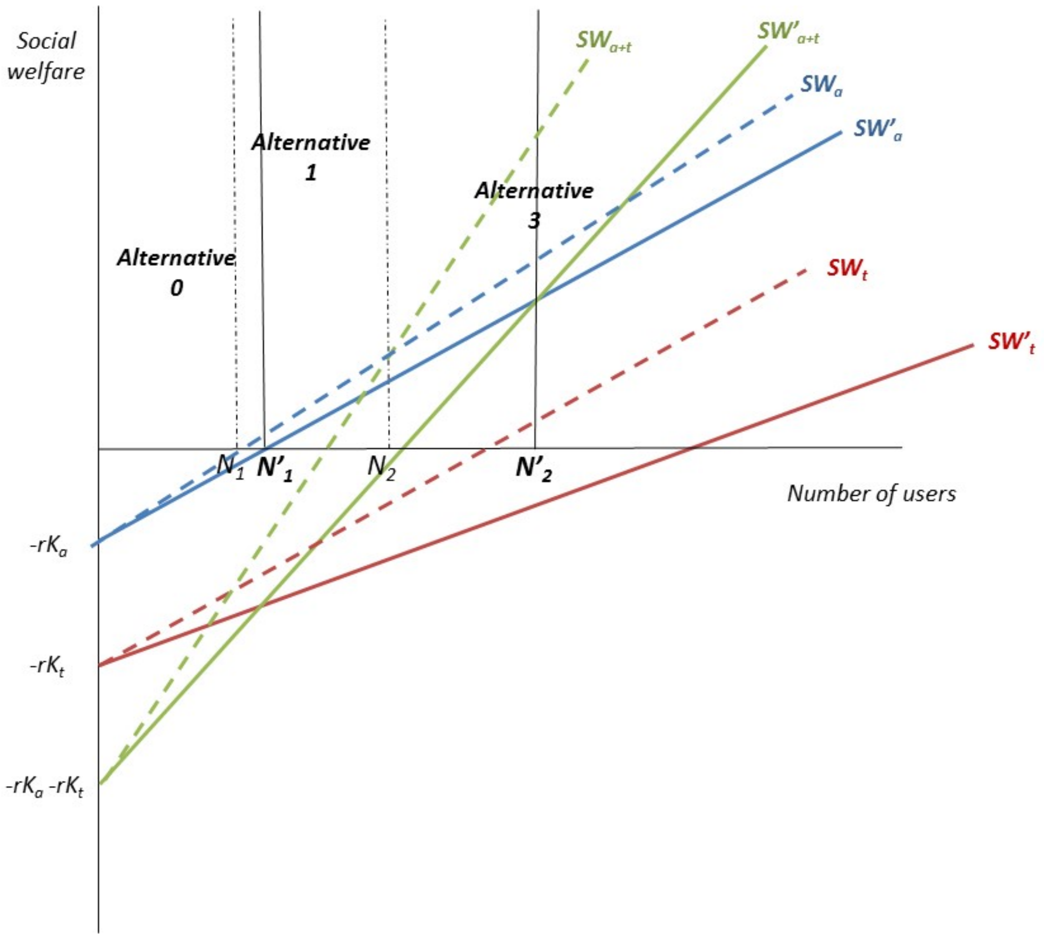


Figure 4 depicts a situation in which if the regulator uses a charging scheme based on short-run marginal costs and the number of users in the economy is lower than N_1, the best alternative for the regulator is ***alternative 0***, that is, to construct no infrastructure today and postpone the investment until the number of users is higher. However, if the number of users is between N_1 and N_2, the regulator should optimally choose ***alternative 1***, that is, to only construct the air infrastructure. If the number of users in the economy is high enough, in particular, higher than N_2, the optimal choice is ***alternative 3***, that is, to construct both the air transport and rail infrastructures. In this example, ***alternative 2*** (to

only construct the rail infrastructure) is never optimal. When the regulator decides to charge transport infrastructure access using mark-ups over short-run marginal costs, critical thresholds for the number of users move from N_1 to $N_1^{'}$ and from N_2 to $N_2^{'}$. Thus, we need more users for *alternative 1* to be optimal and proportionally many more users for *alternative 3* to be chosen.

4. EMPIRICAL ILLUSTRATION

In order to illustrate how the charging scheme chosen by the regulator affects demand thresholds and, hence, the optimality of transport infrastructures let us consider the following empirical illustration. Suppose a route within the range of 600-650 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 (HSR).[3]

The construction cost (land costs and stations excluded) for the 621 km of HSR infrastructure joining Madrid and Barcelona was €9.5 billion in 2008 (see Sánchez-Borrás, 2010, de Rus, 2012, or more recently Betancor and Llobet, 2015). Taking into account that these figures do not include station costs, in our example, we will consider that the total investment required to construct the rail infrastructure is $K_t =$ €10 billion.[4] On the other hand, the investment in airport capacity is assumed to be €1 billion.[5] However, since two airports are needed to operate the route, we assume that $K_a =$ €2 billion. The opportunity cost of capital is assumed to be 5%, that is, $r = 0.05$.

[3] Even though a number of authors set different thresholds on the distance for which the HSR loses its advantage over aircraft, most authors agree that the HSR is competitive for distances below 800 km in length (see for example, Janic, 2003; Commission for Integrated Transport, 2004; de Rus and Nombela, 2007; Givoni and Banister, 2007; Vickerman, 2009; or Socorro and Viecens, 2013).

[4] Construction cost per km in HSR might be lower in flat rural areas or higher when passing through difficult orography or densely-populated urban areas. Thus, construction cost per km in the Madrid-Seville segment was six million euros, while for the Madrid-Valladolid segment it was 18.5 million euros, and in the Frankfurt- Cologne segment it was 33 million euros. In Italy, the average cost per km is between 44 and 62 million euros. See http://www.ferropedia.es/wiki/Costos_de_construcci%C3%B3n_de_infraestructura

[5] 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). However, the construction cost of an airport might be much lower. In Spain, for example, the construction cost for Huelva airport (with one million passenger capacity) was lower than 100 million euros (see http://elpais.com/diario/2005/11/03/andalucia/1130973740_850215.html)

According to the AENA annual report (AENA, 2017), 230.2 million passengers flew from/to Spanish airports during 2016. According to this report, total operating and maintenance costs (including procurement, personnel, and other operating costs) were 1,145,519 euros. Dividing total operating and maintenance costs by the total number of passengers, we get 4.97 euros per passenger. Since for connecting two regions we need two airports, in our empirical illustration we assume that the marginal operating and maintenance cost of the air transport infrastructure is 10 euros, that is, $C_a = €10$.

As far as operating and maintenance costs of the rail infrastructure are concerned, we draw on a recent report from the *Spanish Commission of Markets and Competition* (CNMC, 2016). According to this report, operating and maintenance costs (including personnel and other operating costs) of the Spanish HSR infrastructure during 2015 were 729,755,000 euros. These figures include costs from selling traction energy, whose revenues in 2015 were 298,344,000 euros. Assuming that these revenues are marginally above costs, we estimate that total operating and maintenance costs for the use of the rail infrastructure are around 432,000,000 euros. Taking into account that during 2015 there were 19.4 million HSR passengers in Spain, operating and maintenance costs per passenger are around 22 euros. Thus, in our empirical illustration we assume that the marginal operating and maintenance cost of the HSR infrastructure is 20 euros, that is, $C_t = €20$.

Marginal operating costs are assumed to be covered by the ticket price. Looking at ticket prices on the web for the route Madrid-Barcelona, we observe that they are above €60 for full-service airlines and above €55 for HSR.[6] Thus, in our empirical illustration, we consider that the marginal operating cost for airlines and HSR is $c_a = €40$ and $c_t = €30$, respectively.

Regarding users' preferences, we 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 HSR is $\alpha = 160$ and $\beta = 180$.

[6] Data from *edreams* for a round trip ticket for the route Madrid-Barcelona, bought one month in advance.

Table 1 shows optimal prices, quantities and social welfare functions associated with each alternative when the regulator charges for the use of transport infrastructures according to short run marginal costs, that is, $\mu_a = C_a$ and $\mu_t = C_t$. It also shows the minimum number of users, N, required for each alternative to be optimal. Since each user demands a certain number of trips, we also compute the minimum number of trips required for each alternative to be optimal. Thus, if the number of users in the economy is lower than 15,301 (or, in other words, the total number of trips is lower than 1,558,407 trips), the best alternative for the regulator is ***alternative 0***, that is, to construct no infrastructure today and postpone the investment until the number of users is higher. However, if the number of users is between 15,301 and 258,730, the regulator should optimally choose ***alternative 1***, that is, to only construct the air transport infrastructure. If the number of users in the economy is higher than 258,730 (or, in other words, the total number of trips is higher than 31,914,345 trips; 16,964,926 trips by air and 14,949,419 trips by HSR), the optimal choice is ***alternative 3***, that is, to construct both the air and rail infrastructures. ***Alternative 2*** (to only construct the HSR infrastructure) is never optimal (see **Figure 2** in section 3)

Table 1. Prices and thresholds when charging according to short-run marginal costs

	***Alternative 1*:** **Air transport**	***Alternative 2*:** **HSR**	***Alternative 3*:** **Air transport and HSR**
Access prices	$\mu_a = 10$	$\mu_t = 20$	$\mu_a = 10$ $\mu_t = 20$
Ticket prices	$p_1 = p_2 = 68.33$	$p_t = 115$	$p_1 = p_2 = 60.54$ $p_t = 76.32$
Number of trips per user	$q_1 + q_2 = 102$	$q_t = 65$	$q_1 + q_2 = 66$ $q_t = 58$
Social welfare functions	$SW_a = 6,535.5N - 100,000,000$	$SW_t = 6,337.5N - 500,000,000$	$SW_{a+t} = 8,468N - 600,000,000$
Minimum number of users	$N = 15,301$	-	$N = 258,730$
Minimum number of trips	$N(q_1 + q_2) = 1,558,40$ **Total: 1,558,407**	-	$N(q_1 + q_2) = 16,964,926$ $Nq_t = 14,949,419$ **Total: 31,914,345**

If the regulator decides to charge transport infrastructure through mark-ups over short-run marginal costs, $\mu_a = C_a + A$, and $\mu_t = C_t + T$. Since $K_a < K_t$ and mark-ups aim to cover part of the construction costs of each transport infrastructure, $A < T$. In our empirical illustration we assume that $A = 2$ and $T = 30$.

Table 2 shows optimal prices, quantities, social welfare functions and users' thresholds associated with each alternative when the regulator charges the use of transport infrastructures according to mark-ups over short run marginal costs. As shown in **Table 2**, if the number of users in the economy is lower than 15,385 (or, in other words, the total number of trips is lower than 1,538,500 trips), the best alternative for the regulator is ***alternative 0***, that is, to construct no infrastructure today and postpone the investment until the number of users is higher. However, if the number of users is between 15,385 and 421,300, the regulator should optimally choose ***alternative 1***, that is, to only construct the air infrastructure. If the number of users in the economy is higher than 421,300 the optimal choice is ***alternative 3***, that is, to construct both the air and rail infrastructures. ***Alternative 2*** (to only construct the rail infrastructure) is never optimal.

Notice that when moving from a charging scheme based on short-run marginal costs to a charging scheme based on mark-ups over short-run marginal costs, the social welfare function associated with each alternative becomes flatter. However, since $A < T$, the effect on the slope of the social welfare function is higher in the case of the rail infrastructure (see **Figure 4** in section 3), and we need proportionally much more users for ***alternative 3*** to be chosen. Thus, charging according to short-run marginal costs favors the construction of the rail infrastructure.

Table 2. Prices and thresholds when charging with mark-ups over short-run marginal costs

	***Alternative 1*:** **Air transport**	***Alternative 2*:** **HSR**	***Alternative 3*:** **Air transport and HSR**
Access prices	$\mu_a = 12$	$\mu_t = 50$	$\mu_a = 12$ $\mu_t = 50$
Ticket prices	$p_1 = p_2 = 70$	$p_t = 130$	$p_1 = p_2 = 65.30$ $p_t = 93.17$
Number of trips per user	$q_1 + q_2 = 100$	$q_t = 50$	$q_1 + q_2 = 83$ $q_t = 29$
Social welfare functions	$SW_a = 6,500N - 100,000,000$	$SW_t = 5,250N - 500,000,000$	$SW_{a+t} = 7,686.8N - 600,000,000$
Minimum number of users	$N = 15,385$	-	$N = 421,300$
Minimum number of trips	$N(q_1 + q_2) = 1,538,500$ **Total trips: 1,538,500**	-	$N(q_1 + q_2) = 34,854,149$ $Nq_t = 12,182,311$ **Total trips: 47,036,460**

When charging the use of transport infrastructures according to mark-ups over short-run marginal costs, the regulator aims to cover marginal operating and maintenance costs and at least part of the construction costs. In our example, the minimum number of users required for *alternative 3* to be optimal is 421,300. These users demand 34,854,149 trips by air and 12,182,311 trips by HSR. With access charges, users cover all marginal operating and maintenance costs of the transport infrastructures and part of the construction costs. In particular, they cover 70 million euros of the 100 million euros opportunity cost associated with the construction of the air transport infrastructure, and around 365 million euros of the 500 million euros opportunity cost associated with the construction of the HSR infrastructure.

According to data from **Table 1** and **Table 2**, the minimum number of trips required for constructing both the air and HSR infrastructures is 31,914,345 trips if the regulator uses a charging scheme based on short-run marginal costs, and 47,036,460 trips if the regulator charges a mark-up over short-run marginal costs. Taking into account that this empirical illustration uses real data from the Madrid-Barcelona segment, and that the total number of trips in 2016 (both in air transport and HSR) in this segment was around six million, it is clear how far we are from the minimum demand threshold required. With the present level of demand, the HSR should not have been constructed in the Madrid-Barcelona segment (which is in fact the segment with the highest demand in Spain). With such a level of demand, only constructing the air transport infrastructure is the optimal alternative, even if the regulator decides to charge for the use of transport infrastructures according to short-run marginal costs.

5. CONCLUSIONS

Pricing and investment decisions must be taken together; they are not independent. When analyzing investment alternatives, we must compare the change in social surplus associated with them. Prices affect demand and, thus, surpluses and social welfare. Since social welfare is affected by prices, before deciding whether or not to invest in a project, we need to know the charging scheme. Moreover, different charging schemes may even change the investment decision due to the implied changes in social surplus. In this paper, we show that certain charging schemes may favor the construction of certain transport infrastructures, leading to long-term equilibria that would not be optimal under other charging schemes.

In order to achieve this, we have developed a theoretical model in which users demand services on two transport modes: air transport and railway. Given users' preferences, the regulator must decide whether to invest in air transport, railway; both transport modes; or postpone the investment; using two possible charging schemes: either charging according to short-run marginal costs or charging mark-ups over short-run marginal costs in order to cover part of the construction costs. In this context, we show that the government may favor the construction of the rail infrastructure by choosing a charging scheme based on short-run marginal costs. Moreover, we include an empirical illustration based on the segment connecting the cities of Madrid and Barcelona (Spain). For the Spanish case, we show that, given the current level of demand, to only construct the air transport infrastructure would have been the optimal decision in the Madrid-Barcelona segment, even with the favorable short-run marginal cost charging scheme.

Sunk costs and irreversibility are higher for the rail infrastructure. On the one hand, the cost of building airports varies substantially with the level of demand, since the higher the level of demand, the greater the size of the airport. On the other hand, the cost of constructing the rail infrastructure varies little with the level of demand since the costliest part of such infrastructure are the rail tracks. On the other hand, once two regions have been connected with airports, only one more airport is needed to connect a third region (half of the previous investment). However, once two regions have been connected by rail, the cost of connecting the third region is almost the same. Moreover, airports allow regions to be connected by either short, medium or long-haul flights, while HSR is only competitive for distances below approximately 800 km.

The practical consequence of this analysis for transport policy is straightforward: investment planning at government level should not be separated by product, such as air and rail transport. It is common that public agencies at different government levels are organized by product instead of by function, with independent planning structures and often without due coordination. HSR infrastructure should be constructed only for those cases in which the level of social welfare is clearly higher than the social welfare associated with the next best alternative. This only happens when the level of demand is sufficiently high, a fact that strongly depends on the charging scheme. The long-term consequences of investing in suboptimal infrastructure projects can be paramount. It may well be that this is not the optimal network but the irreversibility of the investment converts this suboptimal state into a long-term equilibrium. Once the infrastructure has been constructed, it should be used (if at least variable costs are covered). However, this does not mean that new segments should be added to the existing network. The planner should wait until the demand reaches the required threshold for social profitability. Meanwhile, postponing the expansion of the network is socially worthwhile.

ANNEX

In this paper, we consider three alternative projects: to only construct the air transport infrastructure, to only construct the rail infrastructure or to construct both the air and rail infrastructure. For the sake of simplicity, we assume infinite-life projects. Thus, the net present value of each alternative project, NPV_s, can be written as:

$$NPV_s = -K + \frac{\overline{B}}{r},$$

where K is the construction cost, $\overline{B}$ are annual net benefits which are constant during the whole life of the project, and r is the discount rate. In this case, $NPV_s > 0$ implies that $\overline{B} > rK$.

The decision about constructing today instead of postponing the investment (*optimal timing*) is taken considering the following expression:

$$\frac{B_1}{1+r} > \frac{rK}{1+r},$$

where B_1 represents net benefits during the first year. In other words, if net benefits during the first year are higher than the opportunity cost of the investment, we should construct the infrastructure today. If annual net benefits are constant, $\overline{B} = B_1$, and we consider infinite-life projects, optimal timing condition is satisfied if and only if $NPV_s > 0$.

If annual net benefits are not constant and the growth rate is $\theta < r$, $NPV_s > 0$ does not imply that the optimal timing condition is satisfied, since now the NPV_s is given by:

$$NPV_s = -K + \frac{B_1}{r - \theta}.$$

In this case, it might be the case that the NPV_s is positive ($B_1 > (r-\theta)K$) but the optimal timing condition is not satisfied since $B_1 < rK$.

In our model, social welfare is defined as annual net benefits (obtained as the sum of users' surplus, transport operators' profits and profits due to the use of transport infrastructures) minus the opportunity cost of public funds. With this definition, positive social welfare has two possible interpretations. On the one hand, if demand and costs are constant every year, and thus annual net benefits are constant, positive social welfare means that the net present value associated with an infinite-life infrastructure is positive. On the other hand, if demand and costs vary during the project life, positive social welfare means that it is optimal to construct the transport infrastructure today instead of postponing the investment one period.

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